iSQAPER
Interactive Soil Quality Assessment

Deliverable 4.2. Tested and validated final version of SQAPP

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6	Technical University of Madrid (UPM)	Spain
7	Institute for European Environmental Policy (IEEP)	UK and Belgium
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15	Agrarian School of Coimbra (ESAC)	Portugal
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18	Institute of Agricultural Resources and Regional Planning of Chinese Academy of Agricultural Sciences (IARRP)	China
19	Institute of Soil and Water Conservation of Chinese Academy of Sciences (ISWC)	China
20	Soil and Fertilizer Institute of the Sichuan Academy of Agricultural Sciences (SFI)	China
21	CorePage (CorePage)	Netherlands
22	BothEnds (BothEnds)	Netherlands
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24	Institute of Soil Science of the Chinese Academy of Sciences (ISS)	China
25	Gaec de la Branchette (GB)	France

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1. Introduction

The Soil Quality App (SQAPP) is the flagship deliverable of the EU-Horizon 2020 iSQAPER project. The SQAPP was designed with the idea that it should provide the user with the opportunity to access fragmented data on soil quality and soil threats in an easy-to-use way. Moreover, the user should not only receive indicator values, but be guided in interpreting these values by providing more contextual information: is a certain indicator value high or low in a given context? The system is set up to use soil quality and soil threat indicators for which spatial data exist as a first estimation for soil quality parameters in a given location, but these values can be replaced with more accurate own data by the app user. Ultimately, the user receives, based on an assessment of the most critical issues, management recommendations on how soil quality can be improved and soil threats be overcome.

Contextual information is provided through analysing indicators within 2098 pedoclimatic zones build up from all relevant combinations of climate zones (n=29) and soil types (n=118), and by distinguishing between arable land and grazing land. The comparative aspect of the soil indicator data is then realized by calculating cumulative probability density functions for each pedo-climatic zone. All indicator values are given as 'best guestimate' for the location. The user can, after specifying some details on crops grown and pest management applied, proceed with generating management recommendations based on these standard values, or replace some or all indicator values with own data to get more accurate recommendations. This design helps to make the SQAPP directly helpful by visualizing available soil information in a systematic and easy-to-access way.

Thirdly, the SQAPP recommends agricultural management practices to improve soil quality and/or mitigate soil threats based on an integrated assessment of the aspects most urgently needing attention. This integrated way of considering soil quality indicators is new in comparison to existing soil apps and indicator systems. This integration avoids consideration of poor single indicator scores in isolation, which could have trade-offs with other soil quality indicators that are also suboptimal.

Fourthly, although the iSQAPER project focuses on Europe and China, it quickly became clear that the amount of work required to develop SQAPP would be more appropriately justified by building an app with global coverage. This inclination to go global was reinforced by some hurdles experienced along the way to harmonise European and Chinese data. As a consequence, the pilot app was designed with global functionality in mind.

Within the project, a pilot version of SQAPP was first developed based on intensive collaboration between researchers, intended end-users and software developers to define, from the outset, what the most important functionalities are. Subsequently a beta-version of SQAPP was released for testing and to collect feedback from different target audiences. These

were used to refine the app by addressing the main issues experienced, giving an indication of the reliability of indicators based on validation against measured data, and elaborating and revising the agricultural management practices recommended by the app. Additional functionality was also added by incorporating a pesticide contamination risk module. The result is a final tested and validated version of SQAPP.

The current report explains the functionality of the final SQAPP and the process followed to develop it. Links to other work packages are highlighted, and an outlook for use and further development is provided.

2. Process to arrive at SQAPP

2.1. Review of existing soil apps

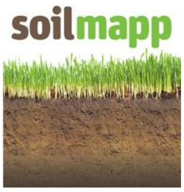
Soil is suffering from intensive farming and unsustainable soil disturbance, leading to severe soil degradation. Great efforts have been undertaken to deal with soil degradation and related problems via research demonstration, agricultural extension services and policy incentives and guidance programs. However, it remains difficult for end-users, like farmers and agricultural workers, to understand soil information which is shown in reports or research publications. Furthermore, access to such information in the first place is also an important barrier to improved soil management. Both barriers can be overcome through the development of easy-to-use interactive tools, such as mobile phone apps.

This opportunity has been acknowledged by several actors, and a range of soil-related mobile/ipad apps have been developed. Prior to developing SQAPP we reviewed a number of such apps, as reported earlier in Deliverable 4.1. The review was conducted through searching on keywords in the Google Play Store and Apple Appstore, and through looking up the apps developed as part of other (research) initiatives that we had learned about through other means. The list is not intended to be exhaustive in terms of the number of existing soil apps, but did attempt to capture the full range of functionalities currently available in soil-related apps. We excluded a number of apps that are focused on offering sampling schemes for soil sample collections and the classification of soils based on (lab-based) soil texture analysis, as these apps do not provide soil information to the user.

When reviewing the existing apps (Table 1) we find quite a range of apps focussing on providing access to soil information, such as SOILINFO (ISRIC, global), mySoil (British Geological Survey, Centre for Ecology and Hydrology & Met office, UK), SoilWeb (Soil Resource Lab, USA), CarbonToSoil (CarbonToSoil, Finland), SoilMapp (CSIRO, Australia), Soilscapes (Cranfield University, UK), SOCit and SIFSS (James Hutton Institute, Scotland), LandPKS (USDA-ARS, global), Soil Test Pro (USA) and the SoilCares Soil Scanner (SoilCares). These available apps provide soil information either at the global scale (SOILINFO) or at a region scale (mySOIL, SoilMapp, Soilscapes and SIFSS), and either focus on a range of soil properties or on single soil property (CarbonToSoil and SOCit). In Table 1 we show a brief description of each app, and list the platforms on which they are available (Apple, Android), the issuing organization, scale and price (whether free or charging fees).

Table 1. Overview of existing soil quality apps.

Name	Platform	Issuer	Domain	Scale	Price
SOILINFO	Apple, Android	ISRIC	SoilInfo provides free access to soil data across borders. Available layers: soil organic carbon (g kg^{-1}), soil pH (-), texture fractions (%), bulk density (kg m-3), cation-exchange capacity (cmol kg^{-1}) of the fine earth fraction, coarse fragments (%), FAO World Reference Base soil classes, and USDA Soil Taxonomy suborders.	World	free
mySoil	Apple, Android	British Geological Survey, Centre for Ecology and Hydrology, EU JRC, Met office	mySoil gives you access to a comprehensive European soil properties map within a single app. Discover what lies beneath your feet and help us to build a community dataset by submitting your own soil information. Discover the latest soil mapping data from across Europe. More detailed data is available for UK.	EU + UK	free
SoilWeb	Apple	Soil Resource Lab, UCDavis	GPS based, real-time access to USDA-NRCS soil survey data, formatted for the iPhone. This application retrieves graphical summaries of soil types associated with the iPhone's current geographic location, based on a user defined horizontal precision. Sketches of soil profiles are linked to their official soil series description (OSD) page. Soil series names are linked to their associated page within the CA Soil Resource Lab's online soil survey, SoilWeb.	USA	free
CarbonToSoil	Apple, Android	CarbonToSoil	The total amount of carbon on Earth is constant but for a balanced and healthy nature it is currently in the wrong form: as carbon dioxide in the atmosphere. In the CarbonToSoil mobile app consumers get to participate in agriculture where regenerative farming is used to draw carbon from the atmosphere into the soil more efficiently than before. Through	Finland (can be scaled up)	free

Name	Platform	Issuer	Domain	Scale	Price
			the app anyone can support farms to change their agricultural methods to regenerative farming. The app also allows the user to personally participate in food production and to see how food is grown.		
SoilMapp 	Apple (only for iPad)	CSIRO	SoilMapp is designed to make soil information more accessible to help Australian farmers, consultants, planners, natural resource managers, researchers and people interested in soil. SoilMapp for iPad provides direct access to best national soil data and information from the Australian Soil Resource Information System (ASRIS) and ApSoil, the database behind the agricultural computer model: APSIM.	Australia	free
Soilscapes 	Apple	Cranfield University	The Soilscapes App is an easy-to-use soil reporting tool which produces summary soils information for a specific location, based upon the "Soilscapes" soil thematic dataset. The Soilscapes map used is a 1:250,000 scale, simplified soils dataset covering England and Wales.	England and Wales	free
SoilCares Soil Scanner	Android	SoilCares	The Soil Scanner will determine the amount of Nitrogen, Phosphorus and Potassium and determine the pH, cation exchange capacity, soil temperature and the organic matter level. The Soil Scanner will provide you with a list of crops suitable for your soil. You will also receive hands-on lime and fertiliser recommendations alternatives that are available in your country. This App allows you as the user of the SoilCares Soil Scanner to connect yourself to the database and obtain your results instantly via the internet.	Scanner available in Kenya, Uganda, Tanzania, Ivory Coast, Poland, Ukraine, Hungary, and the Netherlands	annual license fee; needs a separate Soil Scanner device

Name	Platform	Issuer	Domain	Scale	Price
SOCit (Soil Organic Carbon information)	Apple	James Hutton Institute	The free app is aimed at farmers, land managers and other land users who want to know how much carbon is in their soil, helping them determine fertility and appropriate use. The app uses information about the user's position to access existing digital maps of environmental characteristics, such as elevation, climate and geology. Combining this information with data extracted automatically from a photograph of the soil of interest, it uses a sophisticated model to predict topsoil organic matter and carbon content.	Scotland	free
Soil Information For Scottish Soils (SIFSS)	Apple	James Hutton Institute	SIFSS (Soil Indicators for Scottish Soils) is an app that allows you to find out what soil type is in your area, to explore the characteristics of around 600 different Scottish soils, to discover the differences in soil characteristics between cultivated and uncultivated soils and to examine a range of key indicators of soil quality. You can also use the app to view all of our published soil mapping, plus a selection of our thematic maps, including the popular Land Capability for Agriculture. SIFSS is the only app that gives you access to the Soil Survey of Scotland. This information includes pH, soil carbon, N, P, K etc. directly from the James Hutton Institute database.	Scotland	free
LandPKS	Apple, Android	USDA-ARS, USAID	The LandPKS app helps users make more sustainable land management decisions allowing them to collect geo-located data about their soils, vegetation, and site characteristics; and providing useful results and information about their site. It also provides free cloud storage and sharing, which means that you and others	Global; pilot sites Kenya, Namibia, Malawi, Tanzania, Uganda, and Nepal	Free

Name	Platform	Issuer	Domain	Scale	Price
			can access your data from any computer from our Data Portal at portal.landpotential.org. The LandPKS app walks the user through how to hand texture their soil, as well as document other important site characteristics. The amount of water the soil can store for plants and water infiltration rate for the soil is then directly calculated on the phone. In addition, users receive an outline of their soil texture by depth, which is important for making decisions on agricultural land. A LandPKS Soil Health Module has been announced but is not yet available. The Soil Health module will be a nice complement to the LandInfo module that is currently available on the LandPKS app. LandInfo measures relatively static soil properties, including texture and rock fragment volume by depth. In contrast, Soil Health measures more of the dynamic soil properties that are important for productivity.		
SOILapp 	Android	Capsella H2020 project	SOILapp allows you to collect, visualize and share observations of soil quality using spade-test method. The spade-test is a widely used, qualitative method for performing the observation of soil conditions. It gives the observer information on soil fertility and on mechanical operations effects on its structure. By using the application for recording for soil observations, you are able to share your findings, learn from other users and seek further advice to the users' community. SOILapp guides you through an easy touch-enabled interface to define features for different	Global (generic guidance for spade test)	free

Name	Platform	Issuer	Domain	Scale	Price
			layers in a soil sample. At the end, summary features of the observation are given and shared, eventually adding comments and a short description of farm practices.		
Soil Test Pro	Apple, Android	Soil Test Pro	Use Soil Test Pro to order soil sampling supplies, pull precision soil samples, choose a lab from our recommended list, and ship your samples. Our Precision Ag Specialists will notify you when your lab results have been posted to your Soil Test Pro Web Headquarters, usually in 3-5 days. In addition, we will be glad to work with you to create recommendations, prescription maps and controller files. Just give us a call.	USA	free but test to be paid
国家土壤信息平台	Apple, Android	ISS	soil map 1:4,000,000 and 1:6,000,000; 2nd round soil survey information; CERN long-term monitoring data and city map	China (Chinese)	free

Subsequently, a further analysis was made of the type of information each of the existing apps provides, and for what purpose. We structured the existing apps in 7 categories (Table 2):

1. **Apps providing the user with access to soil data;** these apps mainly focus on giving the user easy access to existing soil data, whether at global or regional level. Communication in these apps is one-directional (information provision only), and the focus is on soil data itself, not on management advice.
2. **Apps building interactive soil datasets;** the mySoil app provides access to soil data, but also explicitly aims at validating such data by users to create better soil data (‘citizen science’).
3. **Apps informing the user about relative soil quality scores;** the SIFSS (Soil Information for Scottish Soils) app of the James Hutton Institute not only gives the user an indication on soil indicator scores, but also wheter such scores are relatively high or low for particular soil types. The user can also enter their own soil indicator data. Moreover, (relative) scores can be shown for cultivated or semi-natural soils. There is no clear link to management advice, although it is stated that is important to maintain properties such as pH, carbon content, loss on ignition and calcium content, which all affect plant growth, at optimum levels.

4. **Apps providing management advice on a single soil quality aspect;** SOCit provides advice on how to increase soil carbon sequestration. Soil organic carbon content (SOC) is an important indicator of soil quality, but overall the scope of an app focussing solely on SOC is rather narrow when considering soil quality.
5. **Apps facilitating data collection for commercial (soil) management advice;** these apps facilitate the link to providing commercial soil management advice, either through managing the process of soil sampling and processing of laboratory analyses (Soil test pro) or through the use of a device (Soilcares Soil Scanner) that can take readings in-situ of which the results are analysed using an online database outputting tailored management advice. While there are more examples of the first type of app, they are not free to use and merely streamline soil information provision based on soil sampling. The Soil Scanner is an innovative soil information collection system, but has as a drawback that it needs upfront investment in the device and subscription to an annual licence fee to get advice.
6. **Apps guiding the user through self-assessment of soil quality;** the Capsella SoilApp and LandPKS are intended to guide users through a self-assessment of soil quality (on quite different grounds, a spade-test and a landscape assessment respectively). Both apps allow users to share and learn from other users submitting their assessments. While some information is partially prefilled, the apps are not providing users with an instant answer to their questions but provide guidance instead.
7. **Apps establishing cross-stakeholder collaboration for soil improvement;** finally, the CarbonToSoil app offers brokering capabilities in addition to soil information: the idea here is to bring together farmers that are willing to manage their soil more sustainably, and users willing to contribute payment to support that.

Overall, when looking at the existing soil apps, they mainly are intended to provide information about the soil. There is limited focus on providing management advice on improving soil quality, and if such focus exists, it is either narrowly focused on particular aspects of soil quality (SOC), or requires payment of a fee. Moreover, none of the reviewed apps explicitly considers soil threats and management advice on how to mitigate them. Thus, our ISQAPER aim to develop a mobile app, referred as Soil Quality Assessment Application (SQAPP) by integrating existing soil quality data consisting of a range of physical, chemical and biological soil quality indicators and associated soil threats was found to go beyond functionalities currently offered by existing soil apps. Moreover, based on the information of soil indicators and soil threats, the SQAPP will provide recommendations on how to improve soil indicators and combat soil threats.

Table 2. Categorisation of existing soil apps.

Apps providing the user with access to soil data	**Apps building interactive soil datasets**	**Apps informing the user about relative soil quality scores**
Apps providing management advice on a single soil quality aspect	**Apps facilitating data collection for commercial (soil) management advice**	**Apps guiding the user through self-assessment of soil quality**
Apps establishing cross-stakeholder collaboration for soil improvement		

2.2. Stakeholder wish-list for functionalities of SQAPP

As input to the development of the beta-version of the soil quality assessment tool, in WP5 multi-stakeholder case study inventories of information needs concerning soil quality and selection of innovative practices were made and reported in Milestone 5.1. A summary of the findings was earlier given in Deliverable 4.1 and is given in Table 3.

We distinguish four broad categories of information needs:

1. **Soil information;** Many stakeholders, ranging from individual farmers to high-level policy makers, expressed a need to have better information about soils. Many of the interviewed stakeholders displayed a keen interest in comparative soil quality data, i.e. the need to know more about the management-varying part of soil quality. There was also widespread interest in broader information about how soils are currently managed, how soil quality can be assessed, what the environmental impacts of agriculture are, and how biological soil quality can be suitably assessed.
2. **Management advice;** the second category related to a widely felt need to get advice on how to improve soil quality. A long list of topics was brought up: measures to improve soils, measures to mitigate soil threats, advice on how to enhance environmental and economic outcomes of farming, and advice on how to most effectively use rainfall in drought-prone environments. Such advice was not only requested by farmers, but also identified by other stakeholders such as extension agents, researchers, environmental NGOs and policy makers as important.
3. **Awareness raising and education;** although this need is of a higher abstraction level, it was reiterated by many interviewees that in order to change unsustainable soil management practices, awareness and education about the functioning of soils and what constitutes good soil management is critical. This awareness raising is a cross-cutting theme across the stakeholder landscape, from individual land users deciding about their land management systems and practices to policy makers making the rules and regulations about soil management.
4. **Procedural;** a final need expressed by multiple stakeholders was more procedural in nature: how to exchange information about soils and innovative agricultural management practices? How to get a quick assessment of soil quality and soil threats? These needs confirmed the notion that developing a soil quality app would have added value in facilitating widespread procedural issues.

Table 3. Categorised multi-stakeholder information needs

<table>
<tr><td>Soil information
Comparative soil quality data
Information on land management
Information about soil quality indicators
Information about the environmental impacts of agriculture
Biological soil quality indicators</td><td>Management advice
Information about soil improvement practices
Information about measures to mitigate soil threats
Information about opportunities for sustainable intensification
Fertilization advice
Increasing economic return
Effective use of rainfall</td></tr>
<tr><td>Awareness raising and education
Knowledge development about soils and environmental protection</td><td>Procedural
Opportunities for information exchange
Quick assessment of soil indicators/soil threats
Faster knowledge transfer
Quick advice on soil management
Methods for soil quality assessment</td></tr>
</table>

Source: based on multi-stakeholder inventories in the iSQAPER Case Study sites (Milestone 5.1).

The level of implementation of layers in the first pilot app was limited due to data processing issues. In particular, the comparative assessment of soil quality indicators by calculating cumulative probability density functions and establishing the minimum and maximum values for different land cover classes within each pedo-climatic zone was very computation-intensive. As this information and the link to management advice was deemed to be the most important to potential app users, it was decided to proceed with the development of the pilot app into the beta-version of the app without participatory testing of the pilot app with stakeholders. This was to avoid the risk of stakeholders losing interest in the app by not meeting the expectations. Instead the feedback from testing with stakeholders was based on the beta version of the app.

2.3. User feedback

SQAPP has been through a number of rounds of evaluation by different groups of stakeholders during its development. These include: a student evaluation of the beta version with farmers in the Valencia region, Spain; a formal evaluation of the beta version by some 90 European stakeholders (researchers, farmers, students, advisory services and policy makers) in locations in Slovenia, Poland, Portugal, Greece, Spain, France, Estonia, Romania and Netherlands; evaluation following a workshop presentation by participants in the Wageningen Soil Conference; an evaluation by some 220 participants in the 11 study site Demonstration Events [D5.1, D6.4 and others].

Review of SQAPP performance has focused on three dimensions: accuracy and relevance of the information provided, as well as its functionality as a tool in the hands of end-users. These dimensions were defined as follows (van den Berg et al., 2018):

Accuracy

Accuracy as a concept can be defined as the difference between the estimated value and the true value. In order to determine accuracy, quantitative measurements of data are necessary. This is expressed by knowing or estimating the actual (true) value (Walther and Moore, 2005). As such, the accuracy in this case can refer to the ability of the app to report information to the best estimation of the true value. Reference values were taken from laboratory analysis of soil samples, or from field measurement or visual soil assessment.

Relevance

The relevance of the information provided by the app can be analysed using the concept of actionable knowledge as stated by Cash et al. (2003): "Science and technology must play a role in sustainable development whilst effectively managing the boundaries between knowledge and action in ways that simultaneously enhance salience, credibility and legitimacy of the information produced". Actionable Knowledge as a concept defines the boundaries of stakeholder participation in the decision making process and fostering solutions together (Geertsema et al., 2018).

The concept of actionable knowledge was channeled into the investigation of relevance. Relevance, in the context of this evaluation process, is used to describe the meaningfulness of the information provided by the app and subsequent action through adjustments in management practices by the end-users. This was tested via discussion of the recommendations with app users during interviews. We also assessed the recommendations provided based on various levels of suitability to the specific farmers' context.

Functionality

Functionality can be defined as the effectiveness of the app as a medium, the accessibility of the language used, and the usability of the tool. Within the concept of usability, Iwarsson and Ståhl (2003) suggest four components that need to be satisfied: a personal component related to human functioning, an environmental component related to barriers within the environment that may inhibit action, an activity component related to the activities that need to be performed, and, finally, an analysis of the three aforementioned parts ensuring individual and group preferences are met within the targeted environment. That means, that the functionality of the app is not only limited by the design of the interface, but it also

encompasses the socio-environmental context in which the user is placed, as well as the individual attitude towards the technology.

Accuracy assessment was an essential part of the SQAPP evaluation process as it was raised as an important issue by stakeholders. It was in several of the rounds of evaluation integrally included in the assessment with app users, but as it relied on testing against other data, this part is reported in Section 2.4: Testing. The evaluation with researchers in the project plenary meeting in Ljubljana and conference participants in the Soil Horizons workshop was labelled as peer review and is reported in Section 2.6: Peer review.

Student evaluation of the beta version with farmers in the Valencia region, Spain

This evaluation sought to understand the accuracy and relevance of the app through assessing how soil properties, threats, and suitable management practices are uniquely interpreted and reported by the application, by field measurements and observations, and by farmers and landowners themselves (Figure 1).

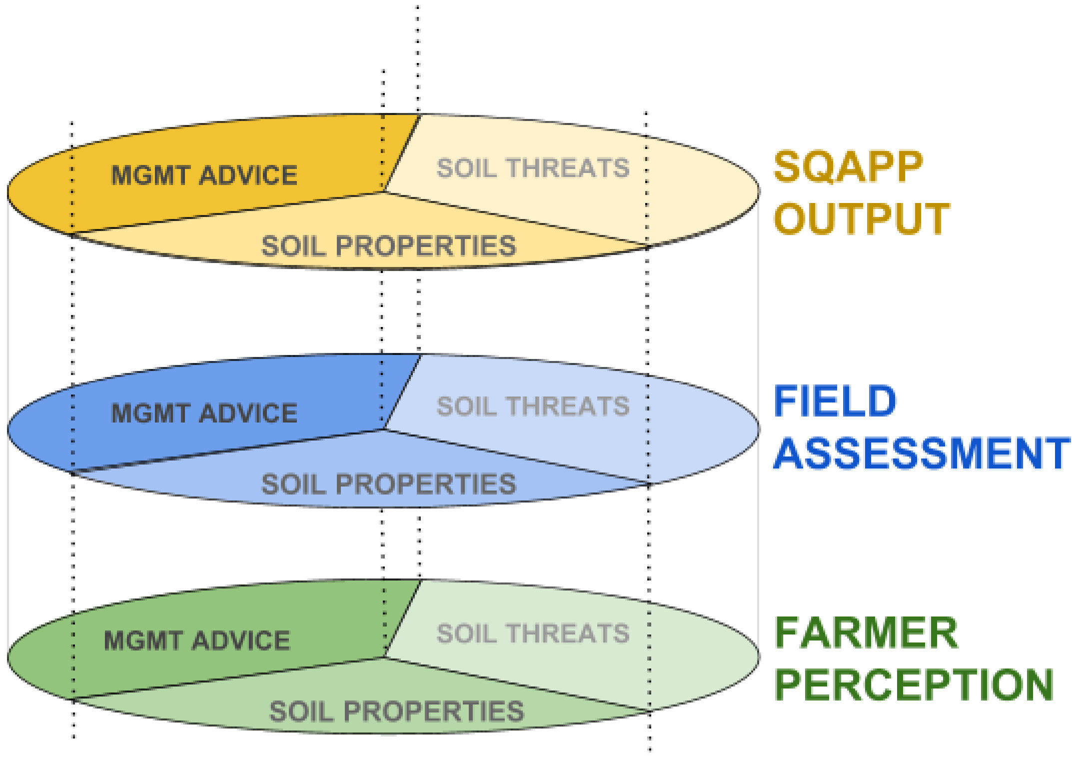


Figure 1. Categories of information sought from three key sources (SQAPP, field assessment, and farmer perception) (source: Van den Berg et al., 2018).

The report (Van den Berg et al., 2018) is accessible from iSQAPERIS[1]. The main recommendations stemming from this report are shown below with an indication on how this was included in SQAPP.

Accuracy:

A1. Insert the option to let users search and specify location using direct address and coordinate entry	This functionality has been added in SQAPP
A2. Reconsider source and evaluate accuracy of datasets for: ● 'Soil pH' ● Nutrient Availability ○ 'Exchangeable Potassium' ○ 'Phosphorus using the Olsen method' ○ 'Total Nitrogen' ● 'Electrical Conductivity' ● 'Wind erosion vulnerability (classified)'	No better datasets were currently available. Users can update global data with their own data. The level of reliability of datasets has been indicated in SQAPP.
A3. Work to fill gaps in datasets for: ● 'Rainfall data' ● 'Altitude' ● 'Soil Wind Erosion in Agricultural Soil' ● 'Wind erosion vulnerability (classified)	Rainfall and altitude data were missing from several coastal areas due to coarse-scale native datasets. These were extrapolated to give a better coverage. Soil quality data is available in these locations but no cumulative probability density functions have been produced, which leads to lower functionality (no recommendations for improvement of soil quality parameters).

Relevance:

R1. Allow for entry of optional field characteristics including crop type and AMPs	Crop types and use of pesticides can now be specified by the user, as well as interest in specific AMP recommendation domains.
R2. Allow user to specify 'user type' during profile creation (Farmer vs Researcher) and curate recommendations accordingly	Modular user specifications have not yet been implemented. The app is intuitively organised so that different types of users can easily find the information they are interested in.
R3. App should not give 10 AMPs arbitrarily, instead listing all that exceed a score threshold	A standard list of 10 AMPs ordered in descending order of relevance is maintained. As the AMP database has grown extensively, the risk of including less suitable AMPs has diminished.
R4. Require that 'land cover' be manually entered rather than auto filling 'arable' or 'other'	Further specification of land cover is now enabled, so that users can verify whether the correct land cover is selected and change manually if required.

[1] https://www.isqaper-is.eu/sqapp-the-soil-quality-app/stakeholder-feedback/479-field-evaluation-of-sqapp-performance-in-the-greater-albaida-region

Functionality:

F1.	Include a detailed/guided tutorial that can be reviewed by the user at any time	Information buttons have been added in SQAPP to briefly explain the elements of the app. A FAQs section has also been provided. On iSQAPERIS app users can find detailed explanation and a video tutorial about the SQAPP.
F2.	Soil properties terminology has to be clarified and links to more information could be provided	Through information buttons the soil properties are explained.
F3.	'Landscape position' should be auto filled (locked to latitude and longitude) and not allowed to be changed manually	Landscape position is now auto-filled, but editable by the user in case the global data are found to be incorrect.
F4.	Re-specifying coordinates for a saved location should automatically update field characteristics to match (altitude, precipitation, landscape position, and slope)	This has been implemented.

Formal evaluation of SQAPP beta-version in case study sites

As part of the process of developing SQAPP, the beta version was formally evaluated by some 90 European stakeholders (researchers, farmers, students, advisory services and policy makers) in locations in Slovenia, Poland, Portugal, Greece, Spain, France, Estonia, Romania and Netherlands. The evaluation used a standardized interview protocol and questionnaire to collect feedback from the stakeholders on the quality and accuracy of information provided by SQAPP and the benefits and disadvantages of its different features. The results of this evaluation are reported in Deliverable 5.1. Key issues identified and how they were considered in SQAPP development are listed below in Table 4.

Table 4. Key issues emerging from the formal SQAPP beta-version and how they were addressed in SQAPP development.

Issue	How dealt with in SQAPP development
Not all soil parameters relevant	Most soil parameters were deemed relevant by users. When not deemed relevant, e.g. electrical conductivity, this was due to a particular aspect of soil quality (e.g. soil salinity) not being an issue locally. Still, all soil parameters are shown when data is available (and confirming that the indicator is indeed in the desired range).
Meaning of the probability density functions	The concept has been explained in information buttons and a video tutorial.

Missing soil parameters: (a) magnesium and sulphur (5 responses); (b) aggregate stability and soil structure (5 responses); (c) soil compaction (4 responses); and (d) the methods used, e.g. for the analysis of potassium, phosphorus, pH in calcium or chloride suspension (2 responses).	For magnesium and sulphur no spatial data was available. For aggregate stability and soil structure visual soil assessment methods need to be applied, for which also no spatial data is available. Soil compaction risk can be predicted, but requires management information and information on weather conditions which is too complex for SQAPP – instead susceptibility to soil compaction is included. The methods used have been specified.
There is a lack of clarity in the units that should be better presented and adapted. Description of the units should be added. Some units should be presented according to the location under consideration (e.g. soil nutrient in Slovenia is expressed with mg/100gr soil).	The units are explained and further specified in the information button for the soil properties. Some common conversion factors are provided in FAQs section.
The source of data should be mentioned. This lack of information sows doubt about the reliability of the parameters. For this purpose, it was suggested to include a reference range (high / medium / low) or an index of estimated accuracy level to indicate the reliability of the results.	The source of data has been mentioned, and an indication of the accuracy of each parameter tested is given (if available).
SQAPP should be available in the local language.	SQAPP has been made available in 14 languages
Soil threat threshold values are not realistic (too high) in the local context and should be in accordance with national legislation	The threshold levels were documented in Deliverable 6.1. They are used as a global reference – indeed local classifications and legislation can deviate from these, but the current version of SQAPP cannot consider nationally and regionally different threshold values.
Difficulty in understanding the outcomes of the threshold values (in a practical way) suggesting appropriate information on the thresholds values, colours (red for high risk, yellow for moderate risk, and green for low risk for threshold).	The low, medium and high risk areas are consistently colour-coded and in the overview page of soil threats each local score is labelled with the respective colour code as well. The colour coding system is explained in FAQs and video tutorial.
Include some other soil threats such as "susceptibility to pests", contamination with pesticides and other relevant organic components	Susceptibility to pests was not deemed a soil threat per se and spatial data on soil pests is not available. For pesticide contamination risk a new module was developed and included in SQAPP.
recommendations should be restricted to the most important and innovative AMPs that can be implemented in any one location, instead of listing many practices that are out of context.	The majority of users found the number of listed AMPs (top-10) appropriate. Some users would like the recommendations to focus on fewer more focused AMPs. The top-10 is ordered in sequence from most to less relevant. The user can indicate a specific category of AMPs of interest and these will be highlighted in bold. Also the number of AMPs considered and the scoring system have

	been expanded, which has led to lower likelihood for inappropriate AMPs being recommended.
The level of innovation of AMPs is insufficient	The AMPs have a quite broad range. The examples highlight innovative approaches within a specific AMP. A huge effort has been made to prepare 381 specific examples of AMPs, providing more inspiration to app users.
Enable the cropping system to be entered manually in order to refine the recommendations.	A further specification layer of the broad land cover categories has been implemented.
SQAPP recommends converting arable land to forest/grassland in areas where the farmers already do not have enough arable land.	The option to convert land use has been removed from the list of AMPs. Although this can be a valid option and is sometimes recommended by researchers and advisors, it was deemed offensive to farmers and land users. Hence, SQAPP now aims to provide recommendation for a given land use system, and not to change land use.
Include more information such as: yield (which crop should be planted in this area), costs, how much manure should be used per ha and what kind is recommended, the possibility to compare results from different areas.	As SQAPP is about soil quality, plant-specific aspects such as crop choice, yield expectations and fertilization levels were beyond the scope of the app development. Costs are also highly variable in practice, but a complexity factor giving an aggregate indication of the magnitude of costs, effort and know-how has been added to the AMP examples.

SQAPP feedback at demonstration events

In the final phase of iSQAPER, demonstrations events were organised in all the study sites (with the exception of Zhifanggou Watershed) to demonstrate and discuss the local soil quality assessment and recommended management practices provided by SQAPP (among other things). An additional deliverable report 6.4 reports on the findings from the demonstration events[2].

A total of 483 people participated in 11 events including representatives from all the target groups of stakeholders (farmers, advisors, suppliers, researchers, students, policy makers and administrators). During the events feedback was collected from some 220 of the participants in response to the following questions.

- What aspect of the SQAPP app interests you most?

  The three most frequent response types from the Europeans were:

  1. **Data provided on soil properties** “The availability of soil data for specific area.” (male agronomist, Crete)

[2] https://www.isqaper-is.eu/sqapp-the-soil-quality-app/stakeholder-feedback/411-stakeholder-feedback-at-demonstration-events

2. Management recommendations “Tips on how to improve soils.” (male farmer, Slovenia)
3. Soil quality evaluation provided “Fast results about soil quality." (male student, Estonia)

The three most frequent response types from the Chinese were:

1. **Data provided on soil properties** “The database is very powerful.” (male farmer, Qiyang/Gongzhuling)
2. **Potential to add own data** “All users can update the data.” (female researcher Qiyang/Gongzhuling)
3. (equally): **Soil quality evaluation and Accessibility of data, ease of use** “I can know the quality of my farmland by the APP.” (female farmer, Qiyang/Gongzhuling) “Data download is very convenient.” (male agro-technician Qiyang/Gongzhuling)

- Are there any improvements or changes you think should be made to SQAPP to make it a tool that you would use regularly?

  The most frequently requested improvement from users in both Europe and China was **to have more of the text translated from English into their own language**. The two other most frequently requested improvements from the Europeans were:

  2. **User input data** “Inputs from users should be checked by experts since there is always a risk for not valid data or data entry mistakes.” (female agronomist, Crete)
  3. **More specific recommendations for local methods/practices** “Recommendations that are more suitable in Estonian conditions.” (female student, Estonia)

  The two other most frequently requested improvements from the Chinese were:

  2. **Android version** Because, at the time of testing, SQAPP was only available on Apple’s App Store in China, the second most frequent request was for an Android version of the app.

  3. **Soil data temporal/spatial resolution** “I think it needs improvement in accuracy.” (male researcher, Qiyang/Gongzhuling)

Regarding the suggested improvements, we have worked on the translations of app commands, AMP recommendations and additional information in 14 languages. We have prepared guidelines for different types of users, in which farm advisors could play a role in supporting farmers and land users to operate SQAPP effectively, and we have expanded the portfolio of AMPs and specific examples to provide to app users. The Google Play store is not accessible in China – an apk installer file has been shared. Accuracy issues have been highlighted by adding a qualification for the reliability of each data layer for which we could perform tests in iSQAPER sites.

2.4. Testing

Two working papers document the testing of SQAPP by comparing measured and SQAPP-derived soil quality and soil threat parameters carried out in WP6. Teixeira and Basch (2019a) discuss the correlation and the agreement between measured physical, chemical and biological soil properties, and the values estimated by the Soil Quality App (SQAPP) for the same location. Teixeira and Basch (2019b) discuss the accuracy of soil properties and soil threats classification based on soil properties estimates of the Soil Quality App (SQAPP) and the correlation and agreement with the soil properties and soil threats classification using measured physical, chemical and biological soil properties, for the same location. The final goal of these studies was to assess if SQAPP can be used to monitor soil quality improvement, and the adequacy of the recommendation system.

Table 5 presents the correlations between measured and estimated soil parameters. Of the 13 properties analysed, only sand content showed a strong positive correlation between measured and estimated values, 9 presented a moderate correlation and 3 a weak correlation. 6 of the moderate and weak correlations were negative. With the exception of the weak correlated (measured/ estimated) properties (Macrofauna, N and K), and Electrical Conductivity, all other correlations had statistical significance. For all properties, agreement between measured and estimated values was low. The standard error of the estimate was calculated for each SQAPP estimated soil property.

Table 5. Correlation between measured soil properties values and values estimated by SQAPP (dependent variable).

	n	Measured	Estimated	r	Regression equation	R^2	Stat. Sig. α	SER
Sand (%)	37	[2,89]	[23,82]	0.77	y = 0.4983x + 15.333	0.60	0.001	10.97
Clay (%)	37	[1,34]	[5,30]	0.70	y = 0.5604x + 13.947	0.48	0.001	5.65
Silt (%)	37	[6,79]	[12,57]	0.68	y = 0.3061x + 26.09	0.46	0.001	7.91
C. F. (%)	27	[0,45]	[1,17]	0.70	y = 0.2375x + 4.0079	0.49	0.001	3.49
B.D. (Mg m^{-3})	33	[1.03,1.75]	[1.27,1.62]	-0.42	y = -0.2272x + 1.7067	0.17	0.05	
SOC (%)	37	[0.53,4.3]	[0.7,4.6]	0.58	y = 0,4918x + 1,4866	0.34	0.01	0.87
pH	37	[4.86,8.35]	[5.3,7.9]	0.57	y = 0.4482x + 3.7755	0.32	0.01	0.66
E.C. (dS m^{-1})	26	[0.02,1.64]	[0.1,7.2]	-0.30			ns	
P (mg kg^{-1})	21	[4.9,583]	[2.7,5.5]	-0.54	y = -0.0032x + 3.9529	0.29	0.05	
Exc. K (mg kg^{-1})	33	[55,544]	[63,489]	-0.12			ns	
Total N (mg kg^{-1})	35	[665,3700]	[570,1730]	-0.08			ns	
Microbial C (g m^{-2})	23	[64,924]	[47,150]	0.60	y = 0.0705x + 76.843	0.36	0.01	24.31
Macrofauna (n)	19	[0,5]	[1,8]	-0.04			ns	

C. F. (%): Coarse rock fragments (%); ns: not statistically significant; (n): number of groups
Source: Teixeira and Basch (2019a).

Teixeira and Basch (2019b) consider the soil threat classifications for 8 soil threats: Erosion, Compaction, Salinization, SOM decline, Acidification, Nutrient Depletion, Contamination and Biodiversity Depletion. For each soil, SQAPP estimates accurately classified the level of threat (Low, Moderate, High), on average, in 53% of soil threats. The percentage of soil threats' classes correctly identified using SQAPP estimates, per soil, varied between 14 and 83%.

Based on these studies, the following qualifications were given to the soil quality and soil threat indicators in SQAPP (Table 6). Of all indicators, 9 are judged to have low accuracy, 8 moderate accuracy, and 2 high accuracy, whereas no verification was made for 7 indicators (mostly soil threats).

Table 6. Accuracy indications of soil quality and soil threat parameters included in SQAPP.

Soil quality or threat parameter	**Accuracy in iSQAPER field tests**
Physical properties	
Depth to bedrock	Low
Bulk density	Low
Clay content	Moderate
Silt content	Moderate
Sand content	High
Coarse fragments	Moderate
Plant-available water storage capacity	Not available
Chemical properties	
Soil organic carbon content	Moderate
Soil pH	Moderate
Cation Exchange Capacity	Not available
Electrical conductivity	Low (only tested for low EC)
Exchangeable potassium	Low
Available phosphorus using Olsen method	Low
Total nitrogen	Low
Biological properties	
Soil microbial abundance	Low
Soil macrofauna groups	Low
Soil threats	
Soil erosion by water	Not available
Soil erosion by wind	Not available
Soil compaction	Moderate
Soil salinization	High
Soil organic matter decline	Moderate
Soil nutrient depletion	Low
Soil acidification	Moderate
Soil contamination by heavy metals	Not available
Soil contamination by pesticides	Not available
Soil biodiversity	Not available

2.5. Spatial modelling

For agricultural policies to be targeted, management should be promoted that i) mitigates all the most severe soil threats, and ii) improves all the soil quality characteristics furthest removed from their potential, optimum state. Till now, however, most research has focused on the effect of management on individual or a few combinations of soil threat/quality indicators only, resulting in contradictory recommendations (Turpin et al. 2017). Based on the the SQAPP management advice algorithm, a policy-oriented, spatially explicit system for need-based and targeted agricultural management advice was developed as part of an MSc internship project by Aleid Teeuwen in collaboration with WU and ISRIC (Teeuwen, 2020). We used the SQAPP algorithm to map i) overall soil threat severity in Europe, ii) potential for soil quality improvement in Europe and iii) the management practice(s) that are best suited to alleviate soil threats and improve soil quality. In order to assess the recommendations, we also evaluated: iv) how sensitive is our management advice was to crop choice, and v) whether we
could optimize the management advice with different methods for weighing on the basis of soil quality indicators and soil threats.

A large range of agricultural management practices (AMPs) were considered as possible means to alleviate soil threats and improve soil quality through improved terrain management, soil management, vegetation management, water management, nutrient management, pest management, pollutant management and grazing management. For a given location, a management advice was created in two steps. First, we checked whether the AMP could be applied given the land cover, slope, annual precipitation, landscape position, soil depth, soil texture and stoniness in that location. Terraces, for instance, cannot be implemented on grazing land, on slopes shallower than 5%, on flat plains, or on soils that are very shallow, or contain more than 50% sand. Second, we ranked the AMPs according to their combined effect on soil quality and soil threat indicators. Negative, neutral and positive effects were given values of -1, 0, and 1, respectively. In order to ensure that the management advice was location-specific, only effects on soil threat indicators with medium or high threat levels, and on soil quality indicators with a relative performance ≤ 33% were considered.

Calculations were set up to be able to run the procedures on a high performance computer cluster facility. This procedure is finalized, but needs further tweaks to produce European scale maps. Tests of the procedure were therefore done on NUTS2 regions encompassing the 10 European iSQAPER case study sites (see Figure 2). Most, but not all, soil quality indicators in most, but not all regions, were no more than one standard deviation away from 50% improvement potential (Figure 3). Notably high relative improvement potentials for CEC were found in the Netherlands, for bulk density in Greece, for nitrogen in the Netherlands and Greece, for SOC in all regions except Estonia, and for water holding capacity in Greece. Notably

low relative improvement potentials for CEC were found in Estonia, Greece, Romania and Slovenia, for bulk density in Poland, for potassium in Estonia, Spain and Romania, for microbial abundance in the Netherlands, for phosphorus in the Netherlands and Poland, and for pH in Greece and Spain (Figure 3). Average soil quality improvement potential, however, did not vary much from region to region. With average improvement potentials of 34% and 31%, respectively, Slovenia and Estonia had the highest average relative soil quality, whilst Greece and Portugal had the lowest average relative soil quality, with 60% and 55% average improvement potential, respectively (Figure 3, Figure 4).

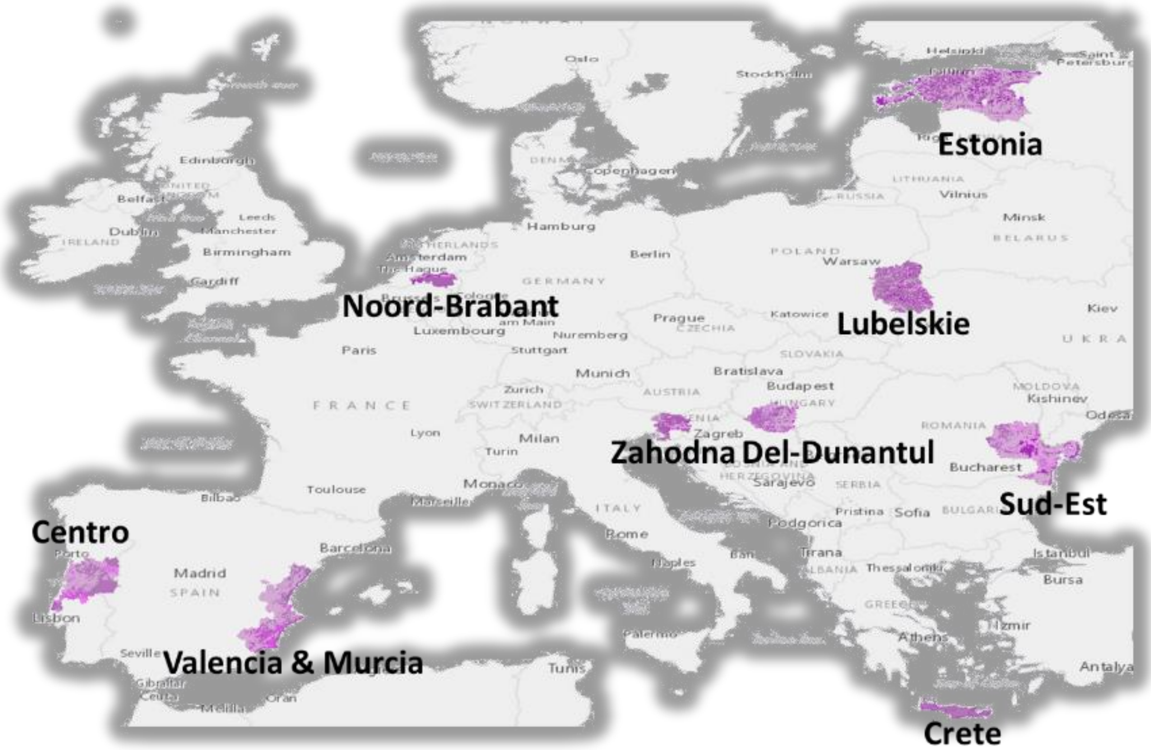


Figure 2. Regions selected for spatial analysis.

Average soil threat severity differed across regions and indicators (Figure 5). Yet, not all indicators were subject to spatial variation: the range of average soil threat severity ± the standard deviation of the average soil threat severity due to contamination, nutrient depletion, and salinization, were low, high, and low, respectively, in all regions. On average, the threat level was 1.70 ± 0.25 (low to intermediate) (Figure 5; Figure 6). Crete (NUTS2 code EL43), Zahodna (SI04) and Valencia (ES52) had the highest threat levels, amongst others due to high levels of acidification (Crete and Valencia), wind erosion (Crete and Valencia), water erosion (Crete and Zahodna), biodiversity decline (Zahodna) and contamination (Zahodna). In some maps, artefacts of low-resolution indicators are readily visible.

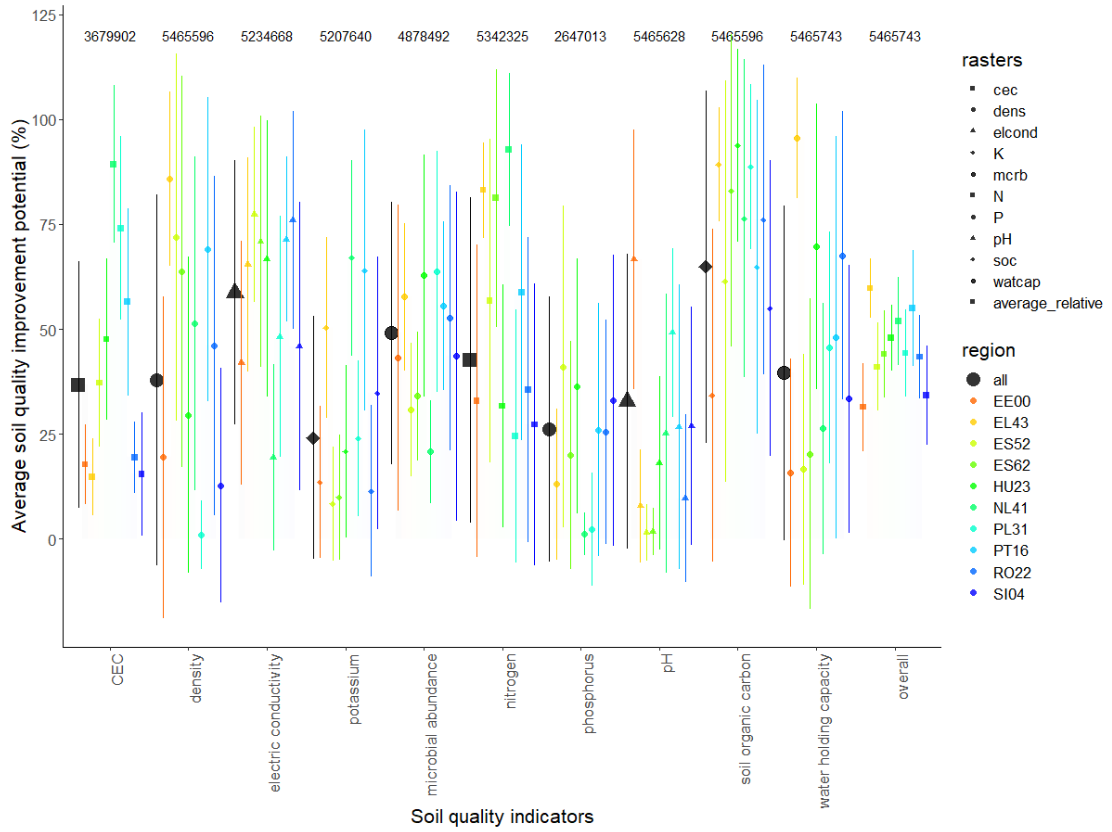


Figure 3. Average soil quality improvement potential (± standard deviation) per region and soil quality indicator. The number of data points per soil threat indicator for all regions combined is written above each soil threat, and overall averages are shown on in the most right column (overall).

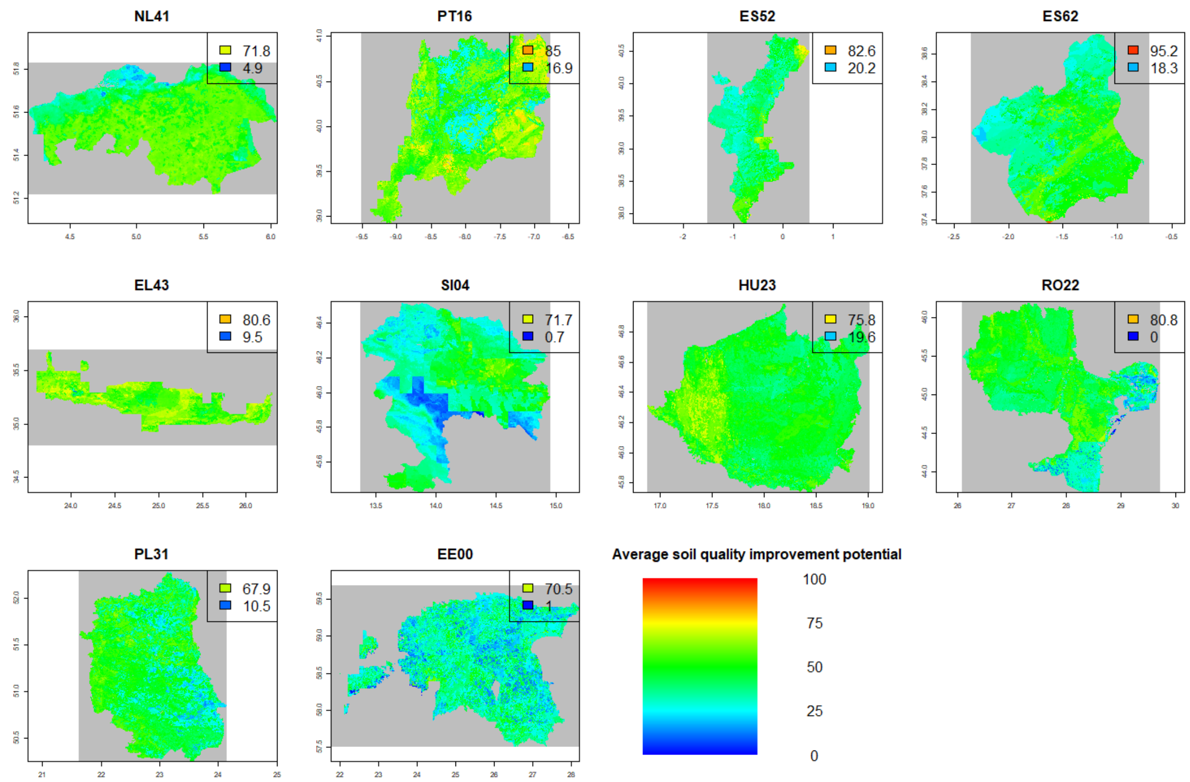


Figure 4. Average relative improvement potential (%) in the selected 10 regions. Minimum and maximum averages improvement potential are displayed in the upper left corners.

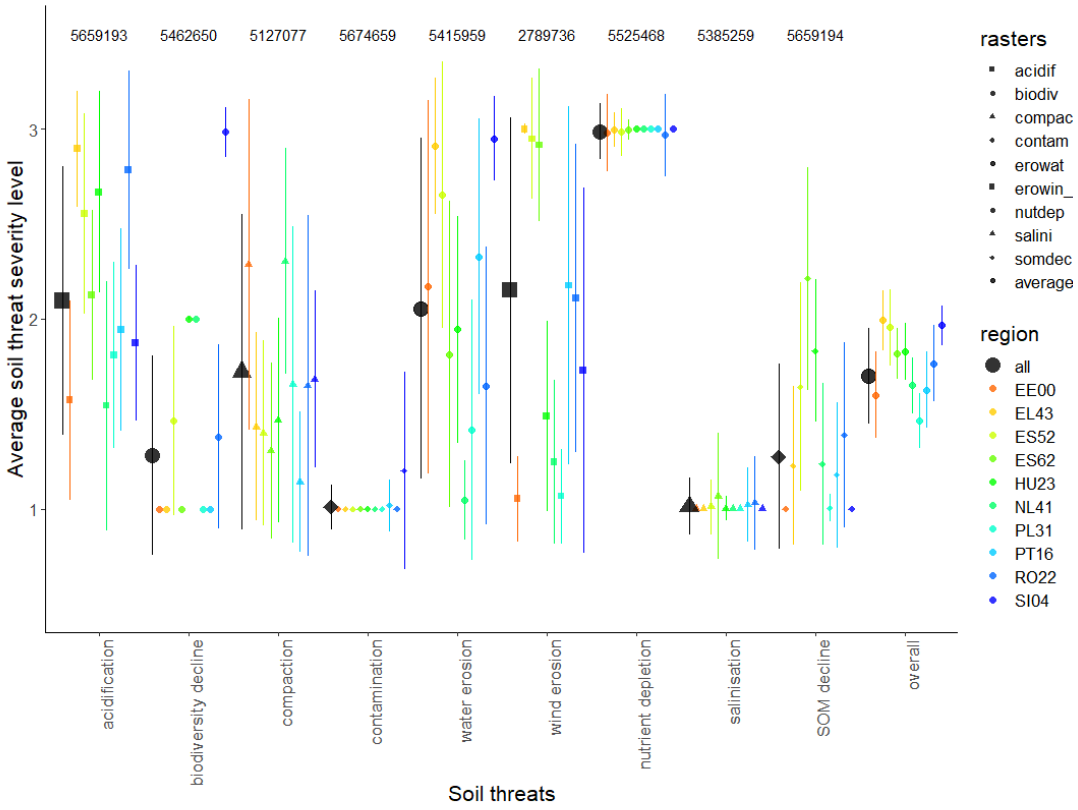


Figure 5. Average soil threat severity level (± standard deviation) per region and soil threat. The number of data points per soil threat for all regions combined is written above each soil threat, and overall averages are shown on in the most-right column

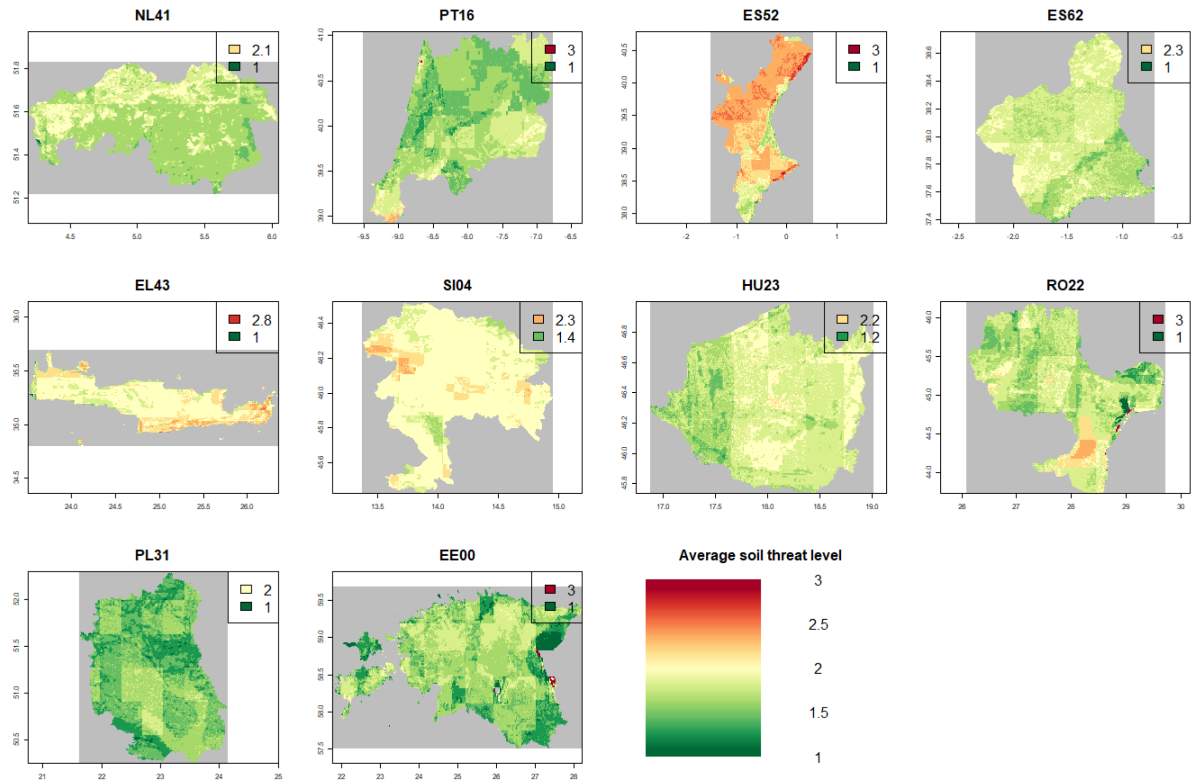


Figure 6. Average soil threat severity level for each of the 10 selected regions. Minimum and maximum averages are displayed in the upper left corners.

The additive scores used to rank AMPs in the SQAPP algorithm were found to differ in space and vary among AMPs (Figure 7). The highest obtained additive scores ranged from 8 in Hungary (HU23), Murcia (ES62), Poland (PL31) and Estonia (EE00), to 11 in Valencia (ES52) (Figure 8). The number of AMPs achieving those highest scores ranged from 1 to 69. Areas where one AMP was the single best practice were rare, as were areas where more than ten AMPs obtained the highest attainable additive score.

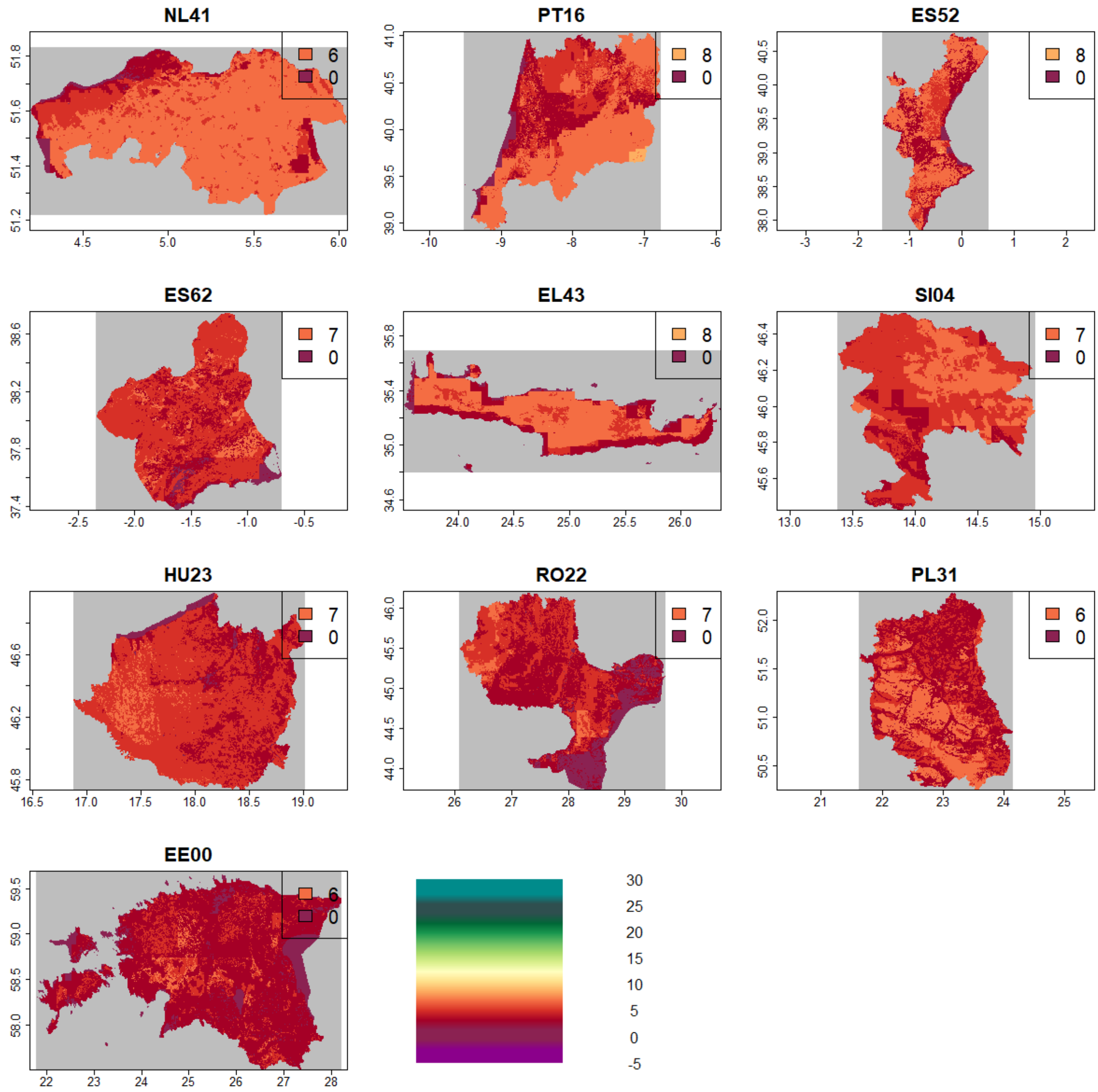


Figure 7. The additive scores obtained by one AMP (agroforestry) in each of the selected European regions, using the SQAPP algorithm (scenario A). The numbers in the upper corners of each map show the maximum and minimum scores obtained by each AMP and their associated colour.

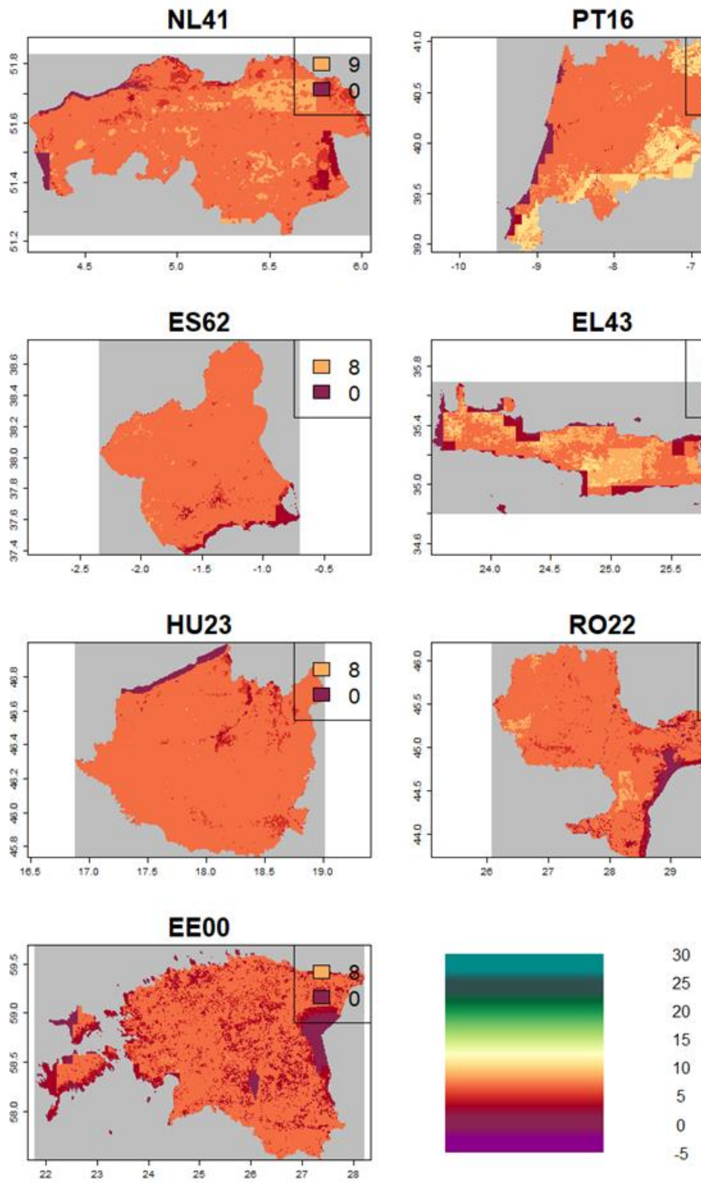


Figure 8. The highest obtained additive scores in each selected European regions, using the SQAPP algorithm (scenario A). The numbers in the upper corners of each map show the maximum and minimum scores obtained by each AMP and their associated colours.

Looking at all AMPs achieving the highest scores and not only the AMPs achieving the highest scores alone, we see that a great diversity of AMPs were recommended (Figure 9), amongst which the most common were compost application (14), crop rotation/diversification (20), growing halophytes (28), minimum-tillage (44), no-tillage (45) and straw interlayer burial (62). Moving away from the highest scores to the second highest and down to the tenth highest scores, the diversity of management practices being recommended increased (Figure 9). When assuming cereals or root crops were produced, the most common agricultural management practices were the same as in the absence of any cropping system assumption. Assuming permanent crops were grown, also resulted in many of the same management practices being recommended as in the absence of any cropping system assumption, with the exception of crop rotation and straw interlayer burial. Assuming the land was pasture or

rangeland, however, management practices such as animal manure application (2), area closure (3), bunds (8), sprinkler irrigation (61) and vegetative strips (69) were more commonly recommended (Figure 10). In rangeland specifically, rangeland rehabilitation (53) was also a commonly recommended practice. Moving away from the highest scores to the second highest and down to the tenth highest scores, the diversity of management practices being recommended increased (Figure 10).

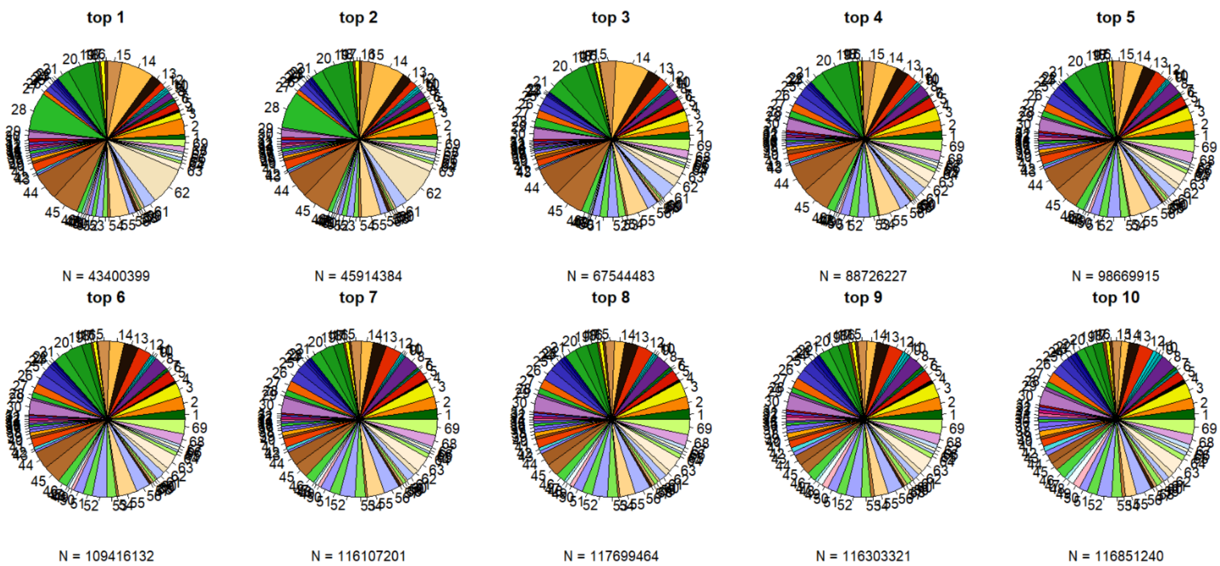


Figure 9. The frequency at which AMPs obtained the highest attainable scores (top 1), second highest attainable scores (top 2), third highest (top 3), and onwards to the tenth highest attainable scores (top 10), in all the selected European regions combined, using the SQAPP algorithm.

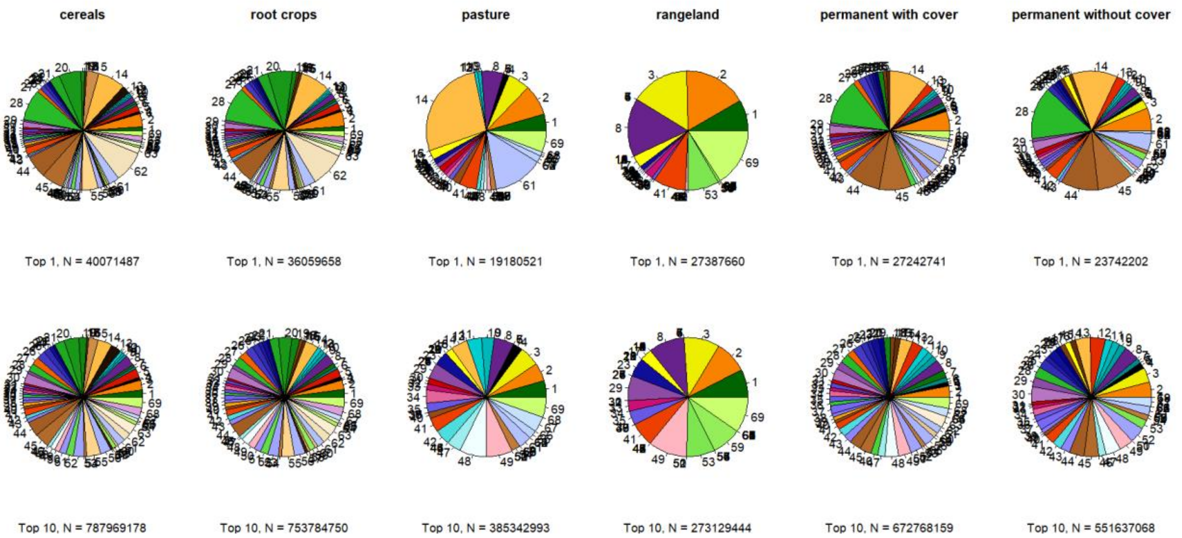


Figure 10. The frequency at which AMPs obtained the highest attainable scores (top 1), or one of the ten highest attainable scores (top 10), in all the selected European regions combined, using the SQAPP algorithm.

The assessment of the AMPs advised revealed that there were seldomly any practices that were considered to be single best. Instead, two or several AMPs were deemed equally suitable. In an attempt to optimize the SQAPP algorithm, we assessed whether specifying cropping systems would reduce the number of equally suitable AMPs. This was effective for some cropping systems, but not for the most dominant annual cropping system in Europe: cereals. Adapting the algorithm itself and allowing for a more continuous scoring of AMP suitability did successfully reduce the number of equally suitable AMPs, but revealed that one single AMP, compost application, was recommended almost everywhere. The cause of the dominance of this AMP was a systematic bias towards well-rounded AMPs (i.e. AMPs that have a positive, though possibly small, effect on many indicators) that was built into the SQAPP algorithm. We suggest that this bias may be overcome by distinguishing between small and large positive effects.

In order to avoid the current bias towards well-rounded AMPs and AMPs addressing high, but still unimportant relative electrical conductivity improvement potentials, we recommend to:

1. Consider the effect of AMPs on electrical conductivity/salinity not in relative, but in absolute terms where thresholds are used to indicate whether the electrical conductivity needs to be addressed or not.
2. Select and further developing a weighing method that allows for a (more) continuous scoring of AMPs so that the number of AMPs obtaining the highest attainable score is reduced and may be visualised in space.
3. Improve the table containing the effects of AMPs on soil threat and soil quality indicators (positive = +1, neutral = 0 or negative = -1), so that not only the presence and direction of an effect is indicated, but also its magnitude. We suggest to start by indicating whether positive effects are large (in which case they might be attributed a large positive effect = +2). We assume this will lessen the bias towards well-rounded practices substantially.
4. Replace low-resolution indicators, low-coverage indicators and low-quality indicators and background data:
    - Low-resolution data: soil compaction, global biodiversity index, precipitation, Koppen climate zone
    - Low-coverage data: soil loss due to wind erosion, wind erosion vulnerability, water erosion vulnerability, soil compaction, Koppen climate zone and CEC and phosphorus
    - Low-quality data: phosphorus, nitrogen and potassium.

2.6. Peer review

Internal review session at plenary iSQAPER meeting Ljubljana

A review session was organized at the plenary iSQAPER project meeting in Ljubljana with project participants in order to review the SQAPP and inform any final adjustments to be

made. The session was born out of a felt need to conduct a peer-review of SQAAP within and outside iSQAPER, to discuss issues concerning the validation of SQAPP against measurements, data origin, data coverage, reliability and accuracy of the data, use of pedo-transfer functions if possible, and the possibility for users to include data and feedback (so that users will not just discard the app, but will make it better and interactive). Four parallel sessions were organized, and each participant could rotate to 3 groups to provide input on specific themes. The themes distinguished were: a) soil quality; b) soil threats; c) AMP recommendations; d) user experience. Tables 7-10 below indicate the points raised and how they were addressed.

Soil quality/soil properties

Table 7. Issues raised concerning soil quality/soil properties and how they were addressed.

Issue raised	**How addressed in SQAPP development**
• Where do the data come from? Important to add in the app information about database, number of samples used for make the scoring curve, resolution (area used for the scoring curve). This information should be added in a button called: more information in the app.	The data source and reliability of spatial data is mentioned in info buttons. These data are interpolated across varying scales with variable numbers of samples depending on the original studies. Pedoclimatic zones used are not easily mappable (too many zones, too dispersed zones). A future option is to include statistics on its total area and spatial distribution.
• Some of the results that we get from the app are really wrong (completely out of reality: nutrients and OM for example) → for this we need to be more detailed? but how to be more detailed (difficult because of temporal and spatial variation, especially for biology)?	This aspect can be solved by better datasets. But these were not (timely) available at global/pan-European/China scale. For now a reliability estimate is provided in info buttons. The challenge for dynamic indicators is even larger. Standardized measurement protocols for sampling on which to base or verify spatial data is one aspect, allowing the user to input data on dynamic dependent variables might be another, but as SQAPP is intended for monitoring long-term changes rather then short-term variations this was not considered a priority.
• Maybe use pedotransfer functions or feedback from the users, we need more details!	Linked to the above point, some experimentation was done with pedotransfer functions in WP6. This could be a promising avenue to replace poor indicator maps.
• Maybe gather more data from other European projects!	Data layers were sourced from other projects. Few projects have produced large scale datasets.
• Important to include a message which says that the results are only an approximation.	This is made clear in the disclaimer of SQAPP for the app as a whole, and in info sheets for specific types of users.
• The feedback should be added in some way (but maybe problems with data: fines given	This point addresses the interactive reporting of soil data and how to overcome issues with using

to people or also we should find a way to control the quality of the data)= this is also the point of the interactive part of the app	user contributed data. We will make a start with assessing user-contributed data that are less likely to be inaccurate, e.g. evaluations of AMPs. Using data to improve datasets is a long-term goal towards SQAPP can evolve, potentially catalyzed by social functionality or use of the app for mandatory reporting requirements.
• But how to include new indicators?	New indicators require an app update, can be data-driven or functionality driven (e.g. the inclusion of a pesticide module relying on user data on pesticide use has already been pursued).
• Indicators: Active lime content (Spain very calcareous area); Drainage class	New datasets can be included in a future release.

Soil threats

Table 8. Issues raised concerning soil threats and how they were addressed.

Issue raised	How addressed in SQAPP development
• Reliability of the data = state clearly; sometime very bad results (for example peatlands= they found less OM)	The data source and reliability of spatial data is mentioned in info buttons.
• Conversion factors	Common conversion factors are provided in info buttons.
• Easiness and effectiveness of the indicators? More for extension, not for farmers= training	The classification system of soil threats is simple with three colour codes. The exact determination of the soil threats may be complicated; farmers should focus on those relevant in the local area, supported by extension.
• Farmers not sure how to assess the severity of threats	The tool can function for awareness creation about soil threats. Providing own data may indeed be complex for farmers. Advisors and researchers could take the lead here.
• Add nuances and not total values	The colour coding scheme of threat levels gives an indicative idea about the severity of soil threats. For the functioning of SQAPP these are more important than the actual absolute values.
• Feedback= we need to make sure that they are used	It will be interesting to monitor the feedback for soil properties (for which farmers and land users often have data) vs. those of soil threats. For use see also the same point in Table 7.

AMP recommendations

Table 9. Issues raised concerning AMP recommendations and how they were addressed.

Issue raised	**How addressed in SQAPP development**
• Provide more details in the AMP descriptions or give a link e.g. to WOCAT database	The number of examples of AMPs have been greatly increased (n=391). Within the app links are not desired as it would take users out of the SQAPP. However, links are provided in iSQAPERIs where the AMP database is provided.
• Consider optimal effects of AMP combination on soil properties – referring to the cluster analysis (D6.1)	Combinations of AMPs would be complex as the number of options multiplies exponentially. Defining combined AMPs is a solution that is implemented that facilitates this.
• Provide as much as tangible advice on an AMP e.g., how many tons/ha/year of organic matter/manure/compost are needed to improve approximately how many percentage of soil organic matter (SOM) content.	This is a step too far for now. Effects of better management are assumed but not quantified.

User experience

Table 10. Issues raised concerning user experience and how they were addressed.

Issue raised	**How addressed in SQAPP development**
• Consistency in capitalization of letters in SQAPP	Resolved.
• When changing data got stuck	Bugs have been resolved. App users can report bugs they encounter for resolution
• AMPs: what is the relation between 18 WOCAT / 72 SQAPP	A linkage table has been provided on iSQAPERIS
• Geographically confine examples or inspire users with global examples?	This discussion point was in feedback from end users implemented as broad global examples being communicated without specifying the country it comes from. The iSQAPERIS website has the links for interested app users to explore further.
• Threat-level not country-specific	Indeed, general thresholds for soil threats were considered; these may deviate from country-specific norms.
• Download for Chinese users	Android version can be installed using .apk file instead of Google Play
• Missing data and need to code something	Where there is missing data, a user may indeed have no clue about what value to enter. Consultation with farm advisors may be a strategy here.

• User guide/Youtube video	Instruction video has been prepared
• Are you curious about your soil intro screen: repeat at every start-up	If the user logs out or did not log into the app in the first place this is the case
• Explain why SQAPP is different from other soil apps	Fact sheets, instruction video and background information explain what SQAPP can do
• Make a flyer to attract people to download the app	Materials have been produced and are used to launch SQAPP on World Soil Day 2020
• Add info button for (characteristics – specify land cover) • Add conversion units in info button soil properties and soil threats • Add technical details about soil parameters such as bulk density and coarse fragments in info button • Add axis titles and an explanation for cumulative density functions, perhaps add a screen between values and cumulative density functions to explain the curve • Change "Provide feedback" to "Improve your data"	These practical suggestions have been implemented in info buttons and instruction materials
• At the end of the SQAPP screens, include questions on barriers to implementation	The current set-up of the evaluation screen requires the user to evaluate AMPs as either already implemented, inappropriate, potentially interesting and definitely interesting – the latter two are taken forward for ranking as exploratory options. It is assumed that the user is made aware about these options but not necessarily already has a clear idea about them and possible barriers to implementation. This aspect could be explored in the future.

External review session at Soil Horizons workshop at the Wageningen Soil Conference August 2019

The iSQAPER and LANDMARK projects joined together to hold a side event on soil quality and soil functions at the Wageningen Soil Conference in August 2019. The workshop, attended by ca. 100 participants, included a demonstration of SQAPP and the collection of feedback from workshop participants. Figure 11 gives a first impression of the perception of SQAPP. It is viewed as simple, quick, easy and global.

Figure 11. One word evaluation of SQAPP by workshop participants.

In focus group demonstrations and discussions of SQAPP a number of issues were raised by the participants. These have been listed in Table 11 together with a comment on how these were or could be addressed in (future) SQAPP development.

Table 11. Issues raised by external experts and how they were addressed.

Issue raised	**How addressed in SQAPP development**
• Recommendations are only accessible if you are registered / logged in. This doesn't have to be necessary, right?	Recommendations are given based on field characteristics for which user input is required. This requires to save user input for a location first, which is why registering is required to view recommendations. Registering is a quick process, as only an email and password are required and no further personal data are solicited.
• Is it possible to display the uncertainties in the data in the app? Via a pop-up with a disclaimer, for example	Yes this has been implemented
• Can a farmer indicate which objectives he / she considers important? For example, a farmer who has an above-average interest in climate, if he can indicate this with a kind of slider at the beginning, and then also receive other recommendations, more focused on climate than on production, for example	The implicit objective in SQAPP is that the ensemble of poorly scoring relative soil quality parameters and high risk soil threats are addressed. Soil quality is hypothesized to support multiple ecosystem services which could be considered objectives. But the SQAPP cannot indicate if and how much individual ecosystem services are improved. What the farmer can do

	is specify the domain of management recommendations (s)he is interested in to get those recommendations highlighted. Alternatively, farmers can be pointed to the iSQAPERIS website where the full overview of AMPs and examples can be consulted per domain.
• Can we register whether the recommendations are actually being followed up on? By means of an extra button "I am going to implement this". It is interesting to see how much effect the app actually has, and encourages action	In the final screen, the app user is asked to answer the question "Do you think you will implement one of the recommendations?" While less definite action-oriented, this formulation is truer to what can be measured, namely the intention of the user, rather than actual implementation.
• Can you see where in the world how many people use the app?	Yes, there are two ways to do this. First, data on saved locations can be analysed to this effect. However, anyone can save a location anywhere in the world, so this information may not tell much about the geographical spread of users. The second source of data are the statistics from the app stores on app downloads in different countries. This statistic gives good data on the spatial distribution of app downloads, but not on its actual use.
• Idea for a follow-up project: link SQAPP and Soil Navigator	SQAPP offers the potential to link to other apps. Within the current project this was not an objective, but further development of functionality is on the radar of the development theme.
• As the privacy conditions are now, the data entered by the user himself may not be used to improve the databases. If we ultimately want that, then the conditions must be changed, and the users until now be asked if they are still okay with their data being used	The privacy conditions state that data may be used: - To improve SQAPP and the information it provides to you - For scientific research purposes Individual (point) data will not be disclosed for privacy reasons. In the future, one may conceive that user-contributed point data could be explicitly intended for building up trusted, open access sample data, but this is currently not the case. In this case, users would be asked to explicitly state their point-data can be made public so that it does not affect data already contributed.
• For regions where more specific data is available (eg NL) also use this	As the relative soil quality is determined based on data for pedo-climatic zones which often occur in multiple regions/countries, ideally the same data source is used. Juxtaposing more specific data for defined areas would still mean that all probability density curves for affected pedo-climatic zones has to be recalculated. These factors make that adding local datasets is

•

	not as easy as it seems. An alternative is to calculate the pedo-climatic zones with the more specific dataset only. This would then give higher quality results in the area considered, but the data to construct the probability density curves would also be available for the region only.
• Add a notification (pop-up) to the soil properties: “If you have better data yourself, you can enter it here”. Now you really have to look for this possibility.	The button text “Provide feedback” has been renamed to “Enter own data” to clarify this issue.
• It would be useful for policy makers if SQAPP could be used on a regional scale, instead of point / plot	As indicated in Section 2.5, a regional scale implementation has been set up. As SQAPP relies partially on user input, there are some scenario options (land cover and crop data) that need to be defined for a ‘real’ regional application. A regional application was not envisaged as part of the project concept, but has emerged as a potential powerful future development.
• Add euros	Data on costs of AMPs and examples of AMPs is scarce and tend to vary significantly. Some require a piece of equipment (used on an unknown number of hectares), others may require costs for investment and maintenance over several years. Another aspect could be availability of subsidies for implementation, which tend to change over time and are region-specific. That is why we have for now chosen a simple ‘complexity’ indicator giving a qualitative scoring of cost, labour and know-how needed.
• Provide more information about how the graphs are constructed. For example: what about if all the soils in your pedoclimatic zone are super bad, except yours? Then this one will come out very well, while it might not be that good at all. And is it possible to show the graphs only the data of your pedoclimatic zone from your country? "Farmers don't find it interesting to compare themselves with people from other countries," it was noted.	The procedure to construct probability density functions is explained in FAQs and instruction video. Indeed, theoretically all soils in a pedo-climatic zones could be bad/degraded. As management information is not (yet) taken into account in the construction of maps, this may particularly apply to the ranges in natural areas being reduced and not represented as land cover is a co-variate in most soil data mapping procedures. Still, the relative score does indicate this would then be the best farmer in the pedo-climatic zone. Regionalizing of the pedoclimatic zones to countries would introduce other biases and limit the comparability in smaller countries while still not offering a more regional perspective in very large ones. A country-specific approach to pedo-climatic zones would be more useful if based on a dedicated higher accuracy soil data system for that country.
• The practical details of the recommendations are also important, if a farmer really wants to apply them. Can we	Links within the app would be confusing as it requires the user to navigate away from the app. The iSQAPERIS section on AMPs in SQAPP is

possibly here. refer (link) to the info in WOCAT?	referred to as a first-stop portal for further advice and links.
• Idea: Integrate feature that brings together users with the same threats / recommendations in the same region. So that a kind of study clubs can arise around a specific theme	Innovations for social collaboration are indeed an important future development potential for SQAPP.
• Expectations management: clearly indicate that this tool is a support, and not the hard truth.	Under the About section we have added the following text: " Scale is an important consideration when using this app. The analysis provided is based on global and regional data and should not be interpreted as exact data for a specific point on the map, such as your garden or farm field. Within the app, you may upload local data to refine the soil quality analysis and resulting recommendations. European and Chinese geography contains the richest data layers within SQAPP."
• Idea: add intro text (eg after choosing the location, before viewing soil properties). Indicate here what the app does and does not do. Similar to previous comments on disclaimer / expectations management	Support text is provided in information buttons and the more information section in SQAPP in order not to break the functional flow of the app.
• Introduce SQAPP in study clubs (such as Kringloopwijzer in K&K) to make it land with farmers	Information sheets on the use of SQAPP by various audiences have been produced. Following the launch event we will monitor and target groups
• Do not throw the app over the fence when the project is over, keep maintaining! And implement it in education; learned young is done old.	Fully agreed! SQAPP has already been integrated in the student education of participating organisations.

3. Building SQAPP

3.1. Premises

The SQAPP was designed with the idea that it should provide the user with the opportunity to access fragmented data on soil quality and soil threats in an easy-to-use way. Moreover, the user should not only receive indicator values, but be guided in interpreting these values by providing more contextual information: is a certain indicator value high or low in a given context? Such contextual information is provided through analysing indicators within combinations of climate zones and soil types, and by distinguishing between arable land and grazing land. Finally, the user should receive, based on an assessment of the most critical issues, management recommendations on how soil quality can be improved and soil threats be overcome.

A second consideration in designing SQAPP was the idea to use soil quality and soil threat indicators for which spatial data exist. This way, it is possible to provide the user with data for any indicator for which data exist for a given location, in combination with the comparative contextual information. The comparative aspect of the soil indicator data is then realized by calculating cumulative probability density functions for each pedo-climatic zone. All indicator values are given as 'best guestimate' for the location. The user can proceed with generating management recommendations based on these standard values, or replace some or all indicator values with own data to get more accurate recommendations. This design helps to make the SQAPP directly helpful by visualizing available soil information in a systematic and easy-to-access way.

Thirdly, the SQAPP recommends agricultural management practices to improve soil quality and/or mitigate soil threats based on an integrated assessment of the aspects most urgently needing attention. This integrated way of considering soil quality indicators is new in comparison to existing soil apps and indicator systems. This integration avoids consideration of poor single indicator scores in isolation, which could have trade-offs with other soil quality indicators that are also suboptimal.

Fourthly, although the iSQAPER project focuses on Europe and China, it quickly became clear that the amount of work required to develop SQAPP would be more appropriately justified by building an app with global coverage. This inclination to go global was reinforced by some hurdles experienced along the way to harmonise European and Chinese data (see below). As a consequence, the app was designed with global functionality in mind.

The overall procedure to develop SQAPP is given in Figure 12. These steps include:

1. Selecting soil quality indicators; based on the review of soil quality indicators in WP3, a selection of the most commonly used was made. For these indicators, we examined availability in terms of global datasets. All relevant indicators for which maps existed were retained as input data layers. Similarly, maps of soil threats were reviewed. Here, available global datasets were used; in Europe some further soil threats were included based on soil threat maps with European coverage.
2. Defining pedo-climatic zones; as one of the principles underpinning SQAPP is a relative assessment of soil indicators, appropriate zones with similar conditions need to be

defined. Within WP2, pedo-climatic zones were developed for both Europe and China (Deliverable 2.1). As the basic climate zones distinguished in these classifications were not comparable and because there were some conversion issues to reclassify Chinese soil types to WRB (World Reference Base) soil types, the resulting pedo-climatic zones in Europe and China were not directly comparable, and moreover, did not cover other areas of the world. This became an issue for calculating relative soil indicator scores at global level. To resolve this issue, a new pedo-climatic zonation was produced within WP4 for the purpose of calculating consistent data layers for the app.

3. Ranging soil quality indicators; once indicators are selected and pedo-climatic zones are defined, it is possible to calculate cumulative probability density functions for each indicator in each pedo-climatic zone. These cumulative probability density functions become the basis for the relative assessment of soil quality. Moreover, within each pedo-climatic zone, attention also needs to be paid to the land use/cover, as land use is known to greatly influence the indicator scores of several soil indicators. To account for this issue, separate calculations are made for the minimum and maximum scores of each indicator in each pedo-climatic zone, specific for arable and grazing land respectively.
4. Scoring indicators; the relative scores of soil property values are considered based on their position on the cumulative probability density curves. That means (considering whether indicators are of the 'more is better' or 'more is worse' type), that the bottom 33% of the frequency distribution are considered as low, and the top 33% as high, with medium the outcome for intermediate values. For soil threats, absolute, expert-based values were considered based on the work conducted in WP6 (Milestone 6.2).
5. Assessing indicators; this step concerns the calculation of the potential for soil improvement (percent score) across all soil property indicators, and the calculation of the average soil threat level (on a bar slider between low and high). All poor performing soil property indicators and soil threats are considered as urgent aspects to be addressed.
6. Recommended practices; the final step in the SQAPP is to recommend agricultural management practices based on the overall soil quality score and most urgent soil quality aspects to be addressed. Underlying the recommendations is the development of a large matrix table of the agricultural management practices and a) applicability factors – defining where each of the AMPs is applicable; and b) effectiveness – where the impact on soil property and soil threat indicators of each AMP are scored. The 10 AMPs reaching the highest overall score for the combination of soil properties and soil threats to be addressed in a given location are presented to the app user.

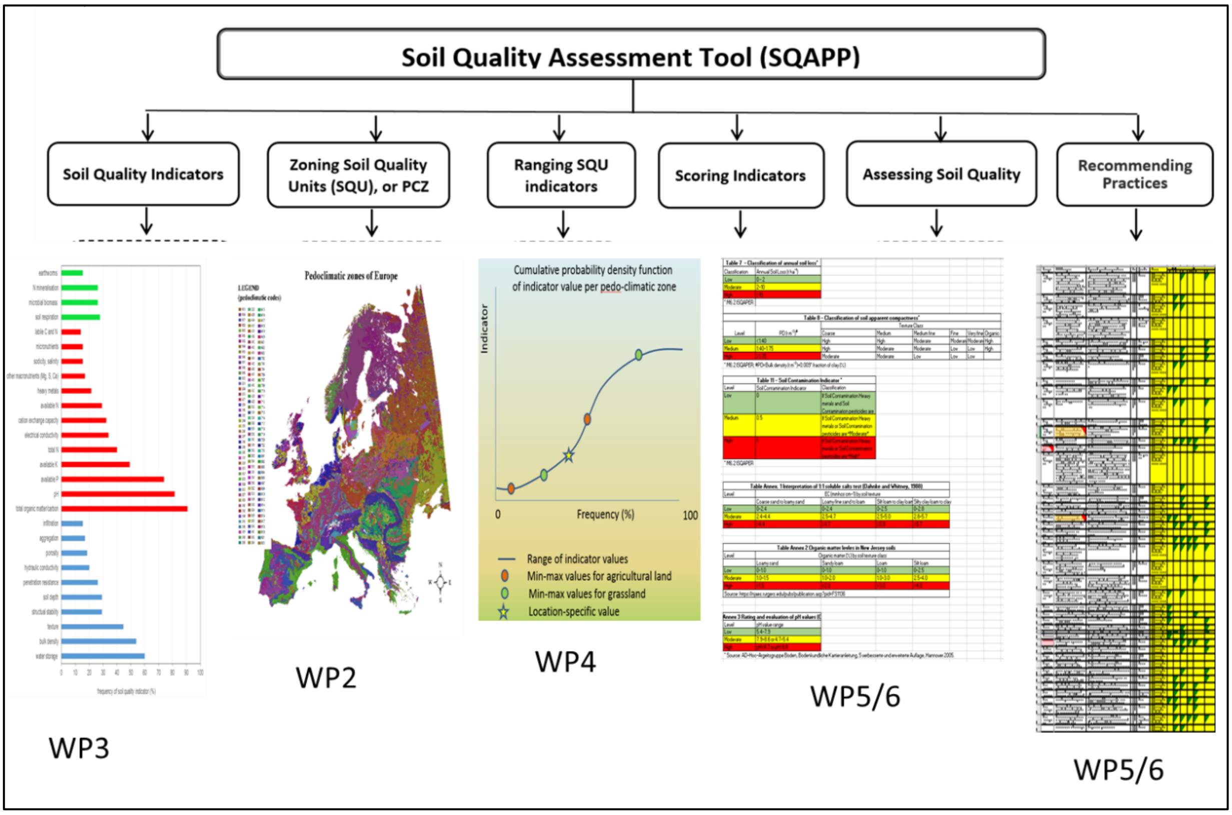


Figure 12. Overview of the procedures followed to develop SQAPP, including links to different work packages.

3.2. Soil indicators

The soil property and soil threat indicators considered for the app are based on respective reviews of indicators in WP3 and WP6. Bünemann et al. (2018) reviewed the most common soil properties in minimum datasets, showing a dominance of physical and particular chemical soil properties, and a underrepresentation of biological soil properties. This dominance remained when considering available spatial datasets (Figure 13). Two datasets that were not included as frequently used indicators in the overview of Bünemann et al (2018) were added: coarse fragments (physical property) and number of macrofauna groups (biological property).

Milestone report 6.2 provided the list of soil threats for availability of spatial datasets (in Europe as a minimum) was already taken as a starting point. Later on, some of the datasets were replaced with newer/better datasets (e.g. Copper in European topsoils), but the indicators remained the same. An exception to this is the soil threat of pesticide contamination. No maps of pesticide pollution are available, but a procedure was designed by which users can, based on their use of fungicides, herbicides and insecticides, get an estimate for the pesticide environmental concentration (PEC) of their soils at the moment of application and after 100 days.

Although PECs are publicly available, up to now they were never compiled into a database and explored as such. This is specially surprising since the presence of mixtures of pesticide residues in soils is the rule rather than the exception. The steps followed to set up the pesticide module included i) to identify the active substances allowed in different crop-EU region units; and (ii) to compile representative uses and PECs of currently approved active substances into a single database. Of the active substances allowed on the EU market under the EC Regulation 1107/2009 concerning the placing of Plant Protection Products on the EU market (EC, 2009; EC, 2019), there were 230 synthetic pesticides applied as fungicide/herbicide/insecticide for which soil degradation data was available. The physical-chemical properties of these 230 active substances, environmental fate data, and (eco-)toxicological data were extracted from the Pesticide Properties DataBase - PPDB (*PPDB, 2019*).

Representative uses refer to authorised good agricultural practices, covering the crops and EU regions to which the active substance is allowed to be applied, as well as recommended timing for pesticide applications, frequency of applications, interval between applications, and application rate per treatment. The representative use of active substances can be found in the individual active substance EU dossiers, publicly available via EFSA (EFSA, 2020). Recommended application rates aim at effective pest control while keeping risk to humans, animals, plants and environment at acceptable levels. Active substance representative uses are used to obtain active substances' predicted environmental concentrations in soil (PECs), which are used as exposure proxies in environmental risk assessments, including by the EC (Ockleford et al., 2017). Da Silva et al. (in preparation) explains the procedure in full.

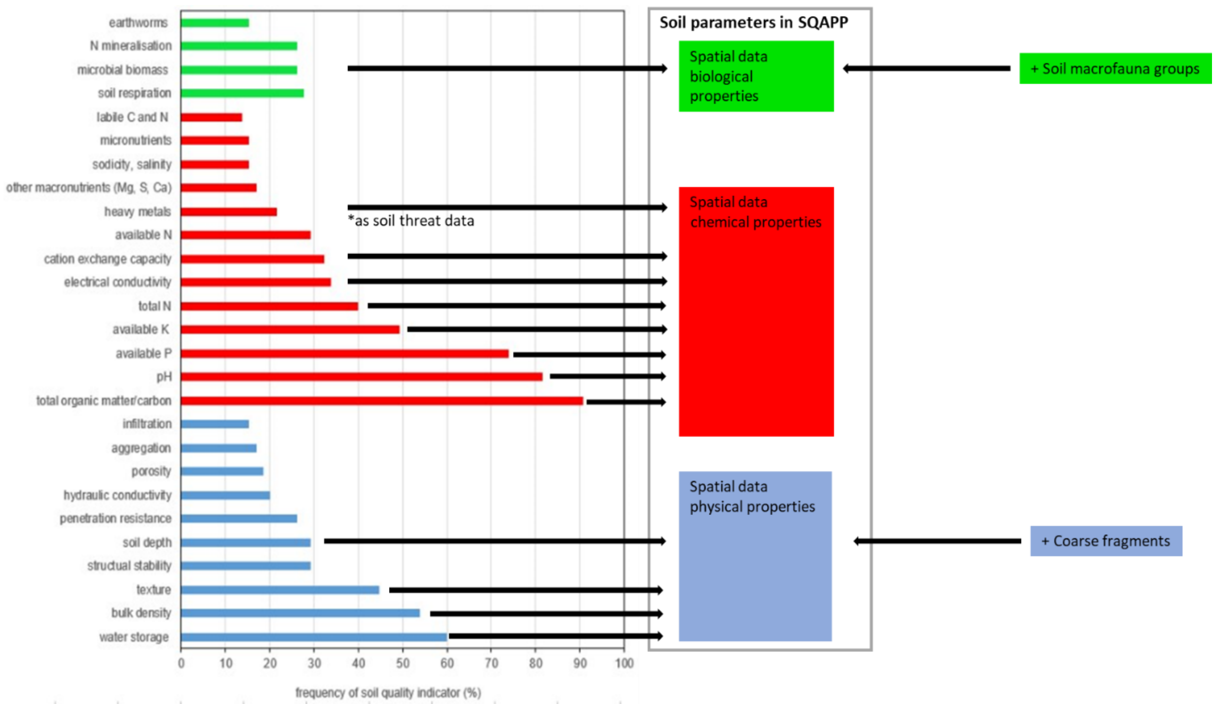


Figure 13. Most frequently used soil quality indicators (Bünemann et al., 2018) and selected indicators in SQAPP for which spatial datasets needed to be available.

3.3. Defining pedo-climatic zones

The pedoclimatic zones were defined based on the overlay of climate zones (Figure 14, Peel et al., 2007) and WRB (Rev. 2015) world soil map (Figure 15). This leads to 29 x 118 = 3422 potential combinations, of which 2098 indeed have overlap and were defined as pedo-climatic zones.

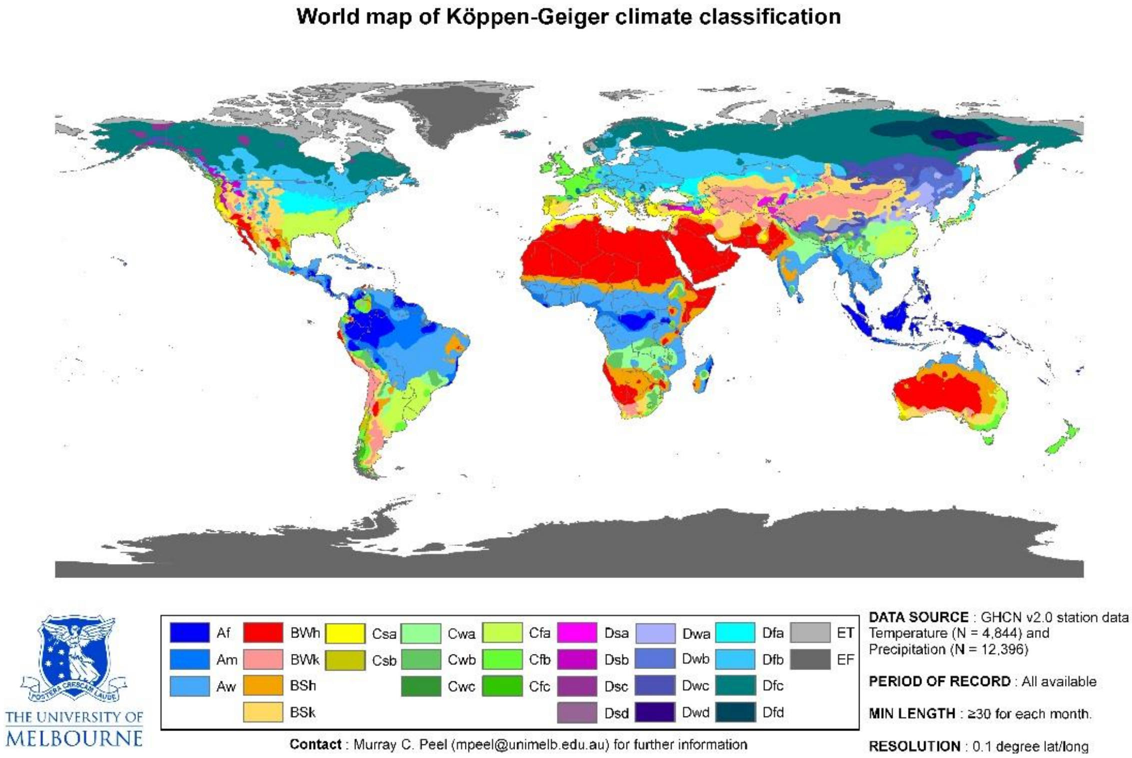


Figure 14. Global map of Köppen-Geiger climate zones (n=29) (source: Peel et al., 2007).

Figure 15. Global map of WRB (rev. 2015) soil types (n=118).

3.4. Ranging soil quality indicators

Ranges for soil quality indicators were constructed for each indicator and pedo-climatic zone. Figure 16 gives some examples of cumulative probability density functions as displayed in SQAPP. The minimum and maximum values are calculated separately for each pedo-climatic zone and land use/land cover class (arable land and grazing land). The visualization of probability density functions is done in plots where on the x-axis is the score of the soil parameter, and on the y-axis the cumulative frequency (0-100%). Minimum and maximum scores, which in the pilot app were always indicated by red (undesired value) and green (desired value) markers, were later replaced by grey markers if either minimum or maximum values (or both) could not be interpreted as desired value (e.g. maximum soil organic carbon (SOC) value was indicated with a grey instead of green marker, as very high SOC content cannot be taken as indicator of superior soil quality.

The calculations required for the construction of cumulative probability density functions were very computationally intensive. The data to construct each curve are sent from the ISRIC REST to the app using 255 values along the curve.

For PECs a different approach was taken. Based on ordering the PECs associated with active substances from high to low and from low to high, the worst-case and best-case scenario for a given number of pesticides applied can be given (Figure 17, indicated by the red and green dotted lines, respectively). When the user knows the number of fungicides, herbicides and insecticides applied, summing the orderings of each type gives a narrower range of possible PEC values, indicated by the yellow markers in Figure 17. If the user would know the exact active substances applied, the range can be further reduced and a specific value is given (in SQAPP indicated by a cyan marker).

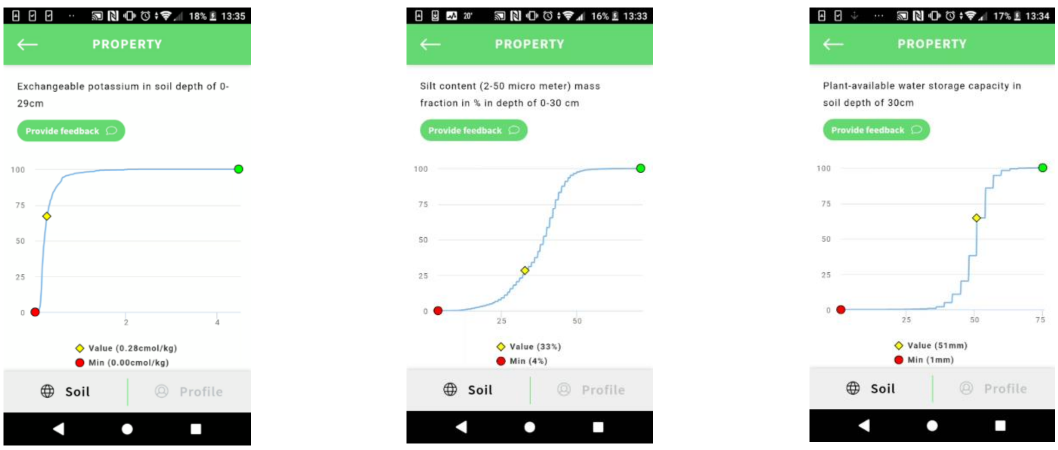


Figure 16. Examples of cumulative probability density functions in SQAPP with indication of the value on the actual location (yellow marker), minimum (red marker) and maximum values (green marker).

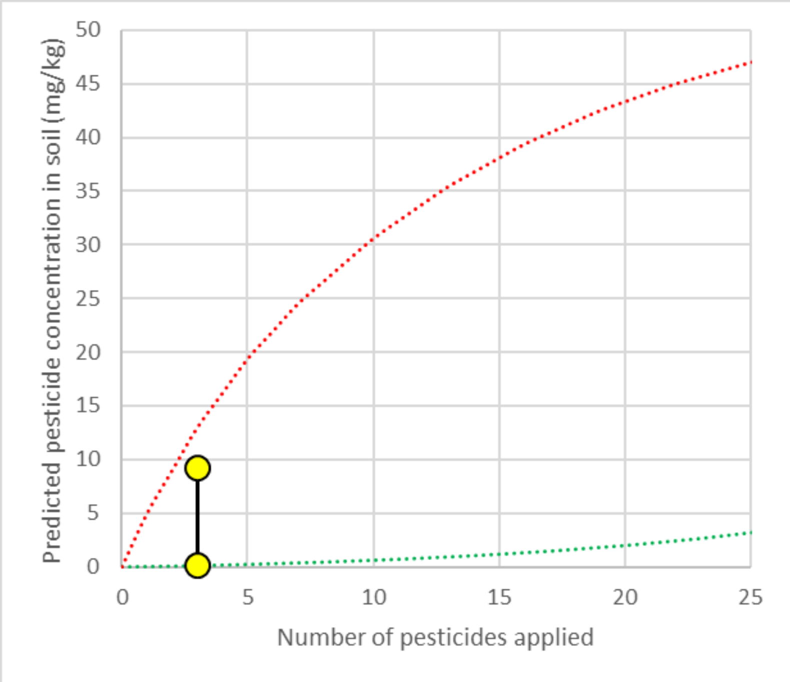


Figure 17. Principle of the construction of PEC ranges – for a given number of pesticides the predicted PEC will range between the maximum and minimum values indicated by the red and green dotted lines, and can be narrowed down by partial identification of active ingredients to the range between the yellow markers.

3.5. Scoring soil quality indicators

Empirical cumulative probability density curves were produced for each soil quality indicator in every pedo-climatic zone. The density curves were based on empirical probability density histograms with 256 bands between the lowest and highest value of each soil quality indicator in every pedo-climatic zone. The cumulative probability (%) corresponding to the actual soil quality indicator value in a given location, was then considered to be the relative performance of that soil quality indicator at that location. The potential improvement of that soil quality indicator at that location was then considered to be the absolute cumulative probability corresponding to the best attainable value minus the relative performance of that indicator (e.g. 7%, Figure 18) of the soil quality indicator (Table 12).

The overall soil quality improvement potential was then considered to be the average improvement potential of all soil quality indicators. The number of soil quality indicators considered was dependant on data availability. Some soil quality indicators, for instance, were only available for countries within the European Union.

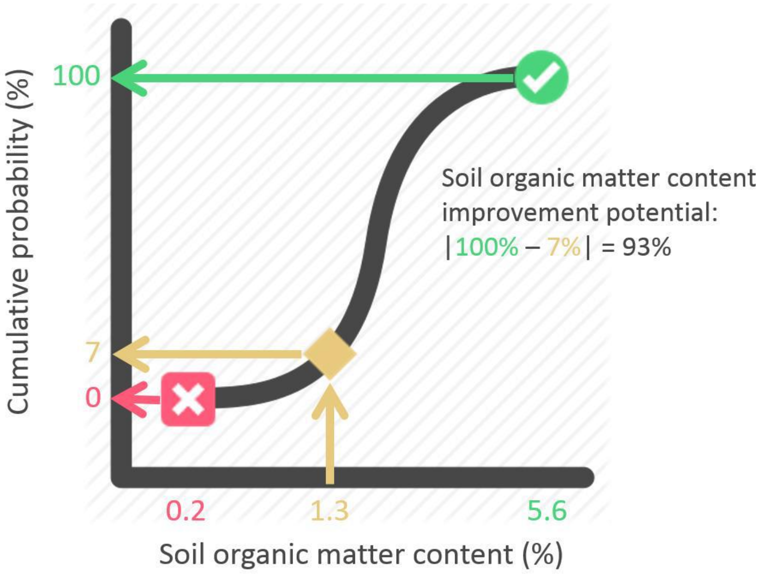


Figure 18. An illustrative example of how the relative improvement potential of a soil quality indicator is calculated. In this example 0.2 is the lowest observed soil organic carbon (SOC) content, and 5.6 is the highest observed SOC content for a specific pedo-climatic zone. 1.3 is the SOC value in our location of interest. Via the cumulative probability curve, we can relate this value to a relative performance of 7%. This means that within this specific pedo-climatic zone, only 7% have a SOC content of 1.3 or lower. The SOC content improvement potential is the absolute cumulative probability linked to the best attainable value (100% linked to 5.6%) minus the relative performance of 7%.

Table 12. Soil quality indicators and optimums used to define relative improvement potential. References: (a) Panagos et al. (2015), (b) Borrelli et al. (2017), (c) Shangguan et al. (2014), (d) Hengl et al. (2017), (e) Lado et al. (2008), (f) Nicholsen & Chambers (2008), (g) Orgiazzi et al. (2016).

Soil quality indicator (reference)	**Unit**	**Best attainable value (optimum)**
Bulk density (d)	kg m^{-3}	Minimum
Cation exchange capacity (d)	cmol kg^{-1}	Maximum
Electrical conductivity (c)	dS kg^{-1}	Minimum
Exchangeable potassium (c)	cmol kg^{-1}	Maximum
Soil microbial abundance (g)		Maximum
Soil organic carbon content (d)	%	Maximum
pH (d)		7
Olsen-extracted phosphorus* (c)	mg kg^{-1}	Maximum
Plant available water storage capacity	mm	Maximum
Total soil nitrogen (c)	g kg^{-1}	Maximum

SOIL THREAT and indicator		THRESHOLDS			
Soil erosion by water					
Soil loss (t/ha/year)		0-2	2-10	>10	
Vulnerability (class)		low	medium	high	
Soil erosion by wind					
Soil loss (t/ha/year)		0-0.5	0.5-3	>3	
Vulnerability (class)		low	medium	high	
Soil compaction					
Natural susceptibility		low	medium	high	
Soil salinisation					
Electrical conductivity (dS/m)		0-2	2-4	>4	
Soil organic matter decline					
Soil organic carbon content (%)		0-1	1-2	>2	
Soil nutrient depletion					
Exchangeable K (cmol/kg)		0-0.2	0.2-0.3	>0.3	
Available P (Olsen method) (mg/kg)		0-20	20-40	>40	
Total N (g/kg)		0-1	1-2	>2	
Soil acidification					
Soil pH	<5.5	5.5-6.5	6.5-7.5	7.5-8	>8
Soil contamination					
Arsenic (mg/kg)		0-37.5	37.5-50	>50	
Cadmium (mg/kg)		0-2.25	2.25-3	>3	
Chromium (mg/kg)		0-300	300-400	>400	
Copper (mg/kg)	pH <5.5	0-60	60-80	>80	
	pH 5.5-6.0	0-75	75-100	>100	
	pH 6.0-7.0	0-101.3	101.3-135	>135	
	ph >7.0	0-135	135-200	>200	
Lead (mg/kg)		0-225	225-300	>300	
Mercury (mg/kg)		0-0.75	0.75-1	>1	
Nickel (mg/kg)	pH <5.5	0-37.5	37.5-50	>50	
	pH 5.5-6.0	0-45	45-60	>60	
	pH 6.0-7.0	0-56.25	56.25-75	>75	
	ph >7.0	0-82.5	82.5-110	>110	
Zinc (mg/kg)		0-150	150-200	>200	
Soil biodiversity					
Soil biodiversity index		low	medium	high	

Figure 19. Soil threat thresholds and classification as implemented in SQAPP.

Figure 19 provides an overview of the threshold values for soil threat indicators based on Milestone 6.2. For the soil threat of risk of pesticide contamination, two scores were considered (Figure 20):

i) of the total number of each type of pesticide ranked from low to high, the PEC score of the 0.25 percentile pesticide was considered the upper boundary for a low risk (green). The 0.75 percentile pesticide constitutes the lower boundary for high risk (red). Intermediate PEC scores are classified as moderate (orange).

ii) The number of pesticides applied was also considered as a factor influencing pesticide contamination risk, as cocktails of pesticides may present additional threats to the environment. Five pesticides was considered the upper threshold for a low threat (green) and ten pesticides the maximum for a moderate threat (orange). If more than ten pesticides are applied the PEC indicator is classified as high (red).

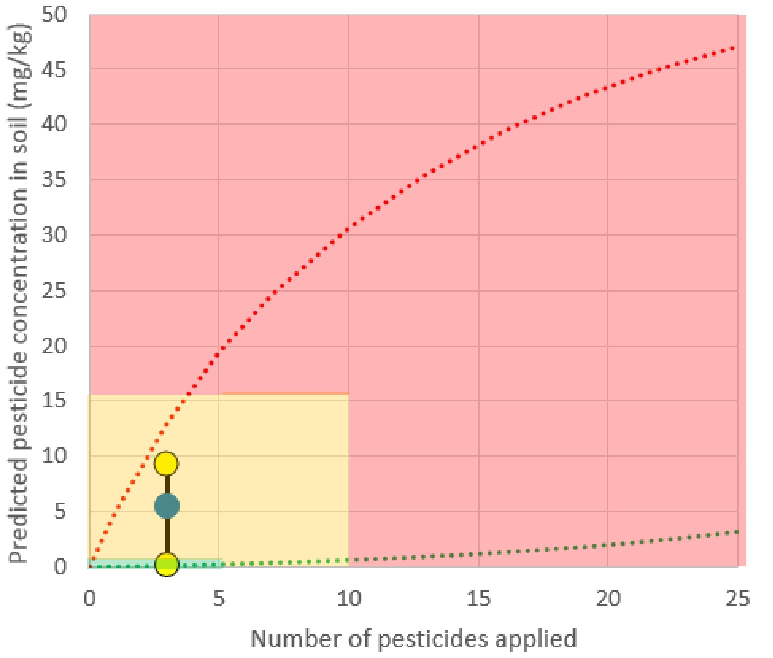


Figure 20. Soil threat scoring of PEC as indicator for pesticide contamination risk. The classification is based on two criteria: 1) the PEC score of the 0.25 and 0.75 percentile ranked pesticide; 2) the number of pesticides applied. Resulting areas in the graph are classified as low risk (green), medium risk (orange) and high risk (red).

3.6. Assessing indicators

The indicators are assessed by i) calculating an overall potential for soil property improvement; ii) calculating an overall soil threat level; and iii) listing the top-3 soil properties and soil threats needing attention (Figure 21).

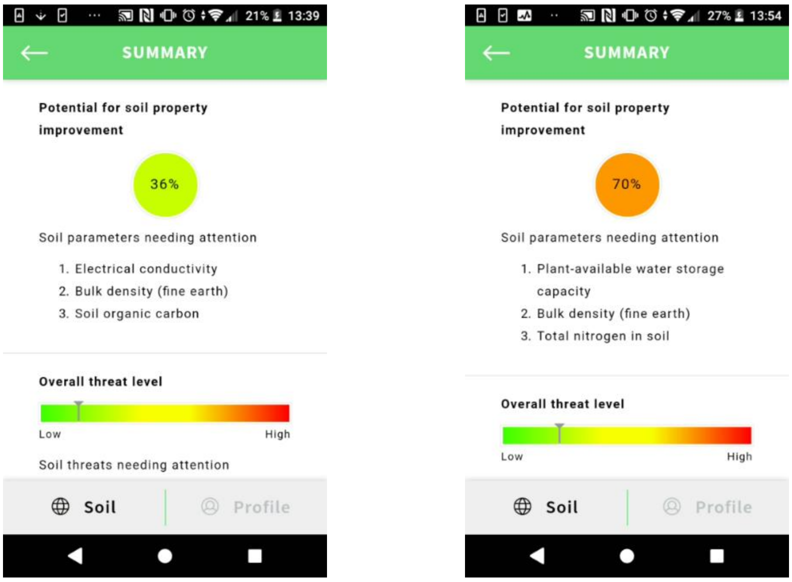


Figure 21. Overall summary of soil property and soil threat indicator scores in SQAPP.

The potential for soil improvement is expressed as a percentage. For any given land use, the average soil would score 50%. Scores of less than 50% mean the soil is better than average; scores greater than 50% indicate that the soil is poorer than average. Extreme values (close to 0 or 100%) are rare due to the skewed distributions and not all soil quality indicators scoring good or bad across the board.

The soil parameters needing attention are those with a potential for improvement score of higher than 67% (i.e. at least a third of soils in the same pedo-climatic zone and under the same land use score better for these parameters).

For any given land use, only soil parameters that can be improved by management are taken into account. The actual values of each these parameters is assessed by comparing the location-specific value with the optimum value found in all locations with similar climate and soil type for a certain land use (arable or grassland). The optimal value is either the minimum or maximum value depending on the soil parameter, or an optimum value in the case of pH. The percentile rank of the location assessed within the range of values determines the improvement score, which can theoretically range between 0 and 100%. The average of the improvement scores for individual soil parameters is calculated for the overall potential for soil improvement score.

The overall threat level is the arithmetic mean of individual soil threat scores for which data is available (low=1, medium=2, high=3). For "soil nutrient depletion" and "contamination by heavy metals" only the worst individual score of nutrients or metals is taken into account.

Soil threats needing attention are all those individual threats with a high score.

3.7. Recommended practices

Finally, agricultural management practices are recommended in response to the underperforming soil properties and most important soil threats. To define the recommended practices two steps were taken: 1) establishing a classification of agricultural management practices; 2) establishing an expert-opinion based matrix table of the applicability and effectiveness of AMPs. The final recommendation is made based on simple additive scoring. Table 13 shows the broad groups (9) of AMPs and AMP categories (34) considered. Under the latter, a total of 89 AMPs has been distinguished (for example, the category cross-slope barriers represents two AMPs, bunds and terraces). A total of 391 example AMPs have been selected to illustrate the different AMPs. The descriptions of AMPs and examples are provided in Annex 1. An illustrated overview of the AMPs and examples is also given on the iSQAPERIS website[3], where app users and other interested parties can browse through them and link to website providing further information.

The applicability limitations and effects of these AMPs on soil properties and soil threats are established in a matrix. The selection of AMPs on the basis of this matrix to generate recommendations is exemplified in Figure 22. Up to 10 individual AMPs are suggested in a given location where the app user is requesting solutions. Applicability limitations are assessed on the basis of (specific) land use, landform, annual precipitation, slope, soil depth, soil texture and coarse fragments. All AMPs are either scored 0 (not applicable) or 1 (applicable). Effectiveness is considered using a four-class system: definite positive effect (2); probable positive effect (1), unknown or no effect (0) or negative effect (-1).

Identified problems:	Lists of options (~80 AMPs)		
	AMP1	AMP2	AMPx
Physical properties			
Plant-available water storage capacity (mm)	0	0	1
Soil organic carbon content (%)	1	-1	1
Soil threats			
Soil erosion by water *- Soil loss (t/ha/year)*	0	1	1
Soil compaction *- Natural susceptibility (low, medium, high)*	1	-1	0
	Total: 2	Total: -1	Total: 3
Rank:	**2**	**3**	**1**

Figure 22. Example of the ranking of different AMPs for a given set of identified problems.

[3] https://www.isqaper-is.eu/sqapp-the-soil-quality-app/amps-in-sqapp

Table 13. Overview of AMPs included in SQAPP, classified in AMP broad classes and AMP categories distinguished as possible recommendation domains.

AMP broad class	AMP category		AMP
Terrain management	Cross-slope barriers	1	Bunds
		2	Trenches and infiltration ditches
		3	Terraces
		4	Trashlines
	Runoff control	5	Half-moon terraces
		6	Gully rehabilitation
Soil management	Tillage	7	No tillage
		8	Minimum tillage
		9	Contour ploughing
		10	Strip tillage
		11	Subsoiling
		12	Roughening the soil surface
		13	Raised beds
	Traffic management	14	Avoidance of traffic
		15	Controlled traffic
		16	Respect wheel load carrying capacity
	Soil replacement	17	Claying soils
		18	Adding sand
	Soil amendments	19	Soil conditioners
		20	Liming
		21	Alkalinity management
		22	Straw interlayer burial
	Conservation agriculture	23	Conservation agriculture
Vegetation management	Vegetation cover	24	Permanent green cover in orchards
		25	Cover crops
		26	Grassland renewal
		27	Rangeland rehabilitation
	Fallow management	28	Planted fallow
	Vegetation bands	29	Vegetative strips
		30	Riparian buffer zones and filter strips
		31	Shelterbelts
		32	Semi-natural landscape elements
		33	Strip cropping
	Crop choice	34	Deep rooted crops
		35	Intercropping
		36	Growing halophytes
	Crop rotation/diversification	37	Crop rotation/diversification
		38	Herb-rich grassland
	Multi-layered vegetation	39	Agroforestry
		40	Silvopasture
Water management	Diversion	41	Diverting water flow
	Drainage	42	Intercepting drains
		43	Subsurface drains
		44	Surface drains

AMP broad class	AMP category		AMP
Water management (continued)	Water harvesting	45	Planting pits
		46	Ridge-furrow systems
		47	Ridge-furrow systems for perennial crops
		48	Micro-basins
	Water conservation	49	Inorganic mulching
	Water distribution	50	Water distribution in rangelands
	Irrigation	51	Drip irrigation
		52	Surface irrigation
		53	Pivot irrigation
		54	Sprinkler irrigation
	Irrigation management	55	Leaching salts
		56	Minimizing saline water irrigation
		57	Reduced water use in rice cultivation
	Irrigation scheduling	58	Irrigation optimization
		59	Supplemental irrigation
	Runoff conveyance	60	Artificial grassed or paved waterways
Carbon and nutrient management	Organic amendments	61	Liquid manure or slurry
		62	Animal manure
		63	Compost
		64	Biochar
		65	Biofertilizers
	Inorganic amendments	66	Inorganic fertilizers
	Green manuring	67	Green manure
		68	Leguminous crops
	Crop residue management	69	Retaining crop residues
		70	In situ composting
	Mulching	71	Mulching with pruning materials
		72	Straw mulching
Pest management	Weed management	73	Mechanical weed control
		74	Chemical weed control
		75	Biological weed control
	Pest management	76	Biological pest control
		77	Physical pest control
		78	Chemical pest control
	Disease management	79	Physical disease control
		80	Chemical disease control
		81	Biological disease control
Pollutant management	Remediation	82	Phytoremediation
	Balanced applications	83	Integrated pest and disease management
		84	Integrated nutrient management
		85	Automated targetting
Grazing management	Grazing management	86	Controlled and rotational grazing
		87	Area closure
		88	Pasture monitoring
	Trampling management	89	Avoiding pugging of paddocks

3.8. Practical considerations

The pilot app was developed for mobile phones/notepads operating under either Apple iOS or Android. These two platforms together cover >97% of smartphones. For geolocation, Bing maps was used as Google products are banned from use in China.

4. SQAPP architecture

4.1. Profile

Upon installing SQAPP, the user can choose to register or use the SQAPP for observing soil data. To register, an email address and password are required. The user can change the language from the opening screen or the profile screen (Figure 23). Currently the app is available in 14 languages: English, Dutch, Chinese, Estonian, French, German, Greek, Hungarian, Italian, Polish, Portuguese, Romanian, Slovenian and Spanish. Registered users can save locations and get recommendations. If a user does not register, (s)he can still explore soil properties and soil threat data, but will not be able to receive recommendations. The user can search or move to a location of interest to explore soil data. If the user allows the app to access the GPS location, the default location will be the current position of the user's mobile device. From the profile screen, users can access previously saved locations, their profile data (name and password), and language settings.

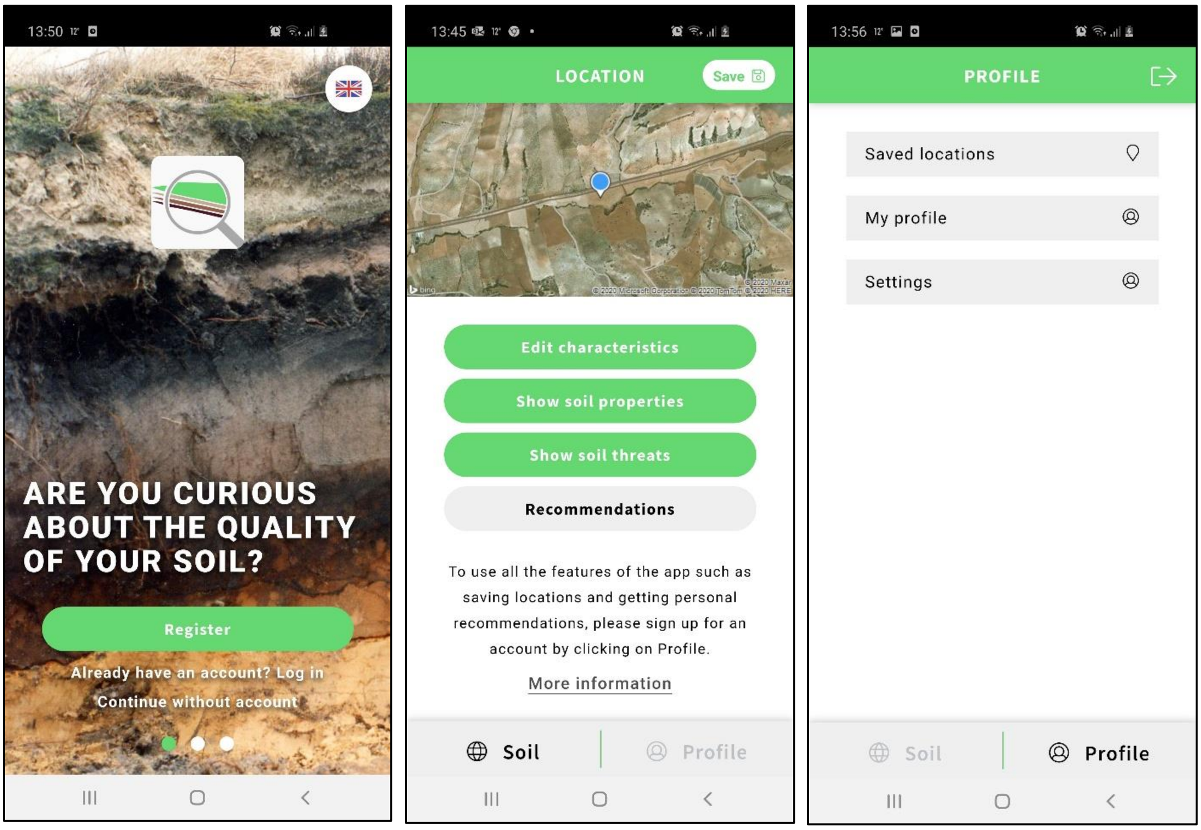


Figure 24. SQAPP intro screen where the user can register (left), main screen if user chooses not to register (middle) and profile screen where the user can also select 'My profile' to register (right).

4.2. Field characteristics

Once a location is selected, the user can edit field characteristics. Going through the field characteristics is required in order to receive recommendations. Respective screens in the field characteristics module are shown in Figure 25. On the first characteristics screen the user can:

- Give the location a memorable name (the default is an automated sequential location numbering)
- Edit the altitude, precipitation, mean annual temperature and slope information available from global data. Precipitation and slope information may affect recommendations, mean annual temperature affects the rate of pesticide degradation.
- Select the right landscape position and land cover. These are prefilled from global data, but the user can correct or further specify these. Both characteristics will affect the agricultural management practices recommended. Recommendations are only given for arable and grassland: for 'other' land use soil property and soil threat data can still be consulted and edited, but no recommendations are given. Land cover, and its further specification in the second field characteristics screen, will furthermore determine the list of pesticide active substances authorized for use.

On the second field characteristics screen, the user can:

- Further specify the land cover with specific types of crops or grazing types. These may in some cases refine the agricultural management practices that will be recommended and be used to select the appropriate pesticides active substances authorized for use.
- Indicate the use of pesticides. To do this, they first have to select the last crop grown, and then check whether they have used herbicides, fungicides and/or insecticides. They may then either indicate the number of components used, or select the specific active substances applied from a list on a pop-up screen. The lists show crop-specific active substances authorized for use in three European zones (North, Central and South). Outside of Europe, the lists show all active substances authorized for use in Europe. The respective lists are ordered in sequence of high-to-low expected pesticide environmental concentration (PEC) one day after application. The aggregate expected influence on pesticide contamination (based on PEC score and number of active substances used) will be shown in the 'Soil threats' screen.
- Indicate any specific category or categories of management recommendations they are interested in. Agricultural management practices belonging to the selected categories will later on in the 'Recommendations' screen be presented in bold.
- Confirm the edits made to return to the main screen from where they can then proceed to view the soil properties, soil threats and recommendations for the location.

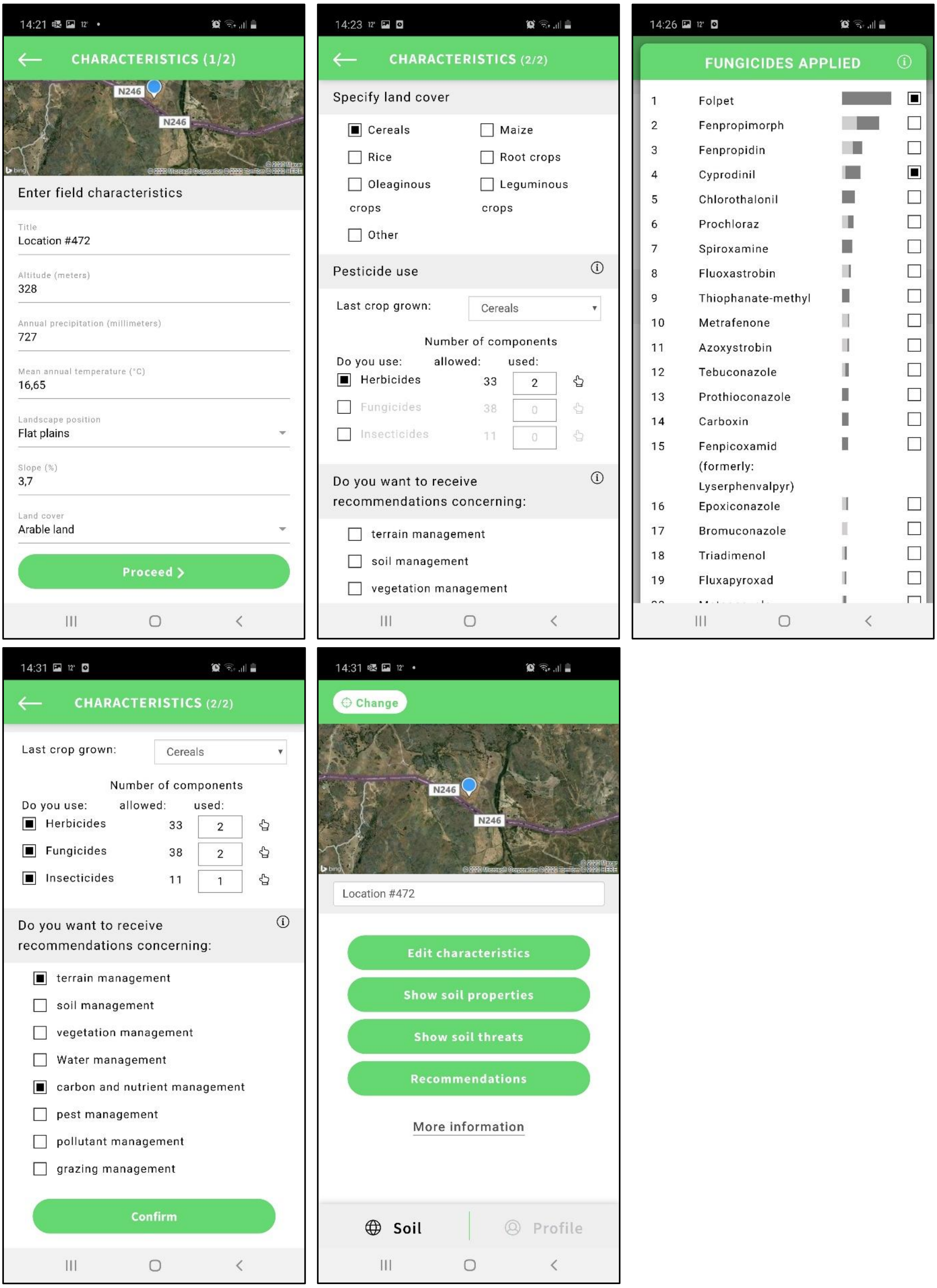


Figure 25. Field characteristics screens 1/2 and 2/2, pop-up screen for selecting applied fungicides (listed in decreasing order of expected PEC after 1 day – relative PEC levels after 1 day and after 100 days are indicated by bars in dark and light grey), the field characteristics 2/2 screen after filling pesticides used and recommendation domains, and the main screen with the recommendations screen now available after having filled the field characteristics.

4.3. Soil properties

The soil properties screen shows an overview of the available data grouped under soil physical, chemical and biological properties (Figure 26). By clicking on the graph symbol, a cumulative density function of the values of the selected property for all locations within a specific pedoclimatic zone is visualized. This graph screen shows:

- The minimum and maximum value of the indicator scores within the pedoclimatic zone for the selected land use (i.e. arable, grassland, or the full range for 'other').
- Whether these minimum and maximum values signify a negative, undesired (red dot symbol) or positive, desired (green dot symbol) soil property score, or whether the value cannot be attributed a desired or undesired score (grey dot symbol).
- The global data value available for the location (yellow diamond symbol). Position on the graph relative to the y-axis shows the percentage of locations having a lower score.
- Visualization of symbols can be switched on and off by clicking on the symbol in the legend, which is helpful if multiple symbols overlap.

Clicking the 'Enter own data' button opens a pop-up screen allowing the user to enter their own data for the selected property. They can specify a value, indicate whether this value concerns an estimate, field measurement or lab result, and the date the data was acquired. By sending this feedback, the value entered is saved for the specified location, and the user returns to the cumulative density graph, where the entered value is now visible with a blue diamond symbol. Returning to the soil property overview screen, the modified value is now visible in blue text. Once the user has checked all data and updated soil properties for which they have data, they can return to the main menu.

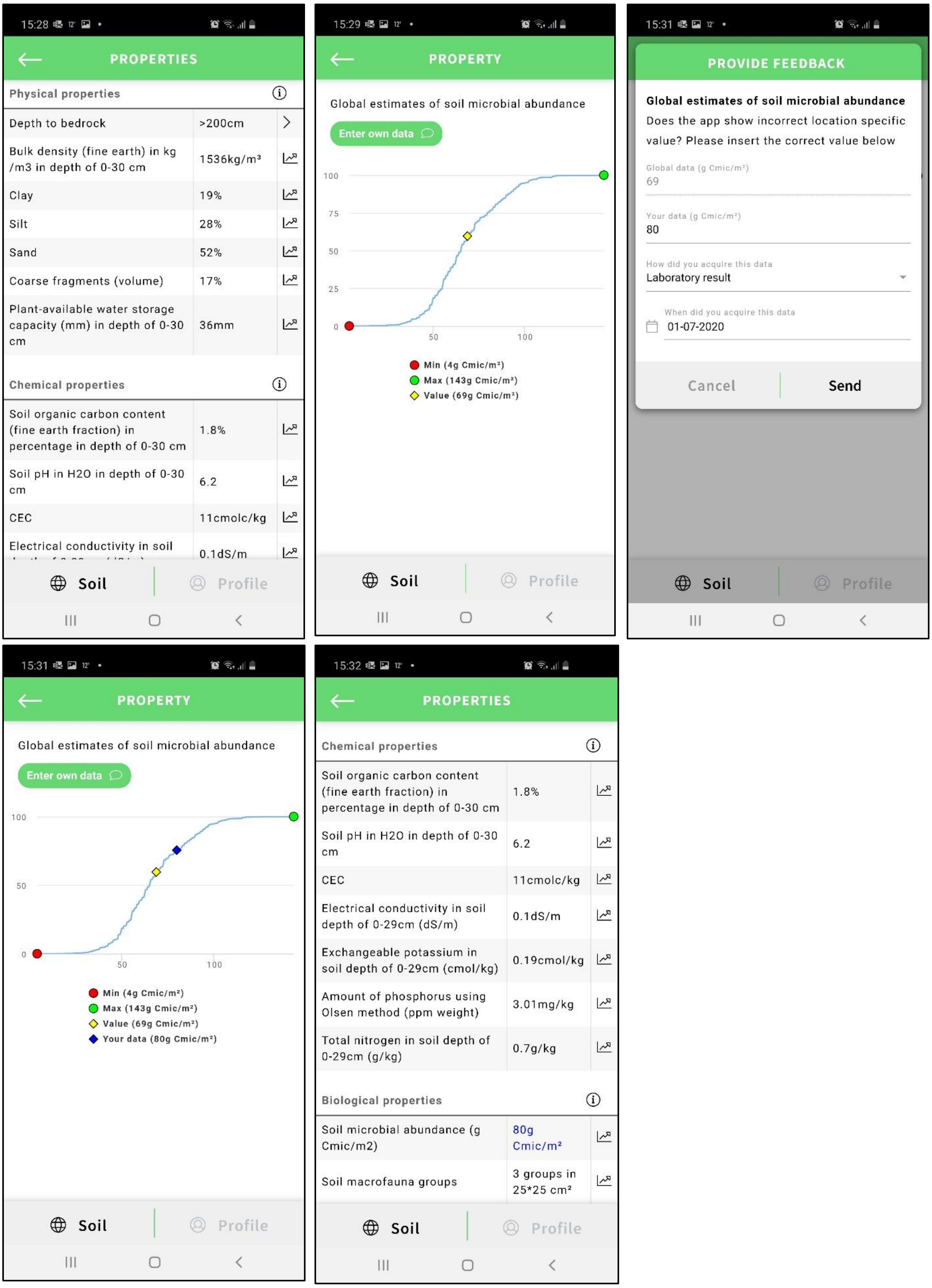


Figure 26. Soil properties overview screen, cumulative probability graph screen for soil microbial abundance, and pop-up screen to enter own data (top). When returning to the cumulative probability graph, the entered data is now visible (blue marker), and when returning to the overview screen the entered data is now also listed in blue font.

4.4. Soil threats

The soil threats screen shows an overview of the available data grouped under soil threat categories: soil erosion by water, soil erosion by wind, soil compaction, soil salinization, soil organic matter decline, soil nutrient depletion, soil acidification, soil contamination and soil biodiversity (Figure 27). Next to the value of the soil threat indicators, this screen also visualizes the soil threat classifications of these values by depicting a green, yellow or red background colour for low, medium and high soil threat classifications, respectively. By clicking on the graph symbol, a cumulative density function of the values of the selected soil threat for all locations within a specific pedoclimatic zone is visualized. This graph screen shows:

- The minimum and maximum value of the indicator scores within the pedoclimatic zone for the selected land use (i.e. arable, grassland, or the full range for 'other').
- Whether these minimum and maximum values signify a negative, undesired (red dot symbol) or positive, desired (green dot symbol) soil property score, or whether the value cannot be attributed a desired or undesired score (grey dot symbol).
- The global data value available for the location (yellow diamond symbol). Position on the graph relative to the y-axis shows the percentage of locations having a lower score.
- The background of the graph, indicating whether the indicator score represents a low (green), medium (yellow) or high (red) threat classification.
- Visualization of symbols can be switched on and off by clicking on the symbol in the legend, which is helpful if multiple symbols overlap.

Clicking the 'Enter own data' button opens a pop-up screen allowing the user to enter their own data for the selected soil threat indicator. They can specify a value, indicate whether this value concerns an estimate, field measurement or lab result, and the date the data was acquired. By sending this feedback, the value entered is saved for the specified location, and the user returns to the cumulative density graph, where the entered value is now visible with a blue diamond symbol. Returning to the soil threats overview screen, the modified value is now visible in blue text, and the soil threat class modified accordingly (in this case from moderate to high). Once the user has checked all data and updated soil threat indicators for which they have data, they can return to the main menu.

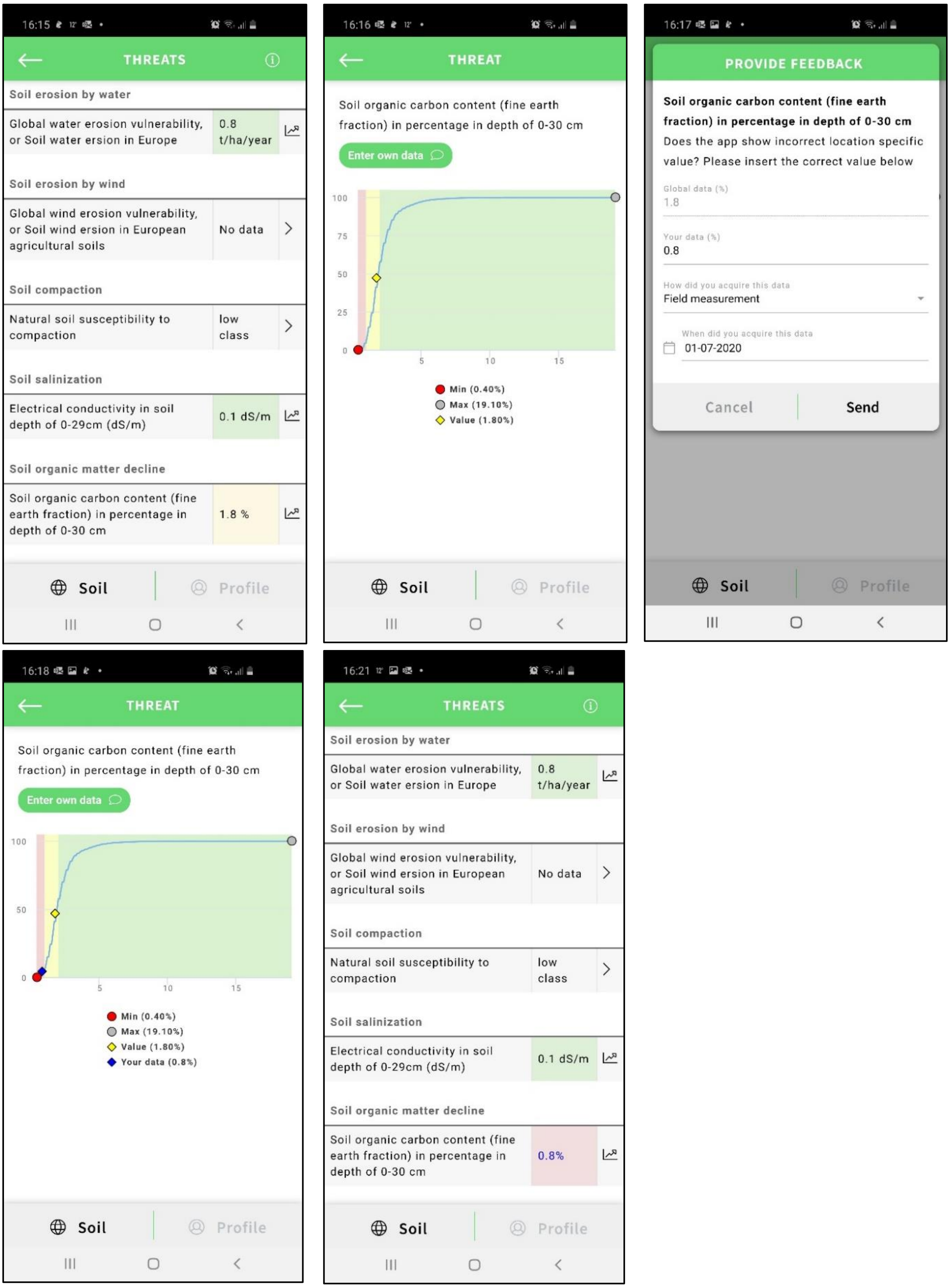


Figure 27. Soil threats overview screen (note colour-coded risk levels – green: low; orange: medium; red: high), cumulative probability graph screen for soil organic carbon content with graph background showing threat levels, and pop-up screen to enter own data (top). When returning to the cumulative probability graph, the entered data is now visible (blue marker), and when returning to the overview screen the entered data is now also listed in blue font (note that the value entered is classified as high soil threat level).

4.5. Summary and recommendations

After the user has reviewed field characteristics, soil properties and soil threats, pressing the recommendations button in the main screen first opens the summary screen (Figure 28) which features two overall indicators:

- The overall potential for soil property improvement, expressed in a percentage 0-100%. An average soil would score 50%, so a score lower or higher than 50% is respectively below-average and above-average. Due to the averaging across multiple soil properties, extreme values (close to 0% and 100%) are rare and mostly relate to locations where the number of soil properties for which there is data is limited. Below the overall indicator is a list of individual soil properties for which the improvement potential is 67% or larger.
- The overall indicative soil threat level, expressed as a bar ranging from low to high. Like for soil parameters, the indicator score is calculated by averaging the soil threat scores across indicators (whereby for nutrient depletion and heavy metal contamination only the worst item is considered). Below the bar is a list of soil threats that are classified as high.

By clicking on the ‘recommendations’ button the user proceeds to the recommendations overview screen listing the 10 agricultural management practices with the highest score for the location-specific combination of soil properties and soil threats requiring attention. The list is shown with those AMPs belonging to the recommendation areas of interest specified by the user in the field characteristics (2/2) screen formatted in bold. For each AMP, the user can see further information by clicking on the ‘i’ symbol on the left-hand side, and review the AMP by selecting the indicator symbol on the right-hand side.

When clicking the ‘i’ symbol, the user sees a description of the AMP and its categorization. Between 1-8 specific examples of each AMP can be viewed and scrolled through by clicking on the ‘view examples’ button. Examples are given a level of complexity rating and illustrated. The reviewing of the AMPs is done by qualifying them as already implemented, inappropriate, potentially interesting or definitely interesting.

After the reviewing of individual AMPs, the ones of interest are shown in the next screen where the user can order them in order of interest (Figure 29). After the ordering, a feedback screen is shown with two simple questions (1. Were the recommendations useful for you? 2. Do you think you will implement one of the recommendations?) and an open feedback field. Upon (later) revisiting of the same location, the user ratings of the AMPs are brought in remembrance, but those that were definitely interesting are left open for a possible new evaluation (note: also the other ratings can be changed).

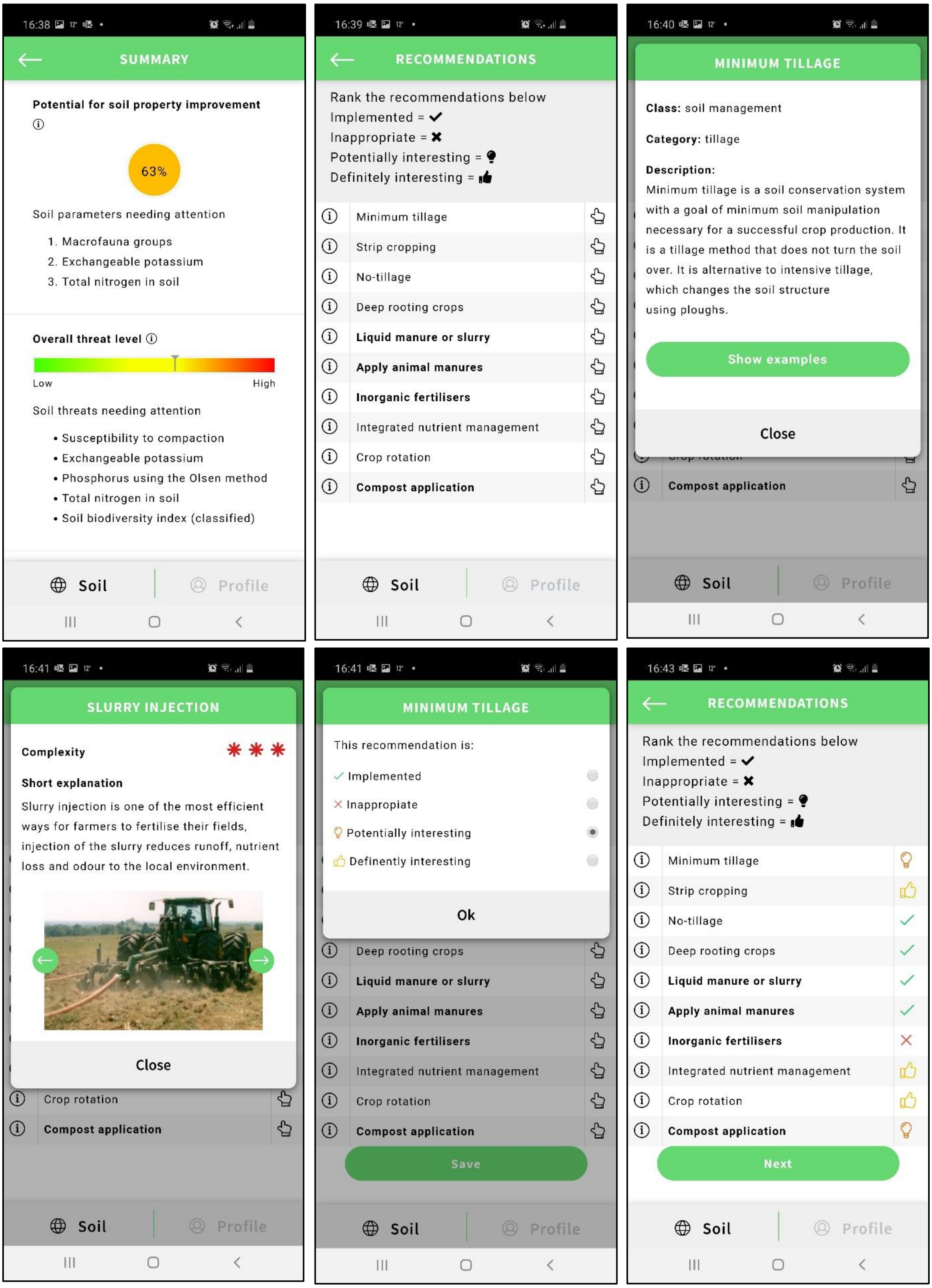


Figure 28. Summary overview screen with potential for soil property improvement score and overall soil threat level, the recommendations screen listing the 10 highest scoring AMPs, and AMP information screen for minimum tillage (top). By clicking 'showing examples' a scrollable pop-up screen opens with photos and short descriptions. By clicking the indicator symbol, each AMP can be evaluated, as shown in the final overview.

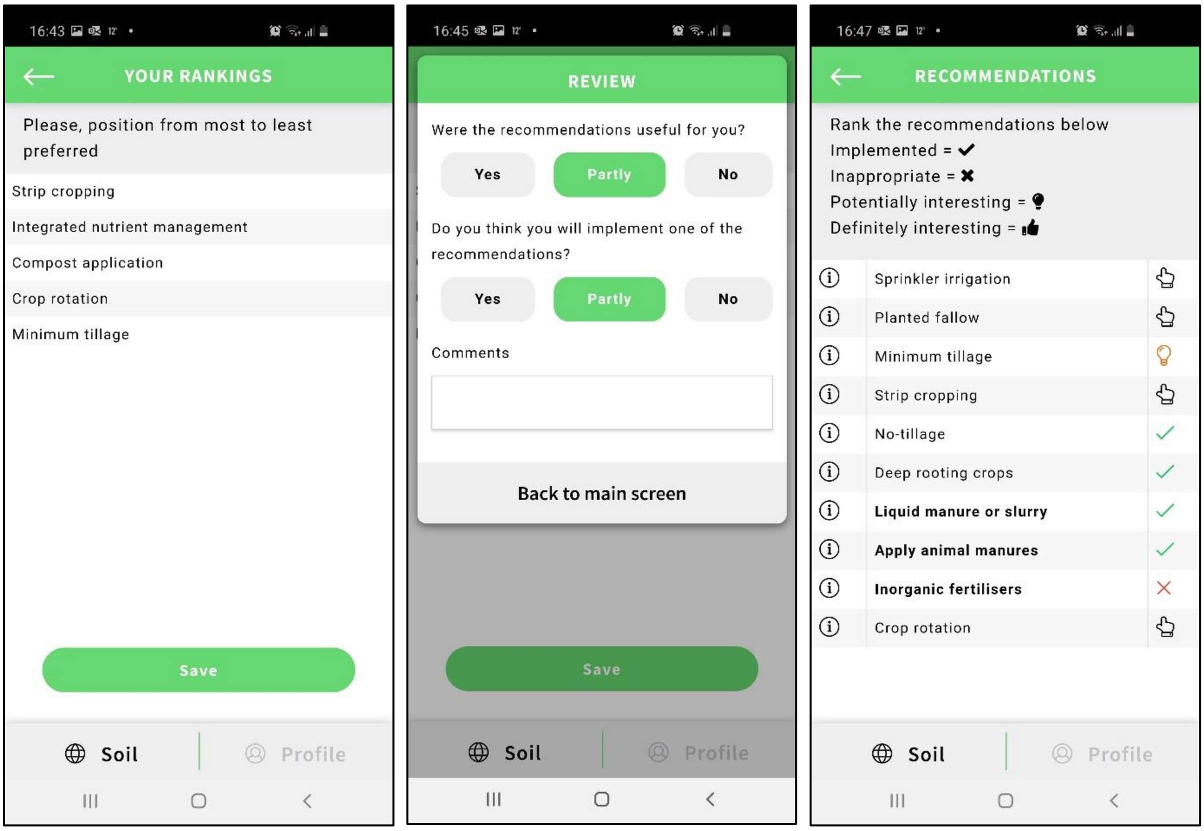


Figure 29. Your rankings screen where the user can swap the order of (potentially) interesting AMPs, after which a final review screen with two questions pops up. Upon later revisiting the recommendations overview screen, all evaluations are saved except the definitely interesting ones (for which the user can now indicate whether they were implemented or otherwise; other evaluations can be changed too).

4.6. More information

By clicking on the ‘More information’ link in the main screen, a series of background information and interaction options are accessible, including the following (Figure 30):

- About – a brief description of the purpose and functionality of the app
- Disclaimer – a legal text explaining that the app is freely supplied but that no rights can be claimed from (implications of) its use.
- Privacy policy – a legal text explaining how user data is handled and how it conforms to the European GDPR regulations.
- Credits – a description of the third party data sources, development partners and financing.
- Feedback – a free-form field to send feedback and questions to the app development team.
- FAQ – a list of frequently asked questions and answers.

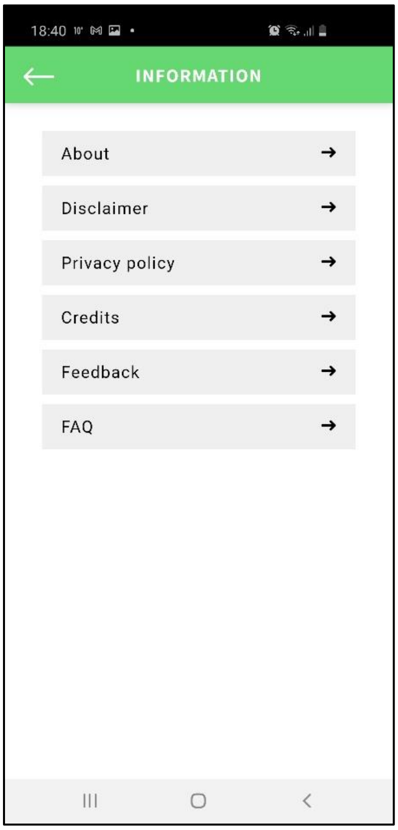


Figure 30. Information overview screen with buttons to access further information or provide feedback on the app.

5. SQAPP data

5.1. Input maps for SQAPP

The following data sets were used for building the final version of the SQAPP:

- Soilgrids (www.soilgrids.org), at 250 m resolution, has been used for the following soil parameters with global coverage: absolute depth to bedrock, bulk density, texture, available soil water capacity, soil organic carbon content, cation exchange capacity, soil pH and its derived soil acidification. For further information on Soilgrids see the paper by Hengl et al. (2017).

- European Soil Data Centre (ESDAC) (https://esdac.jrc.ec.europa.eu/ - Panagos et al., 2012) has been used for the following soil threat data with European or global coverage: soil erosion by water (Panagos et al., 2015), soil erosion by wind (Borrelli et al., 2017), susceptibility to soil compaction (Houšková and Van Liedekerke, 2008), soil contamination by heavy metals (Rodriguez Lado et al., 2008), except for copper for which Ballabio et al. (2018) was used. Global Soil Biodiversity Atlas Maps have been used for the following soil biological data: global estimates of soil microbial abundance and soil macrofauna (Serna-Chavez et al., 2013), and soil macrofauna data (courtesy of Dr Jerôme Mathieu of University Pierre and Marie Curie, Paris VI, manuscript in preparation).

- Global Soil Dataset for Earth System Modelling (http://globalchange.bnu.edu.cn/research/soilw) has been used for: electrical conductivity, exchangeable potassium, phosphorus using Olsen method, and total nitrogen (Shangguang et al., 2014).

More in particular, the following data layers are incorporated in the final version of SQAPP:

Global background info at 250m resolution

1. Altitude (m, a.s.l.)
2. Slope (%)
3. Precipitation (mm/year)
4. Average anual temperature (°C)
5. Landscape (breaks-foothills, flat plains, high mountains-deep canyons, hills, low hills, low mountains, smooth plains)
6. Land cover in 2010 at 30m resolution
7. Pedoclimatic zones (n=2098)

Global soil properties in 0-30cm depth at 250m resolution

1. Soil types (WRB)
2. SOC (%)
3. pH (H_2O)
4. Sand (%)
5. Silt (%)
6. Clay (%)

7. Coarse fragments (%)
8. Bulk density (kg/m^3)
9. CEC (cmolc/kg)
10. Depth to bedrock (cm)
11. Available soil water capacity (volumetric fraction) with FC = pF 2.0
12. Available soil water capacity (volumetric fraction) with FC = pF 2.3
13. Available soil water capacity (volumetric fraction) with FC = pF 2.5
14. Non-available soil water capacity or permanent wilting point (PWP) (volumetric fraction) with FC = pF 4.2

Global soil nutrients in 0-30cm depth at 250m resolution

1. Total N (g/kg)
2. Total P (g/kg)
3. Total K (g/kg)
4. Electrical conductivity (dS/m)
5. P (Olsen, ppm/weight)
6. Exchangeable K (cmol/kg)

Global and regional soil threats and reclassification (low, medium, high) at 250m resolution

1. Soil loss by water erosion in Europe and reclassification
2. Soil loss by wind erosion in European agricultural soils and reclassification
3. Global water erosion vulnerability reclassification
4. Global wind erosion vulnerability reclassification
5. Natural soil susceptibility to compaction in Europe and reclassification
6. Arsenic in European soils
7. Cadmium in European soils
8. Chromium in European soils
9. Copper in European soils
10. Mercury in European soils
11. Nickel in European soils
12. Lead in European soils
13. Zinc in European soils
14. Global soil biodiversity index reclassification
15. Global estimates of soil microbial abundance and reclassification
16. Global soil macrofauna and reclassification

5.2. Matrices

Eight data matrices are included in the SQAPP database in its content management system. Two of these relate to respectively the applicability limitations and effects of AMPs on soil properties and soil threats, while the remaining six are the active substances' expected PECs for respectively fungicides, herbicides and insecticides at two moments: one day and 100 days after application.

The structure of the matrices is as follows:

1. Applicability limitations of AMPs. For each AMP, applicability is defined in binary (0/1) fashion for:
    - Land cover class and subtype
    - Slope class: Flat (0-2%); Gentle (2-5%); Moderate (5-10%); Rolling (10-15%); Hilly (15-30%); Steep (30-60%); Very Steep (>60%)
    - Annual precipitation class: 0-250 mm; 251-500 mm; 501 - 750 mm; 751 - 1000 mm; 1001 - 1500 mm; 1501 - 2000 mm; >2000 mm
    - Landscape position: Breaks-foothills; Flat Plains; High Mountains-deep Canyons; Hills; Low Hills; Low Mountains; Smooth Plains
    - Soil depth class: Very Shallow (0-20 cm); Shallow (20-50 cm); Moderately Deep (50-80 cm); Deep (80-120 cm); Very Deep (> 120 cm)
    - Soil texture class: Coarse (sand > 50%); Fine (clay > 40%); Medium (other)
    - Stoniness class: None (coarse Fragments <2%); Slightly (coarse Fragments 2-10%); Moderately (coarse Fragments 10-25%); Excessively (coarse Fragments >25%)

2. Effects of AMPs on soil properties and soil threats, defined in the following classification: negative effect: -1; no, ambiguous or unknown: 0; slight or very long-term positive effect: 1; definite positive effect: 2. Effects can be entered for the following parameters (in bold the ones that are actually implemented in SQAPP) – note that some of these double as soil property and soil threat indicator:
    - Bulk density (fine earth)
    - **Plant-available water storage capacity**
    - **Soil organic carbon content (fine earth fraction)**
    - **Soil pH**
    - **Electrical conductivity**
    - **CEC**
    - **Exchangeable potassium**
    - **Amount of phosphorus using Olsen method**
    - **Total nitrogen**
    - **Soil microbial abundance**
    - **Soil macrofauna groups**
    - Clay
    - Silt
    - Sand
    - Coarse fragments (volume)
    - Depth to bedrock
    - **Global water erosion vulnerability, or soil water erosion in Europe**
    - **Global wind erosion vulnerability, or soil wind erosion in European agricultural soils**
    - **Natural soil susceptibility to compaction**
    - **Contamination (linked to highest ranked heavy metal risk)**
    - **Pesticide residues (after 1 day)**
    - **Pesticide residues (after 100 days)**

3. PECs (mg/kg) for individual active substances of fungicides expected 1 day after application:
   - Different regions: Central Europe (CEU); Northern Europe (NEU); Southern Europe (SEU); Rest of the world (ROW)
   - Different average annual temperature: 10°C; 20°C
   - Different crop types: cereals; maize; root crops; non-permanent industrial crops; grassland; permanent crops; vineyards; dry pulses, vegetables and flowers

4. PECs (mg/kg) for individual active substances of fungicides expected 100 days after application:
   - Different regions: Central Europe (CEU); Northern Europe (NEU); Southern Europe (SEU); Rest of the world (ROW)
   - Different average annual temperature: 10°C; 20°C
   - Different crop types: cereals; maize; root crops; non-permanent industrial crops; grassland; permanent crops; vineyards; dry pulses, vegetables and flowers

5. PECs (mg/kg) for individual active substances of insecticides expected 1 day after application:
   - Different regions: Central Europe (CEU); Northern Europe (NEU); Southern Europe (SEU); Rest of the world (ROW)
   - Different average annual temperature: 10°C; 20°C
   - Different crop types: cereals; maize; root crops; non-permanent industrial crops; grassland; permanent crops; vineyards; dry pulses, vegetables and flowers

6. PECs (mg/kg) for individual active substances of insecticides expected 100 days after application:
   - Different regions: Central Europe (CEU); Northern Europe (NEU); Southern Europe (SEU); Rest of the world (ROW)
   - Different average annual temperature: 10°C; 20°C
   - Different crop types: cereals; maize; root crops; non-permanent industrial crops; grassland; permanent crops; vineyards; dry pulses, vegetables and flowers

7. PECs (mg/kg) for individual active substances of herbicides expected 1 day after application:
   - Different regions: Central Europe (CEU); Northern Europe (NEU); Southern Europe (SEU); Rest of the world (ROW)
   - Different average annual temperature: 10°C; 20°C
   - Different crop types: cereals; maize; root crops; non-permanent industrial crops; grassland; permanent crops; vineyards; dry pulses, vegetables and flowers

8. PECs (mg/kg) for individual active substances of herbicides expected 100 days after application:
   - Different regions: Central Europe (CEU); Northern Europe (NEU); Southern Europe (SEU); Rest of the world (ROW)

- Different average annual temperature: 10°C; 20°C
- Different crop types: cereals; maize; root crops; non-permanent industrial crops; grassland; permanent crops; vineyards; dry pulses, vegetables and flowers

5.3. User input

User input in SQAPP is used to refine the projected soil threat of soil contamination by pesticides and to tailor the recommended AMPs to land use subtype selected by the user. For these inputs a selection of the user is required as global data provides only a limited specification of land cover and no information on pesticide use:

- Land cover: arable land; grazing land; permanent crops without soil cover; permanent crops with soil cover; vegetables; other
- Land cover specification depending on land cover:
    - For arable land: cereals; maize; rice; root crops; oleaginous crops; leguminous crops; other
    - For grazing land: pasture (intensively managed); rangeland (extensively managed)
    - Permanent crops (both types): vineyards; olives/nut trees; citrus; fruit trees; other
    - Vegetables: indoor vegetables; open field vegetables
- Pesticide use: types used (fungicides; herbicides; insecticides), number used, specific active substances used.

Other input data used by SQAPP can be adjusted by the user if they have their own (more precise) data. This applies to all types of information:

- Field characteristics
- Soil parameters
- Soil threats

Next, there are a series of user preferences that are considered and saved for a specific location of interest:

- Specific interest in recommendation domains: terrain management; soil management; vegetation management; carbon and nutrient management; pest management; pollutant management; grazing management
- Qualifications of recommended AMPs: implemented; inappropriate; potentially interesting; definitely interesting
- Rankings of AMPs deemed potentially and definitely interesting by the user

Finally, users can provide feedback to the app development team:

- Through giving feedback on the recommended AMPs (2 evaluation questions and comment box at the end of a use cycle)
- Through the generic feedback field under ‘More information’.

5.4. SQAPP output

To the app user, the SQAPP provides data on:

- Field characteristics (coordinates, altitude, annual precipitation, mean annual temperature, landscape position, slope and land cover)
- Soil properties (indicator scores: for the specific location; the minimum and maximum of the selected pedoclimatic zone and broad land cover type; the cumulative frequency of scores within the zone and relative position of the specific location)
- Soil threats (indicator scores: for the specific location; the minimum and maximum of the selected pedoclimatic zone and broad land cover type; the cumulative frequency of scores within the zone and relative position of the specific location; the overall soil threat classification and local soil threat level)
- Soil improvement potential score, overall soil threat level indication and specific soil parameters and soil threats requiring attention
- Recommendations of the 10 most effective AMPs to deal with the location-specific combination of soil properties and soil threats requiring attention.

The SQAPP content management system records the following information:

1. User data (email; password - for ensuring app functionality to the user only)
2. Saved locations and field characteristics
3. Location-specific recommendations generated and evaluated by users
4. Location-specific user-suggested data (parameter, global data value, user-specified value, how this data was acquired and when)

6. SQAPP users

6.1. Farmers and land users

Farmers and land users are the first core group of intended app users. The main features of interest for this group are: a) comparative soil quality assessment, allowing to compare their fields' soil quality with those of under the same land use, in similar soil types and climate zones; and b) the management recommendations of specific AMPs.

This group of SQAPP users is specifically suggested to register in order to be able to store information about their fields and receive recommendations. More specifically, it is suggested to save field locations with a plot name (or other identifier) and date in the name. This may be useful when experimenting with new AMPs and reassessment of a field's soil quality at a later point in time. By doing this, the previous information does not have to be overwritten and remains available, and can be used to track progress towards improved soil quality over time.

Often, farmers and land users will have data about their fields' soil. Entering those data is recommended in order to get more tailored AMP recommendations, as some of the global data layers have been shown to be of poor quality, and none of the datasets takes specific local soil management history into account. There are also a number of instances in the app where user input about land management is required, and this group is the key user group that is able to use actual data, e.g. about (rotational) crops grown on a field and pesticides applied. Defining these correctly also enhances the management recommendations by SQAPP. In the case of pesticides, for many farmers this will probably be the first time that they will get an estimate for the pesticide environmental concentration in their field.

Evaluating the AMPs suggested by SQAPP is another important aspect of the use of the app by this group. As with improved or updated data the suggested AMPs may change, it is good practice to take some time to go through the evaluation and indicate which AMPs are already applied, inappropriate, potentially interesting or definitely interesting. As these user-specified evaluations are stored, they can be reviewed at a later time. Also, if a large number of app users evaluates AMP suggestions, researchers can analyse the data and improve the AMP recommendations, e.g. by removing those that are consistently evaluated as inappropriate.

When farmers and land users have selected AMPs that are potentially or definitely interesting, they can search for more information about these. A first recommended portal is the iSQAPERis section on agricultural management practices recommended by SQAPP

(https://www.isqaper-is.eu/sqapp-the-soil-quality-app/amps-in-sqapp). Here, links to websites with more details are provided. This section on iSQAPERis is also of interest to this group in its own right as it provides access to the full set of AMPs that can be browsed at convenience for inspiration.

Throughout the development process of SQAPP, farmers and land users have indicated a number of concerns and ideas about the app. The most common ones are listed in Table 14.

Table 14. Key concerns expressed by farmers and land users during SQAPP development and solutions.

Key concern	**Solution**
Availability of SQAPP in own language	SQAPP is available in 14 languages
Poor quality of global soil data	User can update with their own data
Soil data is provided in different units	Conversion factors are provided
AMP recommendations are too general	391 specific examples of AMPs have been incorporated
AMPs already implemented or inappropriate	AMP recommendations have been revised; user can record which AMPs are already implemented and which are inappropriate
Would like to have spatial information	SQAPP is a point-based tool. Multiple points can be recorded within/across fields.
Would like to be able to import soil data	Follow-up work can be done to link SQAPP with other tools
Would like to be able to export soil data	To be considered in the future
Would like to have information on policy support for AMPs	Follow-up work can be done to link SQAPP to national greening measures support information. As these tend to change a support strategy to keep this information updated is necessary
Who has access to my data?	The privacy policy describes the potential use of data. App developers can use the data to improve SQAPP and report on the use of SQAPP, but will never disseminate point data. (Currently, there is no way to verify the accuracy of user input, so user supplied data cannot be taken for granted to be accurate)

6.2. Advisors and technicians

Advisors and technicians can use SQAPP as a tool to assist them in advising farmers and land users. As they have a network of farmers and land users that they interact with, they are a key target audience in order to explain SQAPP, report on accuracy issues, and keeping abreast of interesting AMPs for the area they operate in. They may be particularly interested in: a) having

access to global soil data and relative soil quality assessment scores as a quick-scan tool; and b) the portfolio of AMPs and specific AMPs frequently recommended for the area they operate in.

This group of SQAPP users is also suggested to register in order to be able to store information about fields and management recommendations. Rather than having accurate data on specific field locations, they may populate saved locations with typical data in order to verify AMPs that are recommended, and keep a list of priority AMPs on which to document interesting information to disseminate to farmers and land users.

They can support farmers and land users with access to data about their fields' soil to enter their data and discuss the tailored AMP recommendations suggested by SQAPP with them. They also play a crucial role in identifying alternatives, e.g. to reduce the use of pesticides with high environmental impact, and experiences with the use of AMPs in experimental settings and/or by other farmers in the region. As they potentially review a large number of AMP suggestions, their feedback to the researchers that develop SQAPP is particularly useful. The iSQAPERis section on agricultural management practices may be an interesting resource for this group.

Throughout the development process of SQAPP, advisors and technicians have indicated a number of concerns and ideas about the app. The most common ones are listed in Table 15.

Table 15. Key concerns expressed by advisors and technicians during SQAPP development and solutions.

Key concern	**Solution**
Reaching farmers and land users with the right information	Especially younger farmers are interested in apps as a tool
Availability of SQAPP in local language	SQAPP is available in 14 languages
Quality of user input data	Advisors working with farmers to complete data input
AMP recommendations are too general	391 specific examples of AMPs have been incorporated
More information on the ways to calculate probability distributions and soil quality score	Information buttons explain main points in the app; instruction video and explanations available on iSQAPERIS
Possibility to consider local/national datasets	Potential to apply SQAPP principles on local datasets; integrating in global data may not be straightforward because of different methods used. This was not taken forward within the scope of the project.
Interacting with researchers to obtain the latest insights in new AMPs	SQAPP can play a role but exchanges through collaborative events and projects remains key.

6.3. Students and researchers

Students and researchers are an important group of intended app users. The main features of interest for this group are: a) access to global soil data and relative soil quality information, using SQAPP as a convenient first-stop data source; b) information about relevant soil threats at a location of interest; and c) learning about AMPs recommended for a certain location.

Depending on interest to consult recommendations, this group of SQAPP users can either register in order to be able to receive recommendations or use the app without making an account. Logging in with an account is helpful if repeated readings are going to be taken and having access to the data from these points is important (e.g. for sampling during field work).

For this group, the distribution of soil parameter values and relative position of a field in relation to other fields with similar land use and pedo-climatic conditions can be insightful information. It is helpful to complement SQAPP readings with visual soil assessment methods if no other data is available to cross-check estimates using different methods. The use of SQAPP for this group can be: a) exploratory – considering different points in an area to get an idea about the variability of soil conditions or about potential soil quality scores; b) gather proxy soil data – collect results from SQAPP as a first indication of local conditions to be cross-checked with other data later; c) as primary data source – caution should be taken with this, but for soil parameters with high or reasonable confidence, for non-critical applications this could be a viable data source.

SQAPP can also be used as a data collection tool while doing research with farmers and land users, where data from these farmers can be registered in SQAPP, whether this relates to the soil parameters or feedback regarding different AMP suggestions. Students can learn directly from SQAPP (exploratory use), or by comparing SQAPP data with other data sources, e.g. to conduct an accuracy assessment (analytical use of proxy data). The full overview of AMPs in SQAPP on iSQAPERIS can also serve as a learning resource.

This group can also perform a key role in validating SQAPP and reporting of soil data. Through feeding back this information within SQAPP or to the researchers that developed the app, improvements can be made. This can consist of refinements of the current data and data processing methods in SQAPP, or development of new functionality and modules.

Throughout the development process of SQAPP, students and researchers have indicated a number of concerns and ideas about the app. The most common ones are listed in Table 16.

Table 16. Key concerns expressed by students and researchers during SQAPP development and solutions.

Key concern	Solution
Clear information on the source of the data	Pop-up screen mentioning the source of each soil parameter
Clear indication of the uncertainty of the data	Pop-up screen indicating the reliability of each soil parameter
Clear disclaimer on what the app can and cannot do	Disclaimer is included in SQAPP
Incorporation of new datasets	Datasets can be updated as and when better data are available. New datasets can be added, requires app update
Would like to be able to export soil data	To be considered in the future
Knowing which pedoclimatic zone a location belongs to and where comparable conditions occur	The SQAPP API can be consulted for the pedoclimatic zone on the location; spatial SQAPP data can be further developed – was not considered in iSQAPER

6.4. Policy makers

Policy makers may not be core users of the app themselves, but awareness of soil quality, soil threats and AMPs that can be implemented to improve poor conditions is essential in order to make the right policy decisions. They may furthermore be interested in the potential of SQAPP to act as an interactive soil quality assessment tool, i.e. its potential for self-reporting. The main features of interest for this group are: a) option to have bidirectional exchange of soil data with farmers and land users; b) relative quality and soil threat information, allowing to plan priority interventions.

This group may not directly use SQAPP themselves, but often, farmers and land users will have data about their fields' soil. Entering those data is directly relevant for farmers and land users in order to get more tailored AMP recommendations, and indispensable in case of data about land management, e.g. about (rotational) crops grown on a field and pesticides applied as there are no global datasets available about such management information. This aggregation of user input about field data and relevant AMPs recommended based on the best available data could potentially be used to help formulate policy. The SQAPP could help to fill some gaps in granular, field level data. This could potentially be a significant assistance in future planning and policy formulation.

Gathering more information about the farmers' and land users' viewpoint on AMPs suggested by SQAPP is another important aspect of interest for policy makers. As farmers and land users

can evaluate the AMPs suggested, indicating which ones they have already implemented, deem inappropriate, or find potentially or definitively interesting, new data is being generated on the relevance of AMPs. If a large number of app users evaluates AMP suggestions, researchers can analyse the data and improve the AMP recommendations, e.g. by removing those that are consistently evaluated as inappropriate. This information could be useful in the formulation of future policy initiatives and serve as useful quantitative feedback on the utility and desirability of certain AMPs.

SQAPP can provide tailored advice to farmers and land managers. The advice is taken from a database on AMPs available as a portal in a dedicated iSQAPERis section on agricultural management practices recommended by SQAPP (https://www.isqaper-is.eu/sqapp-the-soil-quality-app/amps-in-sqapp). Here, links to websites with more details are provided. This portal and the app could serve as the basis for decision support to farmers and land managers in future.

The rules used in SQAPP to calculate the potential for soil quality improvement and overall soil threat level, and the ranking of AMPs have also been worked out in a spatial model. Policy makers may be particularly interested in such a spatial representation as it allows to assess priority areas for soil quality improvement, and the most important AMPs recommended to address site-specific combinations of poor scores on soil quality parameters and high soil threat risks.

7. Outlook

7.1. New data

New data can be considered in different ways:

- Updated zonations of soils and/or climate zones
- Updated data layers
- New data layers
- User input

Updated zonations are the most profound change in the SQAPP database, as all soil parameter distributions are made for specific pedo-climatic zones. If the base zones change, all data has to be recalculated. We have already made a new pedo-climatic zone map, replacing climate data by Peel et al. (2007) by those of Beck et al. (2018). This new map has a much improved spatial resolution and solves some issues of missing land territory in sea-land boundary areas. Re-analysis of all other data layers was not possible within the scope of the iSQAPER project and the new pedoclimatic zones map will be used in a future update.

Data layers can be updated if better data becomes available. E.g. for copper, such an update has already been performed. Other data layers that have become available and would be useful to consider in a future revision of SQAPP include:

- Topsoil nitrogen (N), phosphorus (P) and potassium (K) content in Europe (Ballabio et al., 2019) and soil total nitrogen in China (Zhou et al., 2020). These data could replace the data of Shangguan et al. (2014) that has been found to be inaccurate in iSQAPER field sites. There are some difficulties with this replacement, as the modeled soil parameters are not the same (total instead of available nutrients), and the new data are only available in Europe (with gaps for non-EU countries).
- Nitrogen content is also newly included in the revised SOILGRIDS data (2020). SOILGRIDS is used for predictions of bulk density, texture, coarse fragments, CEC, SOC and pH. All these layers have been produced with improved data modelling procedures and more extensive measured soil data.
- Global soil erosion by water (Borelli et al., 2017). This dataset could replace the soil erosion by water in Europe dataset (Panagos et al., 2015).

New data layers can also be added. When adding new data layers, AMP matrices may need to be extended with these layers to recommend practices that can mitigate low scores of the newly included soil parameters. Potential new data could include:

- calcium carbonates ($CaCO_3$) and C:N ratio in European topsoils (Ballabio et al., 2019)
- depth-to-bedrock map of China (Yan et al., 2020)

- global distribution of earth worm diversity (Phillips et al., 2019)
- soil nematode abundance and functional group composition at a global scale (Van den Hoogen et al., 2019)
- soil loss due to crop harvesting in Europe (Panagos et al., 2019)
- global gridded maps of the top 20 crop-specific pesticide application rates (Maggi et al., 2019)

More data can also be derived from app users. An obvious entry point is to offer the user the opportunity to specify AMPs already implemented. These could then be excluded from the list of recommendations. A difficulty introduced with this approach is that the effects of additional AMPs should then ideally consider the incremental effect on top of that of currently implemented AMPs. The vast range of potential combinations of AMPs makes this hard to do. A second option is to qualify user data entry – either by differentiating types of accounts (e.g. expert users that declare to submit only trustable data) or asking confirmation from users about the quality of data entered (either a self-declaration or proof). Various specifications of management can be conceived as useful for additional soil threat assessments, e.g. fertilization rates, or for more targeted recommendations, e.g. presence of animals on the farm or in the region.

7.2. Data analysis

The SQAPP database will grow as more users start to use the app. Many different analyses will be possible based on user and user-contributed data, e.g.:

- Geographical and temporal patterns of SQAPP use.
- Selections of AMPs that are implemented, inappropriate, or potentially or definitely interesting. These could be linked to pedo-climatic zones or countries, the soil quality and soil threat indicators, land use and crops/grazing types. Assumed should be that evaluations of AMPs are consciously made.
- Correlating user-contributed and global data on various soil quality and soil threat parameters. To do this, first, a solution should be found to ensure (or test) the veracity of user-contributed data.
- Analysing pesticide application data, again on the assumption that user selections are accurate.

The calculation rules of SQAPP can also be implemented spatially as shown in Section 2.5. European or global maps of (relative) soil quality and overall soil threat level, and of the number of AMPs suitable for the location and the best scoring AMP are key outputs of interest for research and policy users.

7.3. Functionality and usage

There are 1892 registered SQAPP users in the app's content management system before the final SQAPP was officially launched, i.e. individuals who installed SQAPP on their mobile phone and registered as a user. 8164 locations are saved. Users do not need to be physically located at the position saved, but the global spread does seem to indicate the SQAPP is used on all continents already (Figure 31).

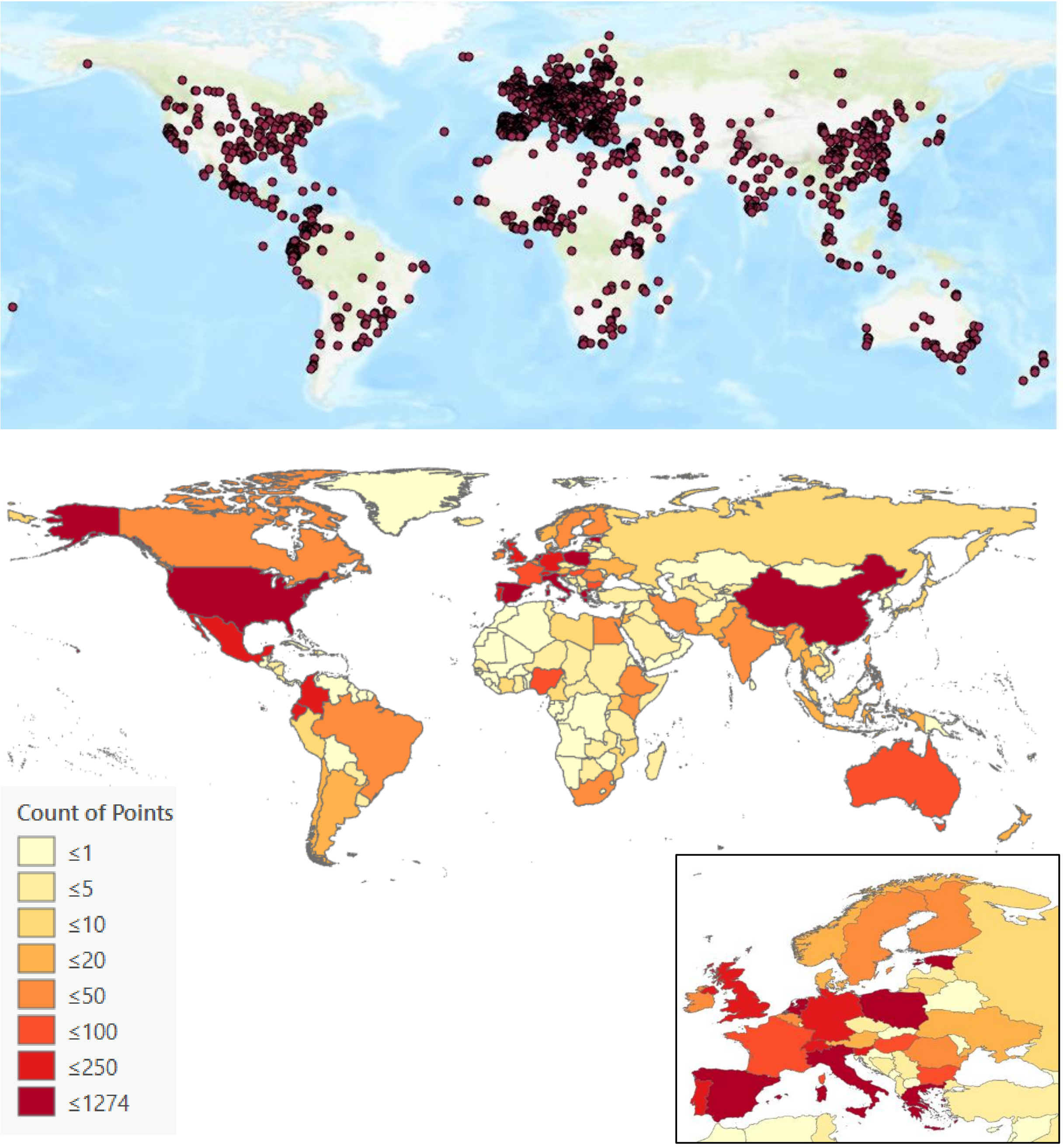


Figure 31. Locations saved in SQAPP.

1418 pieces of user soil data have been entered. This feature of SQAPP is hence so far not used as much as the direct consultation of global soil data. 242 sets of recommendations have been saved, i.e. so far only a small percentage of users has examined the recommendations by SQAPP. Users can however also delete locations and associated recommendations.

Dissemination of information and instructions on the use of SQAPP, and availability of recommendations in a variety of languages is expected to lead to a rise in the number and percentage of users exploring management recommendations.

Future work can explore more in-depth the uses of SQAPP. Multiple directions of providing further functionality can be added. A basic one would be to give the user some insight in the pedo-climatic zone a soil on a location belongs to. This information is already available in the data source of the app (ISRIC REST API), but not communicated to the SQAPP user. The areas of pedo-climatic zones differ significantly. Hence, showing the area with comparable soil and climatic conditions on a map is frequently not useful as no areas are discernible. An alternative visualization would make more sense, e.g. by showing the total area of that pedo-climatic zone, and give a breakdown of countries with the highest area of those zones. Showing a map with the variability of pedo-climatic zones in an area (or also of soil quality and soil threat parameters) may also be of interest, although judging whether the pedo-climatic zoning is correct is difficult for laymen.

Functionality can also be enhanced in terms of links with other apps, tracking progress towards soil quality improvement over time, links to other (nearby) users with expertise in applying certain AMPs – providing social interaction options, and providing information on policy support available.

8. Conclusions

The Soil Quality App (SQAPP) is the flagship deliverable of the EU-Horizon 2020 iSQAPER project. The SQAPP was designed with the idea that it should provide the user with the opportunity to access fragmented data on soil quality and soil threats in an easy-to-use way. Moreover, the user should not only receive indicator values, but be guided in interpreting these values by providing more contextual information: is a certain indicator value high or low in a given context. The system is set up to use soil quality and soil threat indicators for which spatial data exist as a first estimation for soil quality parameters in a given location, but these values can be replaced with more accurate own data by the app user. Ultimately, the user receives, based on an assessment of the most critical issues, management recommendations on how soil quality can be improved and soil threats be overcome.

SQAPP was built through various rounds of stakeholder consultation, testing and review. Rounds of stakeholder consultation included interviews with stakeholders in the iSQAPER studies; a field evaluation of SQAPP performance; a formal evaluation of the beta version by some 90 European stakeholders (researchers, farmers, students, advisory services and policy makers) in locations in Slovenia, Poland, Portugal, Greece, Spain, France, Estonia, Romania and Netherlands; an evaluation by some 220 participants in the 11 study site Demonstration Events. The beta-version of SQAPP was also tested by comparing measured and SQAPP-derived soil quality and soil threat parameters to determine the level of accuracy with which SQAPP describes a location. SQAPP was also subjected to two peer-reviews sessions, one internal review conducted with the iSQAPER partners and concerned with issues concerning the validation of SQAPP against measurements, data origin, data coverage, reliability and accuracy of the data, and the possibility for users to include data and feedback, and the other with scientists at the Soil Horizons workshop at the Wageningen Soil Conference.

Accuracy of spatial soil data was found to be low 9 indicators, moderate for 8 indicators and high for 2 indicators, whereas no verification was made for 7 indicators (mostly soil threats). Although SQAPP has been found easy to use, over the course of the iSQAPER project considerable recommendations were given for improvement, explanation, translation, and statements about data quality and legal aspects of data handling. This report has documented these steps and how they were addressed. The final SQAPP is now ready as a tool for different types of users (farmers and land users, advisors and technicians, students and researchers, and policy makers) for whom guidance is provided about ways in which SQAPP can be useful for them. The tool includes a novel pesticide contamination risk module that can inform land users probably in many cases for the first time about the soil threat of pesticide contamination. SQAPP includes a database of 89 AMPs and provides 391 examples of these AMPs to inspire land users to practice more sustainable soil management. SQAPP is available from Apple and Google Play app stores, in 14 languages: Chinese, Dutch, English, Estonian, French, German, Greek, Hungarian, Italian, Polish, Portuguese, Romanian, Slovenian, Spanish.

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Annex 1 Full list of AMP descriptions and examples

No.		English
1	**AMP name**	**Bunds**
	AMP description	A bund is a line of stones or earth constructed along contour lines. It helps control soil erosion by surface water runoff and allows water to infiltrate, leading to better crop water availability. Over time bunds often gradually form into terraces.
	Example 1 name	Earth bunds
	Example 1 description	An earth bund is constructed by piling a ridge of soil along contour lines to intercept runoff.
	Example 2 name	Earth bunds with tied ridges
	Example 2 description	An earth bund is constructed by digging a shallow ditch along contour lines and piling the earth downslope to intercept runoff. Tied ridges connect the ditch to the bund.
	Example 3 name	Stone-faced soil bunds
	Example 3 description	An earth bund with ditch and tied ridges is constructed along contour lines to intercept runoff. The bund is reinforced by a stone wall.
	Example 4 name	Stone lines
	Example 4 description	Rows of loose stones are laid along contour lines as a semi-permeable sheet erosion control structure, slowing down the speed of runoff, filtering it and spreading it over the field.
	Example 5 name	Fanya juu terraces
	Example 5 description	Earth bunds are created by digging a trench along contour lines and piling the soil upslope to form an embankment that is often stabilized with fodder grasses or shrubs.
	Example 6 name	Rock strip
	Example 6 description	A substantial construction of stones and rocks is piled along the contour line to reduce soil erosion in hilly areas.
2	**AMP name**	**Trenches and infiltration ditches**
	AMP description	A trench or infiltration ditch is a deep and narrow ground excavation. Dug along contour lines, trenches and infiltration ditches are used to harvest surface water runoff and trap sediment, limiting soil erosion and often leading to progressive terrace formation.
	Example 1 name	Contour trenches with bunds
	Example 1 description	A 1.5 m wide trench is dug along contour lines with the soil piled in a bund alongside to reduce the velocity of runoff, conserve moisture in situ and increase ground water recharge. It is appropriate for use in light soils.
	Example 2 name	Soil-faced deep trench bunds
	Example 2 description	A deep trench is dug along contour lines with the soil piled in a compacted bund on the downslope side to harvest surface water and sediment runoff.
	Example 3 name	Contour tied trenches
	Example 3 description	Trenches with tied downslope soil bunds are constructed along contour lines to trap surface water runoff and sediment from degraded uplands.
	Example 4 name	Contour tied trenches with uphill bund

	Example 4 description	A contour trench is excavated along contour lines to trap runoff and increase infiltration. The trenches are tied, and the excavated soil piled upslope to speed up terrace formation.
	Example 5 name	Infiltration trenches
	Example 5 description	A trench with a trapezoidal cross-section is excavated along contour lines to trap runoff and increase infiltration with the aim of improving groundwater recharge and plant growth.
	Example 6 name	Retention ditches
	Example 6 description	A larger infiltration or retention ditch is constructed to trap runoff and increase infiltration for the benefit of the crops.
	Example 7 name	Infiltration ditches and ponding banks
	Example 7 description	A larger scale construction of contour ditches and ponding banks is made to improve rainwater infiltration, groundwater recharge and enhance plant growth while safely discharging excess water to avoid erosion.
3	**AMP name**	**Terraces**
	AMP description	Terraces are a relatively flat areas constructed on sloping land to reduce surface water runoff and erosion and enable more effective farming. A terraced landscape resembles a large flight of steps with the risers often reinforced with stone to prevent erosion.
	Example 1 name	Traditional earth bench terraces
	Example 1 description	Level bench terraces are constructed with risers protected by fodder grasses, used for (irrigated) crop production.
	Example 2 name	Small level bench terraces
	Example 2 description	Narrow terraces are constructed for growing perennial and horticultural crops on hillsides.
	Example 3 name	Agricultural terraces with dry stone walls
	Example 3 description	Dry stone walls are built to reinforce the face of the terrace, creating agricultural land, minimizing soil erosion and retaining soil moisture on steep mountain slopes.
	Example 4 name	Graded stone wall terraces
	Example 4 description	Stone walls are built by digging a shallow trench into which large foundation stones are laid followed by rows of smaller stones. New stones are added to the walls each year to preserve and maintain them. The same methods have been used for generations.
	Example 5 name	Loess terraces
	Example 5 description	Level bench terraces are built on highly erodible loess soils. Terraces like this allow cultivation but should be maintained properly to avoid topsoil losses.
	Example 6 name	Small bench terraces
	Example 6 description	Small bench terraces are constructed along contour lines with a permanent green cover stabilizing the steep terrace face.
	Example 7 name	Bench terraces
	Example 7 description	Wide bench terraces like this require substantial soil mobilization and can only be constructed in deep soils. Large individual terrace plots facilitate cultivation.
	Example 8 name	Stone wall bench terraces

	Example 8 description	Bench terraces supported by stone walls like these are very labour intensive to construct but lead to less loss of land and highly stable terraces.
4	**AMP name**	**Trashlines**
	AMP description	Trashlines are strips of crop residues and/or weeds laid in bands across the slope of annual crop fields to conserve soil and water and to incorporate organic matter into the soil. They form semi-permeable barriers that decrease the surface water runoff velocity and increase the infiltration while allowing passage of excess runoff.
	Example 1 name	Long-duration trashlines
	Example 1 description	Long-duration trashlines are left in place for four seasons before being dug into the soil when they are significantly decomposed. New trashlines are then established between the former lines.
	Example 2 name	Mobile thrashlines
	Example 2 description	Mobile thrashlines are laid out anew annually or biannually. Partially non-decomposed, the material from the old trashlines continues to perform a role as mulch.
	Example 3 name	Squared trashlines
	Example 3 description	Trashlines are placed to form a rectangular basin, with main lines constructed along the contour. The technique is multi-purpose including water harvesting, soil trapping, and soil fertility improvement.
	Example 4 name	
	Example 4 description	
	Example 5 name	
	Example 5 description	
	Example 6 name	
	Example 6 description	
5	**AMP name**	**Half-moon terraces**
	AMP description	Half-moon terraces are stone or earth embankments built in the shape of a semicircle with the tips of the bund on the contour. They can be used for individual shrubs or trees or arranged in staggered rows, so that overflow from one row runs downslope into the next. Their purpose is to collect and concentrate surface water runoff to increase water availability for plant growth.
	Example 1 name	Semi-circular earth bunds
	Example 1 description	Semi-circular earth bunds are used to rehabilitate degraded, denuded and hardened land for crop growing, grazing or forestry.
	Example 2 name	Half-moon terraces for trees
	Example 2 description	Half-moon shaped basins are dug in the soil to collect water and enhance moisture availability. Smaller, closely spaced half-moons are better for growing trees and shrubs.
	Example 3 name	Mini half-moon stone terraces
	Example 3 description	Mini terraces with a stone wall at the edge, spaced in a staggered pattern are used for planting fruit trees. The aim is to conserve water and increase fertilizer efficiency by reducing runoff losses.
	Example 4 name	Large semi-circular stone bunds

	Example 4 description	Semi-circular stone bunds are constructed by excavating a foundation and building a stone embankment that tapers in height towards the tips in order to enable the removal of excess runoff. Within the semicircle 1-3 tree planting pits can be excavated.
	Example 5 name	La Geria half-moons for vines
	Example 5 description	At La Geria, vines are planted in cone-shaped pits that are protected against the prevalent wind by half-moon stone bunds. Vines are rooted into fertile soil that is covered with a layer of mineral-rich volcanic ash.
	Example 6 name	
	Example 6 description	
6	**AMP name**	**Gully rehabilitation**
	AMP description	Gully rehabilitation serves to mitigate gully development or rehabilitate degraded lands. Frequently the aim is to reduce surface water flow velocity and/or protect gully banks and heads through construction of checkdams. While interventions do have on-site effects, they are often undertaken with off-site interests in mind.
	Example 1 name	Check dams from stem cuttings
	Example 1 description	Stem cuttings from trees that have the ability to strike root are used to rehabilitate gullies. These living barriers retard concentrated runoff and fill the gullies gradually with sediment.
	Example 2 name	Gully control by plantation of Atriplex
	Example 2 description	Gullied slopes are rehabilitated by a plantation of Atriplex halimus fodder shrubs. The treated area is fenced off to facilitate plant growth and diversity.
	Example 3 name	Filling gullies with vegetative structures
	Example 3 description	Barriers of willow branches and live mulberry cuttings are used to trap loess soil eroded by runoff to reclaim and infill eroded gullies.
	Example 4 name	Gully rehabilitation using gabions and vegetative cover
	Example 4 description	Gabions with plantations of spanish drok (Spartium junceum L) are used to stabilize a gully.
	Example 5 name	Gully control through silt fences, erosion blankets and brush packing
	Example 5 description	Gullies with active erosion are rehabilitated by re-sloping the banks of the gully to manage the energy of the water entering the system. Bare soil is protected from erosion by covering it with erosion blankets and brush packing.
	Example 6 name	Permeable rock dams
	Example 6 description	Permeable rock dams are built in gullies serve to restore seriously degraded farmland and forest/rangeland. They slow the flow of floodwaters and spread the water over adjacent land.
7	**AMP name**	**No tillage**
	AMP description	No tillage is a soil management practice where, except for a small furrow for planting and/or placement of fertilizers, the soil is not disturbed by tillage. Ideally, residues from previous crops remain on the soil surface and weeds are managed by other means than burying/tillage. The main goal is erosion control through better soil structure and soil surface cover.
	Example 1 name	Direct drilling

	Example 1 description	Specialist direct seed drills place the seeds in the residues of the previous crop without the need for ploughing.
	Example 2 name	No-till perennial cropping
	Example 2 description	In an orchard under no tillage only occasional use is made of disc-ploughing, mowing, grazing or herbicide application for weed control.
	Example 3 name	Animal draft zero tillage
	Example 3 description	An animal drawn mechanical planter is used to plant directly in untilled soil to minimize soil disturbance and leave a cover of crop residues to conserve the soil and water.
	Example 4 name	
	Example 4 description	
	Example 5 name	
	Example 5 description	
	Example 6 name	
	Example 6 description	
8	**AMP name**	**Minimum tillage**
	AMP description	Minimum tillage is a soil conservation practice that aims to reduce soil disturbance to the minimum necessary for successful crop production while not turning the soil over. It is a contrast to intensive tillage which changes the soil structure using ploughs.
	Example 1 name	Minimizing tillage operations
	Example 1 description	Tillage is reduced to a combined, one-pass seedbed preparation and sowing operation. Additional shallow stubble cultivation may be used after harvesting.
	Example 2 name	Non-inversion tillage
	Example 2 description	Non-inversion tillage is a tillage method that does not turn the soil over. Usually only the upper 10-18 cm of the soil surface is tilled.
	Example 3 name	Alternate inter-row minimum tillage in vineyards
	Example 3 description	Minimum tillage in vineyards is performed in alternate inter-row zones, to prevent soil compaction and maintain partial vegetation cover.
	Example 4 name	
	Example 4 description	
	Example 5 name	
	Example 5 description	
	Example 6 name	
	Example 6 description	
9	**AMP name**	**Contour ploughing**
	AMP description	In the practice of contour ploughing the soil is ploughed along the contour, perpendicular to the direction of slope. The aim is to decrease the velocity of surface water runoff and soil erosion by concentrating water in the furrows and increasing infiltration. It is especially important at the beginning of the rainy season when there is little vegetation cover.
	Example 1 name	Conventional contour ploughing

	Example 1 description	Ploughing and all cultivation is carried out along the contour lines, reducing soil erosion.
	Example 2 name	Contour-planted trees intercropped with annual crops
	Example 2 description	Olive trees, planted in lines along the contour, are intercropped with an annual crop.
	Example 3 name	Contour strip tillage
	Example 3 description	Contour tillage is combined with strip tillage enabled through GPS tractor guidance combines residue cover and tillage along contour lines to reduce soil erosion.
	Example 4 name	
	Example 4 description	
	Example 5 name	
	Example 5 description	
	Example 6 name	
	Example 6 description	
10	**AMP name**	**Strip tillage**
	AMP description	Strip tillage is a soil cultivation practice that limits tillage to strips of land in which a crop is planted. The inter-strip area is not tilled with benefits for soil structure, moisture conservation, erosion control, prevention of weeds, and operational cost savings.
	Example 1 name	Maize strip tillage
	Example 1 description	Soil strips 30 cm wide are cultivated and sown with maize seeds. The area between strips is left with a protective vegetation cover.
	Example 2 name	Strip tillage conservation farming
	Example 2 description	A strip of soil is loosened with a strip tillage tool pulled by a draft animal to reduce soil disturbance and improve soil and water conservation.
	Example 3 name	Strip tillage wheat cultivation
	Example 3 description	Wheat is sown in rows with using a strip tiller machine immediately after rice harvesting so that retained soil moisture can germinate the wheat seeds.
	Example 4 name	
	Example 4 description	
	Example 5 name	
	Example 5 description	
	Example 6 name	
	Example 6 description	
11	**AMP name**	**Subsoiling**
	AMP description	Subsoiling is a tillage practice that loosens the subsoil with minimum disturbance of the topsoil. It is primarily used to control plough pans.
	Example 1 name	Subsoiling with mulching
	Example 1 description	A subsoil plough is used to loosen subsoils while leaving the surface soil undisturbed. A stubble mulch is kept on the soil surface.
	Example 2 name	No tillage preceded by subsoiling

	Example 2 description	A subsoiler at a 50 cm depth is used every 5 years in combination no tillage cultivation.
	Example 3 name **Example 3 description**	Decompactor A decompactor is a large subsoiler implement that lifts the soil at a depth of 30-40 cm by 5 cm and moves it sideways; hardpan soil layers are broken so that the permeability and structure of the soil is greatly improved.
	Example 4 name Example 4 description	
	Example 5 name Example 5 description	
	Example 6 name Example 6 description	
12	**AMP name** **AMP description**	**Roughening the soil surface** Roughening the soil surface is a temporary erosion control practice that increases the relief of a bare soil surface to reduce wind velocity, surface water runoff, increase infiltration and trap sediment.
	Example 1 name **Example 1 description**	Tilling strips Strips are tilled across 50% of the field perpendicular to the expected wind direction. This is a temporary wind erosion control measure, the success of which depends on climatic, soil, and cover conditions.
	Example 2 name **Example 2 description**	Emergency tillage As a last resort wind erosion control practice, emergency tillage makes the soil surface rougher by producing clods and surface ridges that trap moving soil particles.
	Example 3 name Example 3 description	
	Example 4 name Example 4 description	
	Example 5 name Example 5 description	
	Example 6 name Example 6 description	
13	**AMP name** **AMP description**	**Raised beds** Use of raised beds is an agronomic method which seeks to create more favourable environmental conditions for germination and crop development. It can be used in areas of poor drainage, salt accumulation and strong wind erosion.
	Example 1 name **Example 1 description**	Raised beds Raised beds 1 m wide and 15 cm high are constructed to ease operations such as watering and weeding. They reduce water losses and keep roots from getting waterlogged.
	Example 2 name **Example 2 description**	Terra Preta raised garden beds Raised beds made from Terra Preta (an anthrosol) are constructed perpendicular to the slope direction. Terra Preta is formed by layering

		organic matter with biochar (charcoal) and ash. The beds are highly fertile and can be used to grow crops in areas where the soil is severely degraded.
	Example 3 name **Example 3 description**	Double dug beds Infertile sub-soil is excavated and replaced with topsoil mixed with farmyard manure to form the planting bed. The increased soil depth provides higher moisture retention in the rootzone.
	Example 4 name **Example 4 description**	Raised beds to enable farming in marshland Wide raised beds and ditches are constructed on marshy land. By building up the beds over a period of years it becomes possible to grow a variety plants and seedlings and the soil becomes stable enough to support tree crops.
	Example 5 name Example 5 description	
	Example 6 name Example 6 description	
14	**AMP** **AMP description**	**Avoidance of traffic** Traffic on wet soil causes soil compaction. Where it is physically and economically possible traffic should be avoided: wet soil should not be ploughed or crossed by machines, carts or livestock.
	Example 1 name **Example 1 description**	Umbilical slurry system with wide spreaders Wide slurry spreaders, in which umbilical systems are connected to a tank through a draghose, avoid traffic on large parts of the field and hence reduce compaction.
	Example 2 name Example 2 description	
	Example 3 name Example 3 description	
	Example 4 name Example 4 description	
	Example 5 name Example 5 description	
	Example 6 name Example 6 description	
15	**AMP** **AMP description**	**Controlled traffic** Controlled traffic is a method for reducing soil compaction by confining all heavy traffic to permanent uncropped wheel tracks or tramlines. It can be used as an element of precision agriculture.
	Example 1 name **Example 1 description**	No tillage with controlled traffic All heavy traffic is confined to permanent uncropped wheel tracks or tramlines. This is facilitated by all farm equipment sharing the same wheelbase width. Between the tramlines no tillage cultivation is used.
	Example 2 name	Single wheel passage

	Example 2 description	The three-wheeled, self-propelled slurry applicator causes less compaction than the usual tractor/trailer combination by reducing the area of soil that experiences more than one wheel passage.
	Example 3 name	On-land ploughing
	Example 3 description	On-land ploughs are used to plough while the tractor pulling it is driving next to (rather than in) the furrow. This avoids compaction of the cultivated soil.
	Example 4 name	
	Example 4 description	
	Example 5 name	
	Example 5 description	
	Example 6 name	
	Example 6 description	
16	**AMP**	**Respect wheel load carrying capacity**
	AMP description	Wheel load carrying capacity is a measure of soil strength. Wheel load is calculated for specific tyres and inflation pressures and, to avoid soil stress, should not exceed carrying capacity. It is a useful and easily interpreted parameter for portraying compaction risk and is therefore respecting it is an effective guide for preventing soil compaction.
	Example 1 name	Modest wheel loads and inflation pressures
	Example 1 description	Modest wheel loads and tyre inflation pressures result in higher soil pore volume, lower penetration resistance and higher hydraulic conductivity than a higher wheel load.
	Example 2 name	Wide tires
	Example 2 description	Lower weight tractors with wide tyres distribute wheel load, resulting in less soil compaction.
	Example 3 name	Assess risk of soil compaction
	Example 3 description	Terranimo® is a computer model that predicts the risk of soil compaction by farm machinery for real operating conditions. It classifies this risk, helping the farm manager to decide on the use of agricultural machines to avoid soil structure damage.
	Example 4 name	Tractors on tracks
	Example 4 description	Tracks distribute pressure over a larger soil surface helping to avoid compaction (under dry conditions).
	Example 5 name	
	Example 5 description	
	Example 6 name	
	Example 6 description	
17	**AMP**	**Claying soils**
	AMP description	Claying soils is the practice of adding and mixing (specific types of) clay to soil to improve plant growth and health. The type and quantity of clay added depends on the current soil composition, the climate and type of crop.
	Example 1 name	Clay spreading

	Example 1 description	Carry graders are used to excavate the clay subsoil and spread it in strips across the field. The source of the clay-rich subsoil needs to be located near the site of application.
	Example 2 name **Example 2 description**	Clay spading Clay spading involves shallow delving tines that penetrate the soil to a depth of 50 cm. Rotary spaders, deep-rippers or shallow delving can be used to lift the in situ subsoil clay.
	Example 3 name **Example 3 description**	Claying to reduce water repellence Claying is used to remediate water repellence by incorporating clay-rich soil into water repellent topsoil. This is achieved by either importing clay rich soils or mixing different soil layers.
	Example 4 name Example 4 description	
	Example 5 name Example 5 description	
	Example 6 name Example 6 description	
18	**AMP** **AMP description**	**Adding sand** Adding sand is the practice of spreading sand or sandy soil on agricultural soil to improve drainage, increase infiltration and reduce evaporation. It may also help to increase soil depth and add nutrients to degraded soil.
	Example 1 name **Example 1 description**	Adding white sand White sand is added to soil to improve infiltration and reduced cracking of topsoil, leading to increased moisture in subsoil. White soil also reduces evaporation (less absorption of sunlight) and repels insects.
	Example 2 name **Example 2 description**	Adding red soil Adding red (fertile, nutrient rich) valley soil to degraded soil on slopes increases the soil depth and adds nutrients. It combats erosion and nutrient depletion.
	Example 3 name **Example 3 description**	Creating a sand substrate Sand is brought from a nearby source to create a new substrate for tree crops that require permeable, light-textured soils with a low clay content.
	Example 4 name Example 4 description	
	Example 5 name Example 5 description	
	Example 6 name Example 6 description	
19	**AMP** **AMP description**	**Soil conditioners** Applied in a thin protective layer, soil conditioners can stabilize a soil surface protecting it from wind and water erosion, retaining soil moisture and/or minimizing evaporation for some weeks. Soil conditioning products are based on liquid polymers, lignite wax or by-products from the sugar and paper industry.

	Example 1 name **Example 1 description**	Biosolids Biosolids (treated sewage sludge) are applied as a protective, fertilizing layer to the topsoil. Their use needs to be controlled because long-term application increases the amounts of heavy metals and other trace elements in the soil.
	Example 2 name **Example 2 description**	Paper Crumble Paper Crumble is a by-product of the paper industry consisting of odourless woody fibres. When spread on agricultural fields it boosts organic matter content and improves the soil structure of arable land.
	Example 3 name **Example 3 description**	Superabsorbant polymers Superabsorbant polymers are functionally inert polymers with good water absorption and holding capacity. Spread on the soil surface they turn into a natural gel and protect the soil beneath.
	Example 4 name Example 4 description	
	Example 5 name Example 5 description	
	Example 6 name Example 6 description	
20	**AMP** **AMP description**	**Liming** Liming is the application of calcium- and magnesium-rich materials such as marl, chalk, limestone, or hydrated lime to soil. These alkaline materials neutralize soil acidity, often improving plant growth and increasing the activity of soil bacteria. However, over-application may result in harm to plants.
	Example 1 name **Example 1 description**	Agricultural lime Agricultural lime (ground limestone or chalk) is spread on the soil surface as a cheap method of adjusting soil pH. Varying release rates help to regulate the pH over several years.
	Example 2 name **Example 2 description**	Granulated lime Granulated lime is ground much more finely (< 0.1mm) than agricultural lime and then formed into granules. It reacts faster than agricultural lime and allows field pH to be kept more precisely at the desired level.
	Example 3 name **Example 3 description**	Dolomitic lime Crushed dolomitic limestone contains a mixture of calcium and magnesium carbonates. It is specifically recommended for use in magnesium-deficient soils and, if it is cheaper, is an alternative to agricultural lime.
	Example 4 name **Example 4 description**	Gypsum Gypsum (calcium sulphate) changes soil pH very slightly. It is more soluble than lime so the calcium can move further down into the soil, inhibiting aluminium uptake at depth, promoting deeper rooting and allowing plants to take up more water and nutrients.
	Example 5 name **Example 5 description**	Shell grit Used as a pH regulator, shell grit has a long-term (>3 years) and long-lived effect, so that micro-organisms in the soil are not disturbed. Being much coarser than lime, grit is not so susceptible to wind erosion.

	Example 6 name Example 6 description	
21	**AMP** **AMP description**	**Alkalinity management** Alkalinity management is needed in agricultural soils with pH >8.4. This occurs in poorly drained soils where evaporation concentrates sodium bicarbonate (alkali) at or near the soil surface. Management consists of improving drainage and/or acidification (either by applying calcium as gypsum or by applying an acid to dissolve calcium already in the soil). This is followed by leaching of the salts.
	Example 1 name **Example 1 description**	Calcareous soils management Water-logged fields with high pH are reclaimed for cultivation by a combination of drainage channel construction and injecting ammonia as an acidifying agent to dissolve calcium carbonates.
	Example 2 name **Example 2 description**	Applying gypsum Gypsum (calcium sulphate) is applied to alkaline soils to provide soluble Ca^{2+} to displace Na^{+} and maintain infiltration rates. Mixing gypsum to a depth of 15 cm is more effective than surface application. Flushing of salts is also needed.
	Example 3 name **Example 3 description**	Applying elemental sulphur, aluminum sulphate or pyrite Sulphur is applied to alkaline soils to lower the pH by biological oxidation, producing sulphuric acid. Cost-effectiveness may be an issue, but sulphur and sulphates may reduce pH faster than gypsum.
	Example 4 name Example 4 description	
	Example 5 name Example 5 description	
	Example 6 name Example 6 description	
22	**AMP** **AMP description**	**Straw interlayer burial** This is a measure in which a straw interlayer is buried in the soil by tillage to act as a barrier to upward moving salts. Straw (e.g. from maize) is buried at a depth of 20-40 cm at a rate of 6 tonnes per hectare.
	Example 1 name **Example 1 description**	Straw interlayer burial A straw layer is buried deep in the soil to serve as a water and salt transport barrier, inhibiting evaporation-induced movement of salts from the subsoil and shallow groundwater to the topsoil.
	Example 2 name Example 2 description	
	Example 3 name Example 3 description	
	Example 4 name Example 4 description	
	Example 5 name Example 5 description	

	Example 6 name Example 6 description	
23	**AMP** **AMP description**	**Conservation agriculture** Conservation agriculture aims to achieve sustainable and profitable agriculture through the application of three principles: minimal soil disturbance, permanent soil cover and crop rotations.
	Example 1 name **Example 1 description**	Conservation agriculture No tillage and residue management are used to improve soil fertility and increase sustainable crop production.
	Example 2 name **Example 2 description**	Large-scale conservation agriculture Maize and soy seeds are planted directly into the soil with the previous crop stubble remaining in situ. This reduces soil erosion and saves costs.
	Example 3 name **Example 3 description**	Conservation agriculture for maize-legume systems Maize seeds are planted directly into a dense legume (velvet bean) cover crop. The practice addresses challenges of land degradation, low crop yields, low incomes, high production costs and climate change.
	Example 4 name **Example 4 description**	Conservation agriculture for smallholders Residues of the previous crop are not removed but left on the soil surface. The new crop is planted directly through the mulch using minimum tillage.
	Example 5 name Example 5 description	
	Example 6 name Example 6 description	
24	**AMP** **AMP description**	**Permanent green cover in orchards** An underlayer of planted or spontaneous vegetation keeps the soil permanently covered, protecting it from the physical impact of water, wind and exposure to the sun. It is relevant for agricultural land under permanent crops that would otherwise have a bare surface.
	Example 1 name **Example 1 description**	Green cover in vineyards A natural grass cover is established in vineyards to control soil erosion, reduce the use of herbicides and increase biodiversity.
	Example 2 name **Example 2 description**	Grass cover in orchard A permanent cover of spontaneous or sown perennial grasses is established between rows in orchards to prevent water erosion and limit the leaching of nutrients (particularly nitrates) and pesticides.
	Example 3 name **Example 3 description**	Cover crops for nematode management A five-species mix of radish and mustard is established between the rows of walnut trees. In addition to the fertility and soil structure benefits, the cover crop helps create an environment beneficial to soil microbes and reduces nematode pressure.
	Example 4 name Example 4 description	
	Example 5 name Example 5 description	

	Example 6 name Example 6 description	
25	**AMP** **AMP description**	**Cover crops** Cover crops are crops planted after the harvest of the primary crop or as an understorey between crops. They are used primarily to manage soil erosion but may also increase soil organic matter, improve water infiltration and provide species diversity in the cropping system.
	Example 1 name **Example 1 description**	Cover crop in maize Cover crops are planted between rows of a maize crop with the primary aim of improving or maintaining ecosystem quality.
	Example 2 name **Example 2 description**	Cover crops in organic vineyard Minimum tillage with rye (Secale cereale) and false brome (Brachypodium distachyon) used as cover crops protects the soil against erosion and increases soil organic matter content.
	Example 3 name **Example 3 description**	Cover crops in olive groves A false brome (Brachypodium distachyon) cover crop is planted the first year to protect against water erosion. Thereafter additional grasses, barley and sainfoin (Onobrychis viciifolia) are planted annually in November.
	Example 4 name **Example 4 description**	Continuous soil cover on croplands Cover crops are sown after the main crop has been harvested to maintain a continuous soil cover. At the end of the crop cycle, they are ploughed in as green manure to improve soil organic matter content, nutrient cycle and fertility.
	Example 5 name **Example 5 description**	Intercropping of grass and maize to increase soil organic matter When the main maize crop has reached knee height, Italian rye grass is sown as an intercrop. The grass is ploughed into the soil several months after the maize harvest, improving soil organic matter content and reducing nutrient leaching.
	Example 6 name Example 6 description	
26	**AMP** **AMP description**	**Grassland renewal** Grassland renewal is usually carried out if the herbage production or quality of the existing sward is lower than its potential. Low performance is often caused by a single or a series of incidents.
	Example 1 name **Example 1 description**	Over-seeding Without taking it out of production, seed is drilled into existing grassland in a process called over-seeding or stitching in. Livestock is allowed on the over-seeded ley after ten days when the new seedlings have established.
	Example 2 name **Example 2 description**	Intensive grazing areas on low productive slopes Soil is ploughed in the autumn and vetch and/or oats are sown. The growing plants are grazed in spring.
	Example 3 name **Example 3 description**	Postpone grassland renewal The ploughing of a rotational grassland field is postponed for one or two years to reduce nutrient losses and organic matter decomposition. Grassland is kept for 6-7 years instead of 5.

	Example 4 name	Pasture manuring
	Example 4 description	Manure is applied to increase grass recovery and reduce shrub encroachment. The practice is used on animal husbandry farms with either deep litter housing systems or manure heaps.
	Example 5 name	
	Example 5 description	
	Example 6 name	
	Example 6 description	
27	**AMP**	**Rangeland rehabilitation**
	AMP description	Rehabilitation through fertilization and reseeding is an effective approach to restoring degraded rangelands. It includes the application of organic and inorganic fertilizers and direct seeding with native perennial grasses. The practice enhances soil cover and recovers rangeland productivity.
	Example 1 name	Restoration of degraded rangeland
	Example 1 description	Treatments including over-seeding with grass and supplementing with lime, cattle dung and “brush packing” are used to eradicate invasive species and revegetate degraded rangelands.
	Example 2 name	Rehabilitation and protection
	Example 2 description	Fencing and seeding with locally adapted herbaceous plants are used to rehabilitate degraded rangeland.
	Example 3 name	Fertilizing and re-seeding
	Example 3 description	Small amounts of inorganic fertilizer and seeds are spread on degraded rangelands.
	Example 4 name	Rehabilitation with alfalfa
	Example 4 description	Alfalfa seeds are broadcast sown on degraded pasture. The area is quarantined for three years to allow the pasture to restore sufficiently.
	Example 5 name	Community supported pasture and rangeland rehabilitation
	Example 5 description	The selection and reintroduction of key pasture and fodder species to strategic areas is supported by structural works and stakeholder participation.
	Example 6 name	Bush thinning and manual or mechanized biomass processing
	Example 6 description	Bushes are thinned manually or by a semi-mechanized means and the cut material is left to dry or chipped. Bush thinning is carried out to restore degraded rangeland by stimulating the re-growth of grasses previously suppressed by excess bush.
28	**AMP**	**Planted fallow**
	AMP description	Grasses or cover crops are planted during extended fallow periods to help increase the fertility of degraded soils. Planted fallows are especially relevant if the process of natural vegetation recovery is expected to be slow or undesirable.
	Example 1 name	Fallow restoration by no tillage seeding
	Example 1 description	No tillage disc harrowing and low density seeding of forage grass are used to restore natural steppe vegetation for fodder production and biodiversity conservation.
	Example 2 name	Catch crops

	Example 2 description	Catch crops are planted to retain and recycle soil nutrients and prevent leaching. When the catch crop is terminated, these nutrients are then released back into the soil for the following crop.
	Example 3 name	Dedicating a full season to green manures
	Example 3 description	Annual green manure species are grown for a full season as part of the crop rotation. This allows flexibility in timing the termination of the green manure and planting the next crop, e.g. to allow soil moisture to be replenished in dry areas.
	Example 4 name	Planted fallows for weed management
	Example 4 description	Dense cover crops are planted during the fallow period, suppressing the majority of the weeds and significantly reducing their ability to reproduce.
	Example 5 name	Improved fallow
	Example 5 description	Fallow is enriched with fast-growing trees, shrubs or vines. This agroforestry practice has its origins in slash-and-burn agriculture. Improved fallow accelerates the process of soil rehabilitation.
	Example 6 name	Multiple-season green manures
	Example 6 description	Perennial legume green manures are planted and allowed to grow for multiple seasons in order to improve soil fertility, reduce soil compaction, erosion and weed pressure, and promote biodiversity. The trade-off with not producing a crop has to be considered, but green manures can provide fodder.
	Example 7 name	Leguminous crop in plots temporarily set outside the crop rotation
	Example 7 description	A plot is cultivated with perennial legumes and set temporarily outside the crop rotation for 4-5 years to recover its soil fertility and reduce the need for biocides while providing supplemental income.
	Example 8 name	Perennial herbaceous fodder plants
	Example 8 description	Perennial herbaceous fodder plants such as alfa-alfa and esparzet are cultivated for fodder production and to fertilize unproductive cropland. They can be harvested for 6-10 years without tillage.
29	**AMP**	**Vegetative strips**
	AMP description	Vegetative strips consisting of grasses or shrubs planted along contour lines are used as a measure to control erosion, reduce and filter runoff and preserve sediment.
	Example 1 name	Slope subdivision with a grass strip
	Example 1 description	A field at risk of erosion by water is divided by a grass strip that prevents soil loss and further damage to the field and downstream areas and infrastructure during heavy rainfall.
	Example 2 name	Planted vegetative strips
	Example 2 description	Economic crops and forage are planted in strips along contour lines to control soil loss through erosion.
	Example 3 name	Natural vegetative strips
	Example 3 description	Within individual plots, strips of land along contour lines are left unploughed in order to form permanent, cross-slope barriers of naturally established grasses and herbs.
	Example 4 name	Progressive bench terraces formed by a vetiver hedge system and trees

	Example 4 description	Vetiver grass hedges are planted along contour lines. Successive deposits of sediment collect on the upslope side. To improve slope stabilization in the long term, new trees are planted along the downslope edge of the hedges.
	Example 5 name	Grass strips
	Example 5 description	Grass strips are planted to slow runoff, increase infiltration and retain sediment. The strips get bigger as the sediment builds up which maintains their capacity to retain water.
	Example 6 name	Aloe vera living hedges
	Example 6 description	Living hedges of Aloe vera are planted along contour lines to form a barrier that efficiently retains eroded sediments and surface runoff. The hedges stabilize the soil and improve infiltration and soil structure.
30	**AMP**	**Riparian buffer zones and filter strips**
	AMP description	A riparian buffer zone/filter strip is an area of land kept under permanent vegetation to help maintain soil and surface water quality. Buffer zones trap sediment and enhance filtration of nutrients and pesticides by slowing runoff that could enter the local surface waters.
	Example 1 name	Grass-covered riparian buffer strips
	Example 1 description	A grass strip is established along cropland waterways to prevent soil and nutrient losses and eutrophication of downstream waterbodies.
	Example 2 name	Tree row and grass strip to sustain riparian zones
	Example 2 description	Tree lines with adjacent grass strips are planted to form a productive and protective riparian area retaining sediments and chemicals used on the field, preventing river pollution and stabilizing the river bank.
	Example 3 name	Cultivation of bamboo
	Example 3 description	Bamboo is planted along the river bank to fix the soil with its deep and widespread roots and control soil erosion during the rainy season when there are high water levels and increased flow velocity.
	Example 4 name	Vegetative filter strip
	Example 4 description	Narrow grassed waterways are installed on the edges of agricultural fields. Besides reducing sediment in storm water runoff, these vegetative filter strips also reduce surface water contamination.
	Example 5 name	Buffer zones
	Example 5 description	Agroforestry and multipurpose trees are planted in buffer zones to protect water bodies and wetland riparian habitats.
	Example 6 name	Fenced natural waterways
	Example 6 description	Natural waterways are fenced in pasture areas. This is very effective at reducing contaminant loads by 10 to 90 %, depending on the nature of the contaminants and local situation.
31	**AMP**	**Shelterbelts**
	AMP description	Shelter belts or windbreak plantations are usually made up of one or more rows of trees or shrubs providing shelter from wind and protection from erosion. They are commonly planted in hedgerows around the edges of fields on farms.
	Example 1 name	Shelterbelts as farmland boundaries in sandy areas
	Example 1 description	Belts of trees are planted in a rectangular grid pattern or in strips, within and on the periphery of farmland, to act as windbreaks.

	Example 2 name **Example 2 description**	Shelterbelts made of leguminous trees and shrubs Shelterbelts of leguminous trees and shrubs are planted to protect annual crops from wind erosion. Soil properties can be improved through nitrogen fixation and the provision of organic matter (leaves).
	Example 3 name **Example 3 description**	Multifunctional windbreaks Herbaceous plants or trees are planted along property boundaries to serve as windbreaks and as sources of fodder and fuel.
	Example 4 name **Example 4 description**	Bamboo for fencing and wind protection Bamboo is planted for fencing agricultural land, protecting it from strong winds and reducing the need to exploit the forest for wood. Bamboo shoots are also a source of nutrition and income generation.
	Example 5 name **Example 5 description**	Pasture-protective forest shelterbelts Wide strips of large shrubs are cultivated perpendicular to the prevailing wind direction to protect pasture. The shelterbelts increase the ecological complexity and forage capacity of desert pastures.
	Example 6 name **Example 6 description**	Live fences in areas with strong winds Shrubs such as sea buckthorn are planted as live fences to protect the cultivation of grain, potato and forage crops in areas with strong winds. The live fences also keep livestock out of the field.
	Example 7 name **Example 7 description**	Wind forest strips on sandy soils A shelterbelt of different varieties of willow, poplar and sea-buckthorn is established to reduce wind speed and protect irrigated cropland from sand deposition.
	Example 8 name **Example 8 description**	Boundary trees as windbreakers Trees (mainly Grevilia robusta) are planted about 1m apart along the edges of fields to protect against wind.
32	**AMP** **AMP description**	**Semi-natural landscape elements** Semi-natural landscape elements include trees or rows of trees, bushes, springs, dikes, hedges, hollow roads, and (parts of) fields that are set aside such as ditches and pools. These elements often give a specific character to a region. They attract fauna and flora that can be natural enemies of pests.
	Example 1 name **Example 1 description**	Rows of trees Rows of trees help protect soils from erosion, attract fauna, provide shade and tree products.
	Example 2 name **Example 2 description**	Farmstead boundaries Farmstead boundaries provide habitat and feeding resources for wildlife and facilitate mobility of wildlife through the landscape.
	Example 3 name **Example 3 description**	Herb strips Herbs are planted in strips to provide additional revenue and as an important food source for pollinator species.
	Example 4 name **Example 4 description**	Field margins Uncultivated field margins provide habitat and feeding resources for wildlife, protect other features (e.g. hedgerows, watercourses) from farm operations, and act as wildlife corridors.
	Example 5 name	Dry stone walls

	Example 5 description	Dry stone walls are an important habitat for small reptiles, insects, mammals and birds. They also affect the micro-climate and provide cultural character to the landscape.
	Example 6 name **Example 6 description**	Hedges Hedges are an important element of cultural landscapes, provide a host of resources for wildlife (food, shelter, nesting sites, refuge from farm operations) and create corridors across the landscape.
	Example 7 name **Example 7 description**	Shrub buffer strip with bund Belts of shrub or grass are planted on level bunds constructed along contour lines in gently sloping farmland.
	Example 8 name **Example 8 description**	Trees as buffer zones Trees are planted between different cultivation zones to prevent pests from crossing between zones and provide a haven for endemic flora and fauna.
33	**AMP** **AMP description**	**Strip cropping** In the practice of strip cropping, fields are partitioned into long narrow strips and cultivated as part of a crop rotation system. Strip cropping is mainly practiced to control pests by using crops which differ in pathogen susceptibility. It is sometimes also used to prevent soil erosion by wind or water.
	Example 1 name **Example 1 description**	Flower strips for biological pest control Flower strips are planted in rice fields as habitats for beneficial pest-controlling arthropods.
	Example 2 name **Example 2 description**	Strip farming Cereals are grown in a strip-fallow pattern to protect the soil from wind. Strips 50 m wide are oriented perpendicular to the wind direction. Cereal and fallow strips alternate from year to year.
	Example 3 name **Example 3 description**	Strip intercropping Several crops are grown in narrow (<3 m) strips next to each other. This intercropping increases biodiversity, inhibits the spread of pests and diseases and allows optimal use of nutrients, water and sunlight.
	Example 4 name **Example 4 description**	Contour strip cropping Alternate strips of row and cover crops or small grains are planted along contour lines. Runoff from the row crop strip is trapped in the neighbouring strip, reducing soil erosion and pollution of waterways.
	Example 5 name Example 5 description	
	Example 6 name Example 6 description	
34	**AMP** **AMP description**	**Deep rooted crops** Growing deep rooted crops can break up compacted soils and improve soil quality. Deep rooted crops can be perennial plants like alfalfa or annuals like forage radish. As part of a crop rotation, deep rooted crops also enable a more balanced soil fertility management.
	Example 1 name **Example 1 description**	Deep rooted cover crops

	Cover crops with well-developed rooting systems are specifically planted to improve soil structure through natural decompaction and increase carbon sequestration within the soil profile.
Example 2 name **Example 2 description**	Perennial shrubs The perennial Korshinsk pea shrub (Caragana korshinskii) is used to protect soil from water and wind erosion. It has long roots and can extract water from deep soil layers. Rhizobium in its root can increase soil fertility.
Example 3 name **Example 3 description**	Alfalfa intercropping in terraced fruit orchard Alfalfa and fruit trees are intercropped in a terraced orchard for fruit and fodder production and soil and water conservation. Because it fixes nitrogen, alfalfa also increases soil fertility.
Example 4 name **Example 4 description**	Biodrilling cover crops Dicotyledonous crops with long taproots like radish, rape and lupine are used to counter soil compaction because they create deep root channels by “biodrilling”, aiding infiltration, gas exchange, and rootability.
Example 5 name Example 5 description	
Example 6 name Example 6 description	
35 **AMP** **AMP description**	**Intercropping** Intercropping involves growing two or more crops in proximity. Intercropping is used to produce greater yield by making use of resources or ecological processes. Intercropping is also used as a method to spread production risk.
Example 1 name **Example 1 description**	Maize and beans Soybean and maize are planted together in the same field to increase soil fertility, yield and financial return. Soybean helps to fix nitrogen in the soil, reducing the net demand for fertilizers.
Example 2 name **Example 2 description**	Vegetables Alternate rows of different vegetables such as lettuce, pak choi, escarole, choy sum and morning glory are intercropped to reduce damage from insects.
Example 3 name **Example 3 description**	Orchard trees and wheat Wheat is intercropped in an existing orchard. Between the trees which are planted along contour lines, a 3 m wide grass strip is left uncultivated to control runoff and to protect the ground from splash erosion.
Example 4 name **Example 4 description**	Cashew nut trees and peanuts Intercropping of annual peanuts with cashew trees fills the free space of land between the trees, prevents soil erosion and improves soil fertility.
Example 5 name **Example 5 description**	Fruit trees and cash crops Intercropping of pineapple between mango and orange trees helps to maintain soil nutrients while enhancing potential economic benefits through producing a bigger variety of crops.
Example 6 name **Example 6 description**	Maize and chilli peppers Intercropping maize and the high value cash crop chilli peppers helps to control erosion, enhance water and nutrient use efficiency, control pests and diseases, and shows improved resilience to drought.

36	**AMP**	**Growing halophytes**
	AMP description	Halophytes are salt-tolerant plants. They can be used for human consumption, forage and animal feed or as oilseed and energy crops. They can also be used for desalination and phytoremediation purposes.
	Example 1 name	Halophytic grasses for rehabilitation of severely saline soil
	Example 1 description	Halophytic grasses (such as Dixie grass) are planted as a cover crop for the ecological restoration of severely salt-affected soil. The grasses maintain a soil cover, enhance biodiversity and can be used as cattle feed.
	Example 2 name	Salt-tolerant vegetables in salt-affected soil
	Example 2 description	Salt-tolerant vegetables (e.g. beets, radish, kale, spinach, tomato) are grown in saline soils on a rotational basis. Double-row beds minimize salt accumulation around the seeds with furrow irrigation.
	Example 3 name	Sea wattle (Acacia ampliceps) to remediate severely salt-affected land
	Example 3 description	The leguminous shrub Salt wattle (Acacia ampliceps) is planted on dikes in severely salt-affected land. Over time the soil becomes less saline, the shrubs improve the microclimate, understorey plant species improve and the branches can be used for forage and fuel.
	Example 4 name	Apocynum to protect and profit from saline soils
	Example 4 description	Drought- and salt-tolerant dogbane (Apocynum pictum and A. venetum) species are planted to protect barren saline soils from wind erosion. They are deep-rooted plants that tap groundwater and (importantly) are also cash crops.
	Example 5 name	Indigofera (Indigofera tinctoria) to restore marginal lands
	Example 5 description	Cultivation of Indigofera (Indigofera tinctoria) can restore degraded saline lands with low agricultural potential. The plant produces natural indigo dye that is of high commercial value.
	Example 6 name	Poplar trees for bio-drainage
	Example 6 description	Poplar trees, known for their tolerance to waterlogging and salinity, are planted to provide ‘bio-drainage' and wood. Excess water is rapidly taken up and transpired, improving conditions for annual crops.
37	**AMP**	**Crop rotation/diversification**
	AMP description	Crop rotation is the practice of growing different crops in succession on a piece of land to avoid exhausting the soil. It reduces soil erosion, increases fertility and yield, and controls weeds, pests and diseases.
	Example 1 name	Crop rotation with legumes
	Example 1 description	Legumes are included in a crop rotation with cereals and other crops because of their nitrogen fixation potential. Legumes help to maintain soil fertility and reduce the use of fertilizer.
	Example 2 name	Crop rotation to promote safe vegetables
	Example 2 description	Vegetables from different plant families are include in the rotation. The occurrence of pests and diseases is reduced, and crop production improved with reduced use of chemical fertilizers and pesticides.
	Example 3 name	Organic agriculture
	Example 3 description	Organic agriculture is based on a 5 year crop rotation with no use of artificial plant protection products and mineral fertilizers. Nitrogen is introduced via organic manure, legume crops and residues.

	Example 4 name **Example 4 description**	Cereals and fodder legumes (lupine) Lupine is included in a biennial crop rotation with cereals. Lupine is able to grow on poor and stony soils, it improves soil quality, controls erosion and provides fodder.
	Example 5 name **Example 5 description**	Rotation program A diverse rotation of at least five crops within a farm is used for more biodiversity and less intensive cultivation practice. There are positive impacts on the soil and reduced use of inputs.
	Example 6 name **Example 6 description**	Agroforestry community garden A rotation of horticulture (during the dry season) and millet (during the rainy season) is used within an agroforestry system, enclosed and protected by a live fence of Prosopis juliflora.
	Example 7 name **Example 7 description**	Diversification of crops in salinized soils with legumes and green manure An existing crop rotation is improved by including legumes and green manure: wheat/legumes/ green manure/cotton ensures year-round soil cover and slows down secondary salinization.
	Example 8 name **Example 8 description**	Crop diversification with the application of rotation techniques Crop diversification is achieved with rotating eleven crop varieties each with an average lifespan of 3 months: spring onions, anise basil, Cambodian mint, bok choy, choy sum, escarole, mint, long beans, cucumbers, bitter melons and lettuce.
38	**AMP** **AMP description**	**Herb-rich grassland** The provision of herb-rich grasslands give livestock a better mixture of minerals and trace elements during grazing, while also improving soil structure and below and aboveground biodiversity. Less supplements need to be added to the roughage and less fertilizer applied.
	Example 1 name **Example 1 description**	Productive herb-rich grasslands Productive herb-rich grasslands are sown using seed-mixtures balancing functional agrobiodiversity and biodiversity by supplying nectar and pollen for flower-visiting insects.
	Example 2 name **Example 2 description**	Extensive herb-rich grasslands A diversity of legumes is sown alongside grasses in a composition adjusted to the geobotanic conditions (landform, soil type and moisture regime) and cultural history.
	Example 3 name **Example 3 description**	Pharmacy meadows Seed mixtures of 15-17 species are sown in pharmacy meadows to maintain and increase the productivity of grasslands while improving the health of the animals.
	Example 4 name Example 4 description	
	Example 5 name Example 5 description	
	Example 6 name Example 6 description	
39	**AMP**	**Agroforestry**

	AMP description	Agroforestry is the practice of integrating the use of woody perennials with agricultural crops and/or animals for a variety of benefits and services including: better use of soil and water resources; multiple fuel, fodder and food products; a diversity of habitats for wildlife species.
	Example 1 name	Orchard-based agroforestry
	Example 1 description	Legumes and cereals are planted in fruit orchards that are orientated according to the prevailing wind direction. The system provides protection against strong winds, rain and flooding, enhances soil quality and produces a variety of crops.
	Example 2 name	Silvo-arable agroforestry system
	Example 2 description	Tree belts 14 m wide are planted in fields that are 40 m wide to enable mechanized cultivation of annual crops. Environmental and economic benefits include higher biodiversity, income and labour diversification, lower energy inputs and reinforcement of natural pest control.
	Example 3 name	Agrisilvicultural agroforestry system
	Example 3 description	Agricultural (intercropping, manure/ compost/mulching), vegetative (Napier grass strips, trees planting) and structural (ditches) measures are combined to maximize overall land yield in a sustainable manner.
	Example 4 name	Intensive irrigated fruit tree-vegetables agroforestry intercropping system
	Example 4 description	A rotation of vegetables are intercropped between mango trees to create permanent soil cover impeding weed growth while reducing evaporation and soil erosion.
	Example 5 name	Coffee agroforestry shade system
	Example 5 description	Coffee is grown under shade trees on mixed farms to reduce yield fluctuations and create more diverse, profitable, healthy and sustainable land-use systems.
	Example 6 name	Dynamic agroforestry system
	Example 6 description	Different canopy strata are used for different crops in a highly diversified agroforestry system mimicking the phases of natural succession. Pruning and selective weeding enhance the dynamic development of plant synergies.
	Example 7 name	Assisted natural regeneration
	Example 7 description	Tree seedlings growing naturally on crop-, forest- or rangeland are selected, protected and preserved. The recommended density on cropland is 60-80 trees per hectare.
40	**AMP**	**Silvopasture**
	AMP description	Silvopasture is the practice of integrating trees, forage and the grazing of domesticated animals in a mutually beneficial way. It utilizes the principles of managed grazing and is one of several distinct forms of agroforestry.
	Example 1 name	Assisted natural regeneration
	Example 1 description	Shoots from stumps of woody and herbaceous vegetation are identified and preserved on communal land used for agro-pastoralism, silvo-pastoralism or pastoralism.
	Example 2 name	Silvopastoral plantings
	Example 2 description	Soil preparation work and planting of fodder shrubs are used to increase rangeland productivity, produce firewood and mitigate wind erosion.
	Example 3 name	Parkland agroforestry

	Example 3 description	Naturally growing, valuable trees are protected and nurtured on cropping and grazing lands to provide food and nutritional security for both human and livestock populations and to protect and enrich soils.
	Example 4 name **Example 4 description**	Silvopastoral agroforestry system Trees such as Ceratonia siliqua (carob) are planted within grazing land. Once established, grazing can continue. Soil is stabilized and improved and the landscape, biodiversity and income are diversified.
	Example 5 name **Example 5 description**	Multi-purpose tree species for pasture supplementation Multi-purpose tree species (such as Calliandra calothyrsus) are planted to improve pasture for soil fertility improvement and livestock production.
	Example 6 name Example 6 description	
41	**AMP** **AMP description**	**Diverting water flow** Diverting water flow involves reshaping fields or field boundaries to divert water to other locations, e.g. to prevent the creation of rills and gullies.
	Example 1 name **Example 1 description**	Fascine drainage Fascine drains are constructed as fishbone-shaped trenches and used to drain excess water from elevated lands that might affect plots of land or houses below. They also help to prevent landslides and gullies.
	Example 2 name **Example 2 description**	Drainage ditches in steep sloping cropland Drainage ditches are dug with a gradient of 10-20% in steep cropland areas to reduce soil erosion by diverting excess rainwater.
	Example 3 name **Example 3 description**	Landslide prevention using drainage trenches lined with fast growing trees Linear gravel bed ditches lined with local tree species are constructed at an angle across the hillslope to channel surface runoff towards the main watershed tributary in land prone to waterlogging.
	Example 4 name **Example 4 description**	Cascading ditches with sediment traps Cascading ditches, silt traps and a larger catch basin are built between pineapple fields to collect runoff during rain and minimise transport of eroded soils to natural water bodies.
	Example 5 name **Example 5 description**	Water run-off control plan on cultivated land Contour banks with a slight gradient are constructed to intercept overland flow on cultivated land. These discharge into larger watercourses that run directly downhill. The contour banks shorten the slope in order to reduce flow velocity and prevent soil erosion.
	Example 6 name Example 6 description	
42	**AMP** **AMP description**	**Intercepting drains** Intercepting or cut-off drains aim to control soil moisture in fields by bypassing water flow before it enters the field. Cut-off drains in saline areas can divert and remove surface water that would otherwise recharge groundwater. Surface drains should be stabilized with fencing and vegetation cover.
	Example 1 name	Gravel curtain drains

	Example 1 description	Gravel is laid in a ditch (often combined with a perforated pipe) to form a curtain drain that acts like a gutter system removing water from a protected area.
	Example 2 name	Seepage interceptor drains
	Example 2 description	Drains are dug at the bottom of a sloping field to intercept the downhill flow of subsurface water. At these locations water can be pushed to the surface due to the sudden gradient change and differences in soil type.
	Example 3 name	Cut-off drains
	Example 3 description	A cut-off drainage ditch is dug by hand hoe with a gradient of 15-50% to facilitate water removal from sloping agricultural land without scouring the soil.
	Example 4 name	Anti-salt dike
	Example 4 description	A retention dike is constructed to avoid the intrusion of saline estuary water into paddy fields during the dry season. The dike is equipped with a sluice that is opened in the wet season so that excess water can flow to the river.
	Example 5 name	
	Example 5 description	
	Example 6 name	
	Example 6 description	
43	**AMP**	**Subsurface drains**
	AMP description	Subsurface drains remove excess groundwater. Most commonly, they are used to drain water from the rootzone to improve aeration, crop production and bearing capacity. Specific drainage systems can also help to regulate CO_2 emissions and salinity.
	Example 1 name	Submerged drains
	Example 1 description	Submerged drains are installed in grassland on peat soils to decrease soil subsidence and CO_2 and N_2O emissions and to maintain suitable groundwater levels for grassland production and grazing. They can be used to allow an inflow of water in summer (to avoid peat oxidation) or outflow in the winter (to remove surplus water).
	Example 2 name	Buried pipe drains
	Example 2 description	Corrugated, flexible and perforated plastic pipelines are wrapped with filter material to improve the permeability around the pipes. These drains help to control the groundwater levels in agricultural fields.
	Example 3 name	Controlled drainage
	Example 3 description	A water structure is used to manage the depth of the drainage outlet, providing control over the outflow of soil water from a field, e.g. to prevent outflow during drier periods when no drainage is required.
	Example 4 name	Sub-soil drainage pipes
	Example 4 description	Sub-soil perforated drainage pipes are laid in agricultural fields to prevent waterlogging and enhance infiltration. Improved salt removal is another beneficial side effect.
	Example 5 name	Mole drains
	Example 5 description	A ripper blade with a cylindrical foot (mole) is pulled through heavy clay subsoils to create an unlined channel or mole drain.
	Example 6 name	Tubewell drainage

	Example 6 description	Ground water is pumped out of a specially dug tubewell to control the salinity and water table level. The amount of ground water removed is equal to the drained surplus water.
44	**AMP** **AMP description**	**Surface drains** Surface drains divert and remove excess water by means of improved natural channels or constructed drains, supplemented when necessary by shaping and grading the land surface to form such drains.
	Example 1 name **Example 1 description**	Bedded drainage system The ground surface is shaped into parallel convex surfaces (humps) separated by hollows. The humps in such a bedded drainage system shed excess moisture relatively quickly while the hollows act as shallow surface drains.
	Example 2 name **Example 2 description**	Drainage ditches Artificial drainage ditches are constructed to transport excess surface water or collect water from other types of drain.
	Example 3 name Example 3 description	
	Example 4 name Example 4 description	
	Example 5 name Example 5 description	
	Example 6 name Example 6 description	
45	**AMP** **AMP description**	**Planting pits** Planting pits are a form of in situ rainwater harvesting for the benefit of the plants and crops grown in the pits. In addition to collecting moisture, the pits facilitate the creation of favorable micro-climates and fertilization.
	Example 1 name **Example 1 description**	Small planting pits Maize, sorghum and millet plants are cultivated in their own micro pits in order to improve water harvesting and efficient use of precipitation.
	Example 2 name **Example 2 description**	Nine maize pits Nine maize plants are planted in pits at a spacing of 30x30 cm. The pits collect runoff from impermeable soils to enhance plant water availability.
	Example 3 name **Example 3 description**	Banana planting pits Pits in banana plantations are filled with a mixture of manure, organic material and soil to improve soil moisture and fertility and enhance production. Relatively large pits are needed.
	Example 4 name **Example 4 description**	Vertical growing of potatoes in pits Potatoes are grown in vertical pits. Compost or enriched soil is gradually added as the plants grow to keep the potatoes covered. They are also watered regularly.
	Example 5 name **Example 5 description**	Precision conservation agriculture Mulch and small doses of nitrogen-based fertilizer (either organic and/or inorganic) are precision-applied. This is facilitated through the

		establishment of planting pits and combines aspects of conservation agriculture.
	Example 6 name **Example 6 description**	Rehabilitating land with planting pits and stone lines Degraded barren land covered with a hard crust is rehabilitated through manured planting pits in combination with contour stone lines. The pits are used for millet and sorghum production.
46	**AMP** **AMP description**	**Ridge-furrow systems** Ridge-furrow systems direct water to furrows, creating more favourable growing conditions. The ridges are sometimes covered with plastic mulch for maximum water harvesting.
	Example 1 name **Example 1 description**	Dyker Using a Dyker (an add-on tool for a potato planting machine) holes are dug into the bottom of the furrows between the potato ridges, generating traverse dykes for water storage.
	Example 2 name **Example 2 description**	Ox-ploughed furrows Ox-ploughed furrows are constructed to harvest water and to prepare seedbeds. The micro-catchment created extends water availability for plant growth and also enhances seed germination.
	Example 3 name **Example 3 description**	Micro-ridging for water harvesting Small micro-basins, locally called “cajetes”, are made after ploughing to facilitate the supply of water, taking advantage of scarce rainfall, and increasing production.
	Example 4 name **Example 4 description**	Ridges for cassava Planting bulky root crops such as cassava in ridges facilitates root development and crop harvesting, while also serving the purpose of water harvesting.
	Example 5 name **Example 5 description**	Cross-tied contour ridges Cross-tied planting ridges are created to catch rainwater for the benefit of young perennial crops. They are suited to areas of water deficit where it is not feasible to provide a soil cover and enhance infiltration and reduce runoff.
	Example 6 name **Example 6 description**	Briggs Tied Ridger Use of the Briggs Tied Ridger, developed to prevent rain and irrigation water runoff from sloping land, gives a dramatic reduction in surface erosion, fertilizer loss and water requirement.
	Example 7 name **Example 7 description**	Ridge-furrow system with plastic mulch Plastic mulch covers two ridges (planting zones) while the furrow between them serves as a rainwater harvesting zone. This ridge-furrow system facilitates supplementary irrigation and reduces weeds.
47	**AMP** **AMP description**	**Ridge-furrow systems for perennial crops** Ridge-furrow is an agronomic system to direct water to furrows, creating more favourable growing conditions. In perennial crops it also reduces runoff and soil erosion.
	Example 1 name **Example 1 description**	Furrow-enhanced runoff harvesting V-shaped furrows are constructed in a sloping orchard to harvest runoff. The furrows collect rainwater and supply the trees with extra water during a rain event.

	Example 2 name **Example 2 description**	Aserpiado A tillage tool is used to create micro-depressions (asperias) along all or alternate inter-vines rows to enhance water infiltration, increase plant available water and decrease runoff and associated soil loss.
	Example 3 name Example 3 description	
	Example 4 name Example 4 description	
	Example 5 name Example 5 description	
	Example 6 name Example 6 description	
48	**AMP** **AMP description**	**Micro-basins** Micro-basins are formed by constructing a ridge around a cultivated area. They are highly efficient at storing water although any excess water cannot run off.
	Example 1 name **Example 1 description**	Vallerani system In the Vallerani system a special tractor-pulled plough constructs micro-catchments combining traditional techniques of rainwater harvesting with mechanization for large scale land rehabilitation.
	Example 2 name **Example 2 description**	Negarims Negarims are V-shaped micro basins particularly constructed for fruit tree production in water-scarce areas. The tree is planted in the downstream corner of the basin, the rest of which serves as the catchment area.
	Example 3 name **Example 3 description**	Water harvesting basins 1 m wide basins with a 2 m wide runoff area are constructed. The basins are mulched with either straw or stones. The runoff area is left bare and untilled to encourage development of a crust over which water runs into the basin.
	Example 4 name Example 4 description	
	Example 5 name Example 5 description	
	Example 6 name Example 6 description	
49	**AMP** **AMP description**	**Inorganic mulching** Inorganic mulching is the practice of covering the soil surface with non-organic materials (e.g. plastic sheeting or gravel) to preserve soil moisture, increase temperature and reduce erosion. However, it can also have a negative impact by polluting soils with plastic residues, possibly affecting soil biota.
	Example 1 name	Plastic mulch film (white)

Example 1 description	Plastic mulch film is used to suppress weeds and conserve water. Crops grow through slits or holes in the thin plastic sheeting. White or metalized films lead to cooler soil and reflection of sunlight to plants.
Example 2 name	Plastic mulch film (black)
Example 2 description	Plastic mulch film is used to control weeds, retain soil moisture, save water and reduces maintenance labour. Black films prevent weed growth but do not transmit light to heat up the soil.
Example 3 name	Biodegradable plastic mulch
Example 3 description	Biodegradable plastic mulches are used as an alternative to conventional polyethylene mulch and can be tilled into soil where they are expected to biodegrade.
Example 4 name	Polytunnels
Example 4 description	Polytunnels are typically made from steel and covered in polythene and are usually semi-circular, square or elongated in shape. They are used to create a favourable micro-climate and protect crops from extreme conditions.
Example 5 name	Gravel mulching
Example 5 description	In arid regions, light weight gravel is applied to a depth of at least 1 cm around more mature plants. The mulch reduces soil moisture loss through evaporation, while still obtaining a significant yield.
Example 6 name	
Example 6 description	
50 **AMP**	**Water distribution in rangelands**
AMP description	The practice of managing the distribution of water resources in rangelands is crucial because forage utilization decreases rapidly as the distance to water increases. Animals will overuse sites near water locations rather than walk greater distances to abundant forage. Water requirements of grazing animals must be considered when planning water resources, and vary with species and class of animal, nature of the forage and weather.
Example 1 name	Improved well distribution
Example 1 description	Water points are optimally and efficiently distributed in rangeland to ensure a balanced distribution of herds and avoid overuse of vegetation around a limited number of wells.
Example 2 name	Water points fed by springs and streams
Example 2 description	Water from springs or other sources is brought to water points in pastures. This greatly increases livestock productivity and reproductive performance, reduces erosion from cattle tracks in critical locations surrounding springs, and protect springs from being destroyed by the animals.
Example 3 name	Water harvesting for livestock watering point
Example 3 description	An artificial watershed (of ca. 100 m2) is installed in remote locations with poor access to water. The watershed is built from cement and drains into a well or tank to collect water during the winter for use during the dry season for livestock watering.
Example 4 name	Planning water points for rotational grazing
Example 4 description	A rotational grazing scheme is introduced following the establishment of new watering points to provide water in summer. The scheme ensures longer growing times for grass recovery on pastures and increases quantity and quality of pastures.

	Example 5 name Example 5 description	
	Example 6 name Example 6 description	
51	**AMP** **AMP description**	**Drip irrigation** Drip irrigation is a method of controlled irrigation in which water is slowly delivered to the root systems of multiple plants. Water is either dripped onto the soil surface above the roots or delivered directly to the root zone. It is often preferred to flood (surface) irrigation because less water is used and lost to evaporation.
	Example 1 name **Example 1 description**	Drip irrigation Drip irrigation is used to provide a constant water supply to crops, minimizing water and labour use while improving crop growth and yield. Salinization of the soil is minimized by efficient water use.
	Example 2 name **Example 2 description**	Low-cost drip irrigation Water is precisely delivered to crops through perforated tubes. In this low-cost drip irrigation system, the pressure is supplied by connecting the tubes to a raised water tank.
	Example 3 name **Example 3 description**	Polyethylene sheeting and intermittent cloth strips Polyethylene sheeting and spaced cloth strips are used to deliver water to individual plants when poor quality irrigation water could clog nozzles.
	Example 4 name **Example 4 description**	Subsurface drip irrigation A low-pressure, high efficiency irrigation system is used in which buried drip tubes or drip tape meet crop water needs. Subsurface drip irrigation minimizes evaporation losses and reduces weed pressure.
	Example 5 name **Example 5 description**	Orchard drip irrigation A network of valves, pipes, tubes and nozzles are used in an orchard drip irrigation scheme to allow water to drip directly onto the root zone of the trees.
	Example 6 name Example 6 description	
52	**AMP** **AMP description**	**Surface irrigation** Surface irrigation is a technique where water is applied to the soil surface and distributed by gravity. This is the most common form of irrigation, in many parts of the world virtually unchanged for thousands of years. However, the water distribution is uncontrolled and therefore inherently inefficient.
	Example 1 name **Example 1 description**	Furrow irrigation In furrow irrigation small parallel channels are constructed along the field length in the direction of the predominant slope. Water is applied to the top end of each furrow and flows down the field.
	Example 2 name **Example 2 description**	Level basin irrigation Water is applied rapidly to the entire basin and it is allowed to infiltrate. Level basin irrigation is favoured in soils with relatively low infiltration rates.
	Example 3 name	Border irrigation

	Example 3 description	A field is divided into strips (usually from 6 to 30 m wide) separated by border ridges running down the slope. The area between the ridges is flooded during irrigation.
	Example 4 name **Example 4 description**	Laser leveling of fields Preparation of fields for irrigation with the use of a laser planner ensures uniform surface leveling. Water is distributed equally across the field providing water savings and increased yield.
	Example 5 name **Example 5 description**	Surge irrigation Water is pulsed on and off according to a planned schedule rather than being supplied constantly. Surge irrigation is an advanced variant of furrow irrigation.
	Example 6 name **Example 6 description**	Furrow irrigation with alternating dry and wet furrows Dry and watered furrows are rotated. In limited water conditions, irrigation with alternating furrows is an effective way to reduce water use while maintaining crops in good vegetative state.
	Example 7 name **Example 7 description**	Contour basins The field is divided into a number of terraced rectangular bays. Water is applied to the highest bay and cascades downhill through consecutive bays. Contour basins are a variant of basin irrigation.
53	**AMP** **AMP description**	**Pivot irrigation** Pivot irrigation is a method of overhead crop irrigation in which equipment rotates around a pivot and crops are watered with sprinklers. An area centred on the pivot is irrigated, often creating a circular pattern in crops when viewed from above.
	Example 1 name **Example 1 description**	Center-pivot irrigation Irrigation pipe and sprinklers rotate round a central pivot which supplies the water. The system is used in large relatively flat fields.
	Example 2 name **Example 2 description**	Lateral-move irrigation A lateral-move irrigation system is configured to move in a straight line and water is supplied by an irrigation channel running the length of the field. While suited to rectangular fields, it requires complex guiding systems.
	Example 3 name **Example 3 description**	End gun pivot irrigation Water guns attached to the ends of a pivot system are used to effectively irrigate additional land. Relatively high pressure is needed to supply the guns with enough water.
	Example 4 name Example 4 description	
	Example 5 name Example 5 description	
	Example 6 name Example 6 description	
54	**AMP** **AMP description**	**Sprinkler irrigation** Sprinkler irrigation is a method of applying water that simulates natural rainfall. Water is distributed through a system of pipes, usually by pumping. It is then sprayed into the air through sprinklers so that it breaks up into small drops which fall on the ground.

Example 1 name **Example 1 description**	Impact sprinklers Impact sprinklers are driven in a circular motion by the force of the outgoing water. They can be used to water large areas of land, albeit unevenly because the larger water drops fall closer to the sprinkler than the smaller.
Example 2 name **Example 2 description**	Micro-sprinkler irrigation Small-sized water droplets are delivered through a rotating head. This micro sprinkler system allows longer watering time with less runoff.
Example 3 name **Example 3 description**	Travelling big gun Water is delivered to the crop by a large-capacity, high pressure nozzle. The travelling big gun is pulled along a track in the field by a wheel that winds up the water hose.
Example 4 name **Example 4 description**	Underground sprinkler system Underground sprinkler systems are installed with some effort. They are only considered to be viable for perennial crops and are often located in orchards.
Example 5 name Example 5 description	
Example 6 name Example 6 description	

55	**AMP** **AMP description**	**Leaching salts** Leaching is a practical way of removing excess salts. It is effective only to the extent that water moves down through the soil profile and below the root zone. It is often accomplished by occasional excessive irrigation applications to dissolve, dilute and move the salts.
	Example 1 name **Example 1 description**	Continuous ponding Water is impounded using a surface irrigation method. Continuous ponding reduces water use efficiency but increases velocity of salt leaching.
	Example 2 name **Example 2 description**	Intermittent ponding The rise in water table following ponding is allowed to subside before water is next applied. Leaching salt with intermittent ponding is appropriate in poorly drained areas with low evaporative demand.
	Example 3 name **Example 3 description**	Rainwater leaching In areas where good quality water is scarce, rainwater is collected during the rainy (monsoon) period to be used for salt leaching.
	Example 4 name **Example 4 description**	Sprinkler leaching Sprinkler irrigation is used to leach salt with the advantage that water can be applied to unprepared fields. It is an efficient method on coarser textured soils as application losses are lower than with surface irrigation.
	Example 5 name **Example 5 description**	Alternate row irrigation Alternate row irrigation is used in high water table areas to reduce salt accumulation. Every other row is flooded to remove salts into the unirrigated area.
	Example 6 name Example 6 description	

56	**AMP**	**Minimizing saline water irrigation**
	AMP description	Applications of saline irrigation water are minimized to reduce accumulation of salts in the soil. This can be done by using water from precipitation more effectively to reduce the amount of irrigation required or by replacing saline irrigation water with better quality water from other sources.
	Example 1 name	Pipe irrigation
	Example 1 description	Pipes are used to draw less saline water from nearby rivers in order to minimize the salinization of agricultural fields. Pipes also reduce water loss by seepage during transport.
	Example 2 name	Rainwater storage
	Example 2 description	Rainwater is stored for later use to minimize the application of saline irrigation water. This is useful in areas of irregular rainfall where irrigation is required during dry seasons.
	Example 3 name	More reliance on rainwater
	Example 3 description	More direct use is made of rainwater to reduce reliance on saline irrigation water. However, it is difficult to plan and other water conservation strategies also need to be used.
	Example 4 name	
	Example 4 description	
	Example 5 name	
	Example 5 description	
	Example 6 name	
	Example 6 description	
57	**AMP**	**Reduced water use in rice cultivation**
	AMP description	Paddy rice is conventionally grown in anaerobic conditions for 80% of the growing period, requiring high amounts of irrigation water. Reduced use of water is recommended for increased productivity, adaptation to water scarcity and reduction of methane emissions (potentially offset by carbon dioxide emissions).
	Example 1 name	System of Rice Intensification
	Example 1 description	System of Rice Intensification (SRI) is a climate-smart, agro-ecological methodology for increasing rice productivity by 1) early plant establishment; 2) reduced plant density; 3) soil enrichment with organic matter; and 4) reduced and controlled water application.
	Example 2 name	Rice intensification through organic rice-duck farming
	Example 2 description	The usual rice farming system (seedling condition, planting distance, irrigation time and water requirement) is modified, an organic fertilization scheme is introduced, and ducks are incorporated in the system. Ducks help weeding, pest biocontrol and fertilization.
	Example 3 name	Alternate wetting and drying
	Example 3 description	Rice fields are flooded to a depth of 5 cm then allowed to dry. They are flooded again when the water level (monitored by perforated PVC tubes) reaches 15 cm below the soil surface. The practice decreases water use while having no impact on yield, decreases methane emissions and water pump fuel consumption.
	Example 4 name	Aerobic rice

	Example 4 description	Specifically developed "aerobic rice" varieties are grown in well-drained, non-puddled, and non-saturated soils. The system aims for yields of at least 4-6 tons per hectare. Crop rotation replaces flooding for weed management.
	Example 5 name	Saturated soil culture
	Example 5 description	The soil is kept as close to saturation as possible by shallow irrigations (of about 1 cm floodwater) a day or so after the disappearance of standing water. It leads to water savings at slight yield impact (4-9%).
	Example 6 name	
	Example 6 description	
58	**AMP**	**Irrigation optimization**
	AMP description	Irrigation optimization is a water-saving scheme using precise irrigation scheduling. Irrigation system managers determine the correct frequency and duration of watering to minimize costs and maximize yields.
	Example 1 name	Soil sensor network
	Example 1 description	Sensors are used to measure soil moisture and temperature at different depths in the rooting zone. The farmer can retrieve the data at any time using his mobile phone or computer.
	Example 2 name	Portable soil moisture sensor
	Example 2 description	Soil moisture sensors are used by the farmer to manage seasonal water application. This smart irrigation is essential to refine irrigation techniques and to meet specific soil and crop needs.
	Example 3 name	Local agreements on irrigation management
	Example 3 description	Local agreements between water users are made to prevent and manage conflicts concerning irrigation water. Under conditions of water scarcity, agreements ensure that irrigation water is used rationally and sustainably.
	Example 4 name	Alternate wetting and drying
	Example 4 description	Irrigation is only supplied to a (rice) field whenever the soil moisture content reaches a certain level. This scheduling reduces water input without significantly affecting the yield.
	Example 5 name	
	Example 5 description	
	Example 6 name	
	Example 6 description	
59	**AMP**	**Supplemental irrigation**
	AMP description	Supplemental irrigation is the addition of small amounts of water to rainfed crops during times when rainfall is insufficient for normal plant growth in order to improve and stabilize yields.
	Example 1 name	Cisterns and water tanks
	Example 1 description	Cisterns and water tanks are used to store rainfall and runoff water for multiple purposes such as drinking water for human and animal consumption and supplemental irrigation.
	Example 2 name	Plastic-lined pond
	Example 2 description	A plastic-lined pond is created to store water for irrigating crops in periods of low rainfall when plant growth would be otherwise limited.

	Example 3 name **Example 3 description**	Deficit irrigation A moderate plant water deficit is maintained to improve the quality of some crops such as grapes. While irrigation scheduling is often used to maintain soil water content near field capacity, deficit irrigation requires accurate soil moisture or plant 'stress' sensing, the ability to estimate crop water demand, and the ability to irrigate frequently.
	Example 4 name **Example 4 description**	Off-season irrigation Supplemental water is applied to fields and pastures during the off-season pre-seeding period when irrigation water is available and not being used by other farmers. Water accumulates at depths of 1.5-2 m in the soil and is available for pasture and crop growth in spring and early summer.
	Example 5 name Example 5 description	
	Example 6 name Example 6 description	
60	**AMP** **AMP description**	**Artificial grassed or paved waterways** A grassed waterway is a natural or constructed ditch, usually broad and less steeply sloping than the rest of the field. It is used to conduct surface water from or through cropland, enhancing infiltration, trapping eroded sediment and helping prevent the development of gullies.
	Example 1 name **Example 1 description**	Grassed waterways Grassed waterways are constructed along natural drainage lines in a field or in an existing watercourse to control erosion. They reduce damage from storm events to agricultural fields.
	Example 2 name **Example 2 description**	Paved waterways An artificial drainage channel, lined with stones, is constructed along the steepest slope. This paved waterway receives runoff from cutoff drains and graded structures, discharging it to the natural waterway without causing erosion.
	Example 3 name **Example 3 description**	Controlled waterways Bio-engineered retaining walls are built using bamboo poles, rocks and soil-filled sacks across the slope and strengthened by grass planted on top. Erosion is reduced during the rainy season and water is conserved during the dry season.
	Example 4 name **Example 4 description**	Sunken gully pits Sunken gully pits are dug to trap water, enhance groundwater recharge and to reduce flow velocity. These pits are often provided with spillways for excess water runoff.
	Example 5 name Example 5 description	
	Example 6 name Example 6 description	
61	**AMP** **AMP description**	**Liquid manure or slurry** Application of liquid manure is a common method for supplying nutrients. It also forms a thin layer on the soil surface to protect from wind erosion. There is a potential risk of eutrophication affecting water quality.

Example 1 name **Example 1 description**	Land surface spreading Manure is spread on the soil surface as a convenient way to fertilize fields. However, uneven distribution, soil compaction, nitrate leaching and runoff are issues that should be taken into account.
Example 2 name **Example 2 description**	Manure irrigation Liquid manure (effluent) is applied to cropland through a sprinkler irrigation system. Manure irrigation is likely to result in uneven application and poses threats like surface runoff and environmental pollution.
Example 3 name **Example 3 description**	Slurry injection Using a specialized implement, slurry is injected in narrow bands directly into the soil or on the soil surface, often underneath the crop canopy. Slurry injection is one of the most affordable ways for farmers to fertilize their fields and reduces odour, nutrient runoff and gaseous emissions.
Example 4 name **Example 4 description**	Umbilical slurry injection An injection system with an umbilical pipe is used to inject slurry into the soil. The practice reduces the threat of soil compaction and allows use of lighter tractors.
Example 5 name **Example 5 description**	Real-time slurry analysis NIR sensors are used to measure the components of the slurry during tank filling or application, allowing more precision in manure application. Application rates can also be adjusted to crop performance on a field.
Example 6 name Example 6 description	
62 **AMP** **AMP description**	**Animal manure** Animal manure is commonly applied to supply nutrients to a field. Addition of organic matter is generally a secondary objective, but it is an important way of avoiding soil organic matter depletion. There is a potential risk of eutrophication affecting water quality.
Example 1 name **Example 1 description**	Farmyard manure Farmyard manure is a mixture of dung, urine, bedding material and fodder residues left to decompose for > 4 months. It is spread using a rear discharge spreader or wheelbarrow and incorporated into the soil to increase soil fertility and structure.
Example 2 name **Example 2 description**	Chicken manure Chicken manure should be mixed with straw before application. It contains high levels of nitrogen, phosphorus and potassium and improves soil structure. It can also be used for composting.
Example 3 name **Example 3 description**	Corralling Animals are corralled on cropland for the mutual benefit of both crop farmers and pastoralists. Crop residues are used as fodder and animal dung is used as a fertilizer.
Example 4 name **Example 4 description**	Manure application in dripper points Manure is annually applied to holes dug at the foot of orchard trees underneath the nozzle locations of a drip irrigation system. This enhances soil organic content over the long term, impacting orchard productivity and making the trees less prone to pests and diseases.
Example 5 name	

	Example 5 description Example 6 name Example 6 description	
63	**AMP** **AMP description**	**Compost** Composting is decomposing organic matter for recycling as a fertilizer and soil amendment. Compost is a key ingredient in organic farming.
	Example 1 name **Example 1 description**	Compost (making and) application Farmyard manure, a mixture of dung, urine, bedding material and fodder residues, is left to decompose for > 4 months. It is spread on the soil using a rear discharge spreader or wheelbarrow and incorporated to increase soil fertility and structure.
	Example 2 name **Example 2 description**	Vermicompost (making and) application Vermicompost is produced by the decomposition of organic waste at ambient temperature through the synergistic actions of earthworms and microbes. It has a high nutrient content and contains beneficial soil microorganisms, humic acids and enzymes.
	Example 3 name **Example 3 description**	Anaerobic digestate Biodegradable materials are decomposed in a controlled manner in the absence of oxygen. Digestate and methane are the end products. Digestate may be separated in solid and liquid fractions.
	Example 4 name **Example 4 description**	Carbon enrichment with industrial organic waste recycling Agricultural soils are enriched with locally available industrial organic matter waste (e.g. sugarcane filter cake, sawdust, coarse wood chips). Such carbon enrichment is a win-win solution for organic matter waste recycling and soil quality.
	Example 5 name **Example 5 description**	Micronized organic fertilizers Specifically developed micronized organic fertilizers are applied through an irrigation system. Before and/or after fertigation, irrigation lines should be cleaned by flushing with water.
	Example 6 name Example 6 description	
64	**AMP** **AMP description**	**Biochar** Biochar is produced from pyrolysis (thermal decomposition of biomass in partial or total absence of oxygen) of plant and waste feedstock and is used as a soil amendment. Biochar is a stable solid, rich in carbon and can have benefits for plant growth. Its particle size distribution and carbon storage fertilizer (P, K, S, and Mg only) and liming properties vary.
	Example 1 name **Example 1 description**	Biochar application for carbon sequestration Biochar is applied every few years to increase carbon sequestration. In order to contribute to climate regulation, the quality of the pyrolysis process, its carbon storage value, application rate and deep incorporation in the soil are important. Improved productivity may avoid future need for further land conversion.
	Example 2 name **Example 2 description**	Biochar application for land restoration Biochar is used as a soil amendment for land restoration. It can enhance the cation exchange capacity and absorb nutrients for slow release. Initially it is

important to mix biochar with nutrient-rich organic material such as manure or compost. The largest effect on yield is seen on degraded land.

Example 3 name **Example 3 description**	Biochar application for prevention of nutrient leaching and pollution Biochar is applied to soil to prevent nutrient leaching. It can also raise the pH and reduce problems with aluminum toxicity and heavy metals. However, due to strong sorption of pesticides, increased pesticide concentrations can also build up.
Example 4 name **Example 4 description**	Biochar application to make dryland agriculture more resilient to drought Biochar is applied to soils to make dryland agriculture more resilient to water deficiency. Acting over a long period, biochar improves soil moisture and nutrient capacity, activates microorganisms and raises pH.
Example 5 name Example 5 description	
Example 6 name Example 6 description	
65 **AMP** **AMP description**	**Biofertilizers** A biofertilizer is a substance containing living micro-organisms. When applied to seeds, plant surfaces or soil the organisms colonize the rhizosphere or the interior of the plant, promoting growth by increasing the supply or availability of primary nutrients.
Example 1 name **Example 1 description**	Rhizobium inoculation Rhizobium inoculation is used to ensure adequate nitrogen (N) for legumes. Rhizobium infects the roots of leguminous plants and produces nodules where it fixes nitrogen gas from the atmosphere, which becomes available to the host plant.
Example 2 name **Example 2 description**	Azospirillum / Azotobacter inoculation Azospirillum and Azotobacter inoculation is used in various cereals and other crops. They are nitrogen-fixing bacteria that live around the roots of plants in a rhizosphere association. The bacteria feed on plant exudates while promoting plant growth.
Example 3 name **Example 3 description**	Blue Green Algae inoculation Blue green algae (Anabaena) inoculation is used for paddy rice. Anabaena in association with water fern (Azolla) fixes 60 kg N/ha/season and also enriches soils with organic matter.
Example 4 name **Example 4 description**	Mycorrizhae Mycorrizhae inoculant is applied when seeding crops or pasture. Mycorrhizae are able to create a vast connective network between the roots of a plant and the soil around them, which allows the fungus to uptake nutrients such as nitrogen and phosphorus for the plant and increase the surface area of the roots.
Example 5 name **Example 5 description**	Phosphate solubilizing bacteria Soil is inoculated with phosphate solubilizing bacteria (PSB) capable of dissolving inorganic phosphorus from insoluble compounds. As P-fertilizer is rapidly immobilized, PSB soil inoculum plays an important role in making P available for crops.
Example 6 name Example 6 description	

66	**AMP** **AMP description**	**Inorganic fertilizers** Inorganic fertilizers (e.g. N, P and K or micro-nutrients like boron, copper, cobalt) are applied either singly or mixed to enhance plant growth. Overfertilization may lead to pollution.
	Example 1 name **Example 1 description**	Broadcast fertilizer application Fertilizer is broadcast spread on field crops, with or without being incorporated into the soil. A first (basal dressing) application is made at the time of planting/seeding and, in some crops, a top dressing of nitrogenous fertilizer is given to growing plants.
	Example 2 name **Example 2 description**	Band placement and side dressing Fertilizer is applied in bands where developing roots will easily reach it (e.g. 5 cm to the side and below the seed row). Band placement is more localized and reduces nutrient losses. When row crops develop, further fertilizer may be given as a side dressing.
	Example 3 name **Example 3 description**	Slow- and controlled-release fertilizers A single pre-planting application of a slow- or controlled-release fertilizer is made to ensure gradual or staged availability of nutrients for efficient plant growth. Such fertilizers lower operational costs and reduce losses.
	Example 4 name **Example 4 description**	Microdosing Fertilizer (NPK 16-16-16; or DAP) is applied at a micro-dose of 0.3 g per planting station. This is equivalent to 3-8 kg fertilizer/ha, depending on planting pattern. Microdosing is combined with seed priming (soaking seeds for 8 hours prior to sowing) to boost yield.
	Example 5 name **Example 5 description**	Fertigation In fertigation fertilizers, soil and water amendments and other water-soluble products are injected into an irrigation system. Fertigation allows continuous, gradual fertilization of crops.
	Example 6 name **Example 6 description**	Foliar application Foliar sprays are widely used to apply micronutrients (especially iron and manganese) to many crops. Foliar application is also an effective way to remediate nutrient deficiencies as and when they become apparent.
67	**AMP** **AMP description**	**Green manure** Green manure or catch crops are rotation crops that are ploughed into the soil or spread on it rather than being harvested. They provide nutrients and organic matter for the subsequent crop. Growing green manure is crucial for maintenance or improvement of soil fertility.
	Example 1 name **Example 1 description**	Tancy Phacelia Tancy Phacelia is grown as a green manure. It is an annual species native to drylands, and adds organic matter, nitrogen and other nutrients to the soil while at the same time decreasing weeds.
	Example 2 name **Example 2 description**	Mexican Sunflower Leaves of the Mexican sunflower (Tithonia diversifolia) are used as a green manure. The sunflower grows along roadsides or farm boundaries and its leaf has a high nitrogen and phosphorus content.
	Example 3 name	Sesbania

	Example 3 description	Sesbania is grown as a green manure. It is a versatile species primarily used between rice crops or as an intercrop in transplanted rice. It enhances soil structure and soil fertility.
	Example 4 name	Sorghum
	Example 4 description	Sorghum is used in green house cultivations as a green manure in crop rotation (e.g. with tomato plants). It aims to reduce pest cycles and soil borne diseases while improving soil structure and nutrient content.
	Example 5 name	Green manure in orchards
	Example 5 description	Nitrogen-fixing green manure species are planted around orchard trees. This is an ecological option to maintain and enhance soil fertility.
	Example 6 name	
	Example 6 description	
68	**AMP**	**Leguminous crops**
	AMP description	Leguminous crops are those which belong to the pea family (Leguminosae). Plants in this family generally have root nodules hosting rhizobium bacteria that fix nitrogen from the atmosphere. When plant residues decompose, this fixed nitrogen can increase soil nitrogen content.
	Example 1 name	Leguminous annuals
	Example 1 description	Leguminous annuals (such as crimson clover, hairy vetch and field peas) are used in a crop rotation to fix nitrogen in the soil for the next year or growing season.
	Example 2 name	Fodder legumes
	Example 2 description	Leguminous crops are often used as a relay crop or intercropped with maize, millet and rice to enhance the soil fertility. Fodder legumes are viable alternatives in regions with an established diary industry.
	Example 3 name	Leguminous crop in plots temporarily set outside the crop rotation
	Example 3 description	A plot is cultivated with perennials legumes and set temporarily outside the crop rotation for 4-5 years to recover its soil fertility and reduce the need for biocides while providing supplemental income.
	Example 4 name	Leguminous perennials
	Example 4 description	Leguminous perennial crops (such as red, white and sweet clover) are used to fix nitrogen in the soil for the next couple of years.
	Example 5 name	Leguminous shrubs
	Example 5 description	Leguminous shrubs and trees are used to fix nitrogen to the soil for multiple years. These species often also enhance the biodiversity in an area but are not commonly used within agricultural practice.
	Example 6 name	Leguminous tree shelterbelts
	Example 6 description	Barriers of leguminous trees or shrubs are established along field boundaries to provide a favourable micro-climate and protect against wind erosion. They also enhance soil properties by fixing nitrogen to the soil and providing organic matter.
69	**AMP**	**Retaining crop residues**
	AMP description	The practice of retaining crop residues involves keeping crop stubble on the field, rather than removing it. This can offer many benefits including increased soil organic matter, improved soil structure and plant nutrient cycling.

	Example 1 name **Example 1 description**	High stubble cutting height High stubble cutting height is used to leave more organic material on the field and reduce the time taken to harvest the crop. For increased nutrient cycling and disease control the stubble is chopped and incorporated into the soil.
	Example 2 name **Example 2 description**	Stubble management Crop residues are chopped and incorporated in the topsoil where they decompose. Properly used this leads to higher soil fertility and less disease. However, an excessive amount of stubble can obstruct subsequent seeding operations.
	Example 3 name **Example 3 description**	Residue incorporation Crop residues are left on agricultural fields. Incorporating residues in the soil will enhance organic matter content and improve the soil structure.
	Example 4 name **Example 4 description**	Return process residues Process residues (such as husks, seeds, bagasse and roots) are returned to the field as fertilizers or animal fodder.
	Example 5 name Example 5 description	
	Example 6 name Example 6 description	
70	**AMP** **AMP description**	**In situ composting** In the practice of in situ composting crop residues, green and farmyard manures, organic waste and ashes are composted in the field in trenches or pits. Crops are directly grown on or next to the pits which also serve to harvest rainwater and regulate soil moisture. Organic matter recycling like this can be developed into a circular system, depending on what materials are available locally.
	Example 1 name **Example 1 description**	In situ compost cultivation Trenches (0.6 m x 0.6 m and 0.9 m apart) are dug across the slope, filled with organic residues and backfilled with soil until slightly below the soil surface to capture runoff. Water and nutrient demanding crops are grown in the trenches, leguminous crops in between.
	Example 2 name **Example 2 description**	Kibanja cropping system Compost pits (3x3 m in size and 0.6 m deep) are dug between 4 widely spaced banana plants and filled with farm manure, crop residues and ash. They are covered with soil to activate nutrient release though microbial disintegration and avoid volatilization of greenhouse gases.
	Example 3 name Example 3 description	
	Example 4 name Example 4 description	
	Example 5 name Example 5 description	
	Example 6 name Example 6 description	

71	**AMP** **AMP description**	**Mulching with pruning materials** Mulching with pruning materials (such as chipped branches) is an effective soil management practice to reduce surface runoff, conserve soil moisture and control water erosion. Prunings have several advantages over other mulching materials such as low cost and ready availability, especially in orchards.
	Example 1 name **Example 1 description**	Bark mulch Bark mulch is applied to the bare soil surrounding trees in orchards. It is a relatively cheap method of suppressing and controlling weed growth, while at the same time retaining soil moisture and enhancing fertility.
	Example 2 name **Example 2 description**	Chipped branches Chipped branches from trees are used to cover bare soil, reducing surface water runoff after heavy rainfall and increasing soil organic matter content through decomposition.
	Example 3 name **Example 3 description**	Leaf prunings Leaf prunings (e.g. from bananas) are applied to the soil surface, enhancing organic matter content, reducing evaporation and protecting against erosion.
	Example 4 name **Example 4 description**	Wood chips Wood chips are used as a soil mulch. Because they are a highly resistant organic material, wood chips are ideal for increasing stable organic matter in the soil. Once incorporated, wood chips are slowly broken down by the soil fauna and (partly) converted into humus.
	Example 5 name Example 5 description	
	Example 6 name Example 6 description	
72	**AMP** **AMP description**	**Straw mulching** Straw mulching is the practice of spreading a layer of straw on the soil surface. The straw can be the residue from a harvested crop or sourced from elsewhere. The practice aims to conserve moisture, improve fertility and health of the soil and reduce weed growth.
	Example 1 name **Example 1 description**	Grass mulch Grass mulch is applied to the soil surface to reduce moisture stress, increase soil water retention, reduce soil erosion and improve soil organic matter content with the aim of increasing crop productivity.
	Example 2 name **Example 2 description**	Straw mulch Straw mulch is applied to the soil surface. It is effective weed control and soil erosion prevention, conserves moisture and increases soil organic matter content.
	Example 3 name **Example 3 description**	Spreading straw residues Rice straw is left on the field after mechanized harvesting. Successive crops benefit from increased moisture and nutrient levels in the soil.
	Example 4 name Example 4 description	
	Example 5 name	

	Example 5 description	
	Example 6 name Example 6 description	
73	**AMP** **AMP description**	**Mechanical weed control** Mechanical weed control is the physical removal of weeds by mowing, cutting and pulling. Other alternatives include using hot water, a flame thrower or laser.
	Example 1 name **Example 1 description**	Duckfoot-bladed hoe The duckfoot-bladed hoe is often used in tractor-pulled cultivators, but a single hoe can also be used manually to get rid of the weeds which are not too close to the crops.
	Example 2 name **Example 2 description**	Finger weeder When the crop is at a mature stage (with a well-developed root system) a finger weeder is used to remove weeds that grow within difficult to access crop rows.
	Example 3 name **Example 3 description**	False seedbed technique A regular seedbed is created but, before it is used, the weeds are allowed to germinate and are mechanically removed before the actual crop is planted or sown.
	Example 4 name **Example 4 description**	Interrow cultivator Interrow cultivators are used to accurately hoe between rows of growing crops to cut off the weeds just below the surface. Interrow cultivators are fully adjustable and configured to suit any row width or combination of widths.
	Example 5 name **Example 5 description**	Weed flame throwers Weed flame throwers are used to burn weeds on a plot prior to seeding/planting as an effective method of removing them. When used in dry areas extra care should be given to the surrounding environment to avoid wildfires. There are also selective inter-row flame weeders.
	Example 6 name **Example 6 description**	Wheel hoe A wheel hoe is used in smaller plots to remove weeds between crop rows. It is a cheaper version of the duckfoot-bladed hoe.
	Example 7 name **Example 7 description**	Mowing Mowing is used as an effective weeding method if the weeds do not have to be removed completely and the crop is not at risk of being damaged by the operation. Swing-arm mowers are particularly well-suited to mowing perennial crops.
	Example 8 name **Example 8 description**	Weed control using steam Steam is used to set back weed development with heat but without additional fire risk. Due to the latent heat of condensation it provides rapid heat transfer and it can operate well in windy and wet conditions.
74	**AMP** **AMP description**	**Chemical weed control** Chemical weed control is the removal of weeds using herbicides of different types (e.g. emergence and contact herbicides). Herbicides can pollute soils and water and might affect soil and aquatic life.
	Example 1 name	Selective herbicides

	Example 1 description	Selective herbicides are used to destroy only weeds without harming the crop. Their selectivity is based on translocation, differential absorption, physical or physiological differences between plant species.
	Example 2 name **Example 2 description**	Non-selective herbicides Non-selective herbicides are often used to clear waste land. They eradicate all plant material they come into contact with. It is important that the herbicides applied pose a minimal risk (through contamination of groundwater, air or crops) to public health.
	Example 3 name **Example 3 description**	Organic herbicides Organic herbicides are usually used alongside mechanical weed control. They are often non-selective and potentially replace synthetic herbicides, though may be less effective.
	Example 4 name **Example 4 description**	Vinegar application Vinegar solutions (of 5-20%) are used to control weeds. However, vinegar mainly destroys surface growth and often the root system remains intact. Repeated treatment is therefore recommended.
	Example 5 name Example 5 description	
	Example 6 name Example 6 description	
75	**AMP** **AMP description**	**Biological weed control** Biological weed control uses other organisms to remove or control the weeds. It relies on predation, parasitism, herbivory or other natural mechanisms and typically also involves an active human management role.
	Example 1 name **Example 1 description**	Animal grazing Herbivores with different preferences can be used to control certain weeds. Goats are browsers that can control toxic or thorny plants (e.g. leafy spurge, knapweed). Care should be taken that grazing animals do not feed on crops.
	Example 2 name **Example 2 description**	Grazing as part of integrated weed control practice Sheep are used to graze vineyards during autumn and winter when the vines are dormant. This is an example of an integrated weed control practice.
	Example 3 name **Example 3 description**	Biological control agents The alligator weed flea beetle (Agasicles hygrophila) is used as an agent for the biological control of the aquatic plant alligator weed.
	Example 4 name **Example 4 description**	Mycoherbicides Fungi (like Chondrostereum purpureum and Lasiodiplodia pseudotheobromae) are applied as mycoherbicides to 'weed' trees. The fungus is applied directly to the trees in a nutrient paste or inserted as a capsule in the stem.
	Example 5 name **Example 5 description**	Conservation biocontrol Existing natural enemies of weeds and other pests are protected or provided with habitats. This conservation biocontrol is the main strategy for promoting weed seed removal by predators and microorganisms.
	Example 6 name Example 6 description	

76	**AMP**	**Biological pest control**
	AMP description	Biological pest control is a method of controlling pests (such as insects, mites, weeds and plant diseases) using other organisms. It relies on predation, parasitism, herbivory, or other natural mechanisms, but typically also involves an active human management role.
	Example 1 name	Importation of natural predators
	Example 1 description	A pest's natural enemies (e.g. beetles or larvae) are introduced to a new locale. It is important to note that this kind of introduction may have additional consequences.
	Example 2 name	Improve habitat for native fauna
	Example 2 description	Pests can be controlled and combatted by improving the habitat for fauna, thus attracting native predators, parasites or herbivores. Active management is required to (re-) establish and maintain the native fauna.
	Example 3 name	Inductive augmentation
	Example 3 description	Natural predators (e.g. ladybirds) of a particular pest (e.g. aphids) are released to augment the predator population in an area.
	Example 4 name	Hoverflies
	Example 4 description	Hoverflies (syrphids) are used as a biological pest control. In their larval stage hoverflies are capable of consuming vast amounts of small-soft-bodied insects daily.
	Example 5 name	Green lacewings
	Example 5 description	After they have hatched, the larvae of Green lacewings are distributed by sprinkling. They feed on aphids, small worms, eggs, mites and thrips.
	Example 6 name	Beneficial nematodes
	Example 6 description	Beneficial nematodes (such as the Heterorhabditis bacteriophora) are applied to control different beetle larvae in the soil. The nematodes use the larvae as hosts, killing them in the process.
	Example 7 name	Push-Pull integrated pest management
	Example 7 description	In an area affected by stemborer moths, maize is intercropped with a repellent "push" plant (e.g. desmodium). The plot is surrounded by an "pull" plant (e.g. napier grass), attractive to the moths but which secretes a sticky substance trapping their larvae.
77	**AMP**	**Physical pest control**
	AMP description	Physical pest control is a method of removing insects and small rodents by trapping, setting up barriers or kaolin sprays to prevent further crop damage. It also includes controlling pests before plants are sown.
	Example 1 name	Insect traps
	Example 1 description	Coloured traps emitting pheromones are set up in agricultural fields to attract and kill flying insect pests. These traps are intended to provide an effective replacement for expensive insecticides.
	Example 2 name	Tree bufferzone
	Example 2 description	Indigenous trees are used to create a buffer zone between fields, preventing the spread of diseases. The trees also enhance the biodiversity of the area.
	Example 3 name	Kaolin spray

	Example 3 description	Kaolin (a clay mineral) is sprayed onto tree and vegetable crops. The spray leaves a particle film that protects from pests and environmental stresses.
	Example 4 name **Example 4 description**	Rodent traps Traps are placed at strategic locations to capture or kill rodents that often cause serious harm to crops and plants.
	Example 5 name **Example 5 description**	Fences Fences are constructed from (typically locally grown) wooden poles and galvanized iron netting (for example to keep wild boars off pasture).
	Example 6 name **Example 6 description**	Nets and nethouses Nets are used in fruit cultivation to protect against birds. A net house is a structure that is enclosed by a nylon net (like a mosquito net) protecting vegetables from insects and damage by rainfall, wind and sunlight.
	Example 7 name **Example 7 description**	Temporary inundation Bulb fields are temporarily inundated to clear the soil of nematodes, weeds and bulb residues. Inundation reduces the use of chemical pesticides and the submerged plots are popular with birds attracted by mosquito larvae, worms, and water fleas.
78	**AMP** **AMP description**	**Chemical pest control** Chemical pest control uses pesticides to control pest populations. Pesticides can be sprayed or added as seed dressings. Application of pesticides may contaminate soil and water, and might have negative impacts on soil and aquatic life.
	Example 1 name **Example 1 description**	Systemic insecticides Systemic insecticides are applied as a drench to the crop or as a granule to the soil. They are water soluble and become absorbed and distributed systemically throughout the whole plant. When insects feed on the plant, they ingest the insecticide.
	Example 2 name **Example 2 description**	Contact insecticides Contact insecticides are commonly sprayed onto the crop. They are designed to be toxic upon direct contact with insects and include inorganic insecticides (containing metals and sulfur), organic insecticides (synthetically produced) and natural insecticides (like pyrethrum and neem oil).
	Example 3 name **Example 3 description**	Insect growth regulators Insect growth regulators (such as Diflubenzuron which is used to control caterpillars and Hydroprene which is used to control cockroaches and moths) are used to control insect populations. IGRs makes use of insect hormones to inhibit their growth.
	Example 4 name **Example 4 description**	Rodenticides Rodenticides are used to reduce rodent populations by poisoning them via ingestion, either being lethal after one exposure or multiple exposures. Rodents are sometimes very harmful for agriculture.
	Example 5 name **Example 5 description**	Botanical pesticides Tree rosin, oleoresin (produced by conifer species) and neem oil are applied as botanic pesticides. These are some of the many organic compounds produced by plants to defend themselves from predation.
	Example 6 name	

	Example 6 description	
79	**AMP** **AMP description**	**Physical disease control** Physical disease control involves targeted applications of hot water, steam, hot air, fire or flooding to combat plant diseases. It can also include actions and barriers to avoid contamination.
	Example 1 name **Example 1 description**	Hot water seed treatment Seeds are treated with hot water as an effective way to kill pathogens (especially bacteria and viruses) without affecting seed quality.
	Example 2 name **Example 2 description**	Soil solarization The soil surface is covered with transparent plastic film, taking advantage of solar radiation to heat the soil to temperatures that are lethal to many fungal pathogens and nematodes.
	Example 3 name **Example 3 description**	Soil steam sterilization Soil in open fields or greenhouses is sterilized using steam. The steam kills plant pathogens (bacteria, fungi, viruses) by causing vital cellular proteins to unfold.
	Example 4 name **Example 4 description**	Burning crop and pruning residues For diseases for which no cure exists, infected crop and pruning residues are burned as a last resort option. Burning is an effective control of all kinds of pathogens.
	Example 5 name **Example 5 description**	Flooding Temporary flooding is used as an effective method to control plant-parasitic nematodes and other soilborne pathogens.
	Example 6 name **Example 6 description**	Cleaning farming equipment Farming equipment is cleaned to remove contaminated debris and soil that can harbor pathogens (such as Verticillium or nematodes) and prevent their introduction into non-infested fields.
	Example 7 name **Example 7 description**	Pre-harvest fruit bagging Bags are placed around the growing fruit as a means of physical protection. They: improve the visual quality of fruit by promoting skin colouration, reducing blemishes, sunburn and cracking; change the micro-environment for fruit development; reduce the incidence of disease, insect and bird damage; and reduce agrochemical residues.
80	**AMP** **AMP description**	**Chemical disease control** Chemical disease control is the application of pesticides to combat plant diseases. There are numerous pesticides available for different diseases. Application of pesticides may pollute soils and water and affect soil and aquatic life.
	Example 1 name **Example 1 description**	Treated seeds and planting materials Seeds or planting materials are treated with fungicides for protection against fungi causing seed rot, seedling rot (damping off) and seedling diseases, especially when planted in cold, wet fields.
	Example 2 name **Example 2 description**	Soil-applied fungicides Soil-applied fungicides are used to control soilborne diseases (such as Rhizoctonia solani (black scurf) and Phytophthora erythroseptica (pink rot) in potatoes) either prior to seeding or by in-furrow application during seeding.

Example 3 name **Example 3 description**	Foliar fungicides Fungicides are applied to the plant leaves prior to pathogen establishment or appearance of symptoms as a method of controlling disease. Systemic fungicides can eradicate specific pathogens even after they have become established in the host tissue.
Example 4 name **Example 4 description**	Injecting pesticides Systemic pesticides are injected directly into the xylem of perennials. They are distributed throughout the plant with the transpiration stream to protect against pathogens.
Example 5 name **Example 5 description**	Applying antibiotics Antibiotics (substances produced by micro-organisms that are capable of destroying or injuring living organisms) are used to combat several bacterial plant infections. The relatively rapid build-up of resistance is problematic.
Example 6 name **Example 6 description**	Soil fumigation Fumigants are used before planting in order to eradicate nematodes and fungi in the soil profile. The practice carries a high environmental risk (because of toxicity and dosage of fumigants used) and is strictly regulated.
81 **AMP** **AMP description**	**Biological disease control** Biological disease control is the suppression of diseases caused by organisms by one or more other organisms (often referred to as natural enemies). This may involve disease-resistant plant varieties, or the purposeful utilization of introduced or resident living organisms to suppress the activities and populations plant pathogens.
Example 1 name **Example 1 description**	Choosing disease-resistant varieties Disease-resistant plants are chosen to eliminate the need for additional efforts to reduce losses caused by a specific disease. Resistant plants are developed using standard breeding procedures (selection and/or hybridization) or through genetic engineering.
Example 2 name **Example 2 description**	Biofungicides Biofungicides (based on Trichoderma viride) are used for seed and soil treatment to suppress various diseases caused by fungal pathogens (e.g. Rhizoctonia, Pythium, Armillaria).
Example 3 name **Example 3 description**	Antagonistic bacteria as nematicide Pasteuria nishizawae (an obligate bacterial pathogen of the soybean cyst nematode) is added as a seed treatment causing immediate infection, stopping the nematode feeding and reproducing and ultimately killing it.
Example 4 name **Example 4 description**	Antibiotic suppression Antibiotics are applied to the crop by spray, with ground equipment or added into an irrigation system. They are microbial toxins, some of which have been shown to be particularly effective at suppressing plant pathogens and the diseases they cause (e.g. Bacillus Amyloliquefaciens, Pseudomonas fluorescens).
Example 5 name **Example 5 description**	Antagonistic bacteria outcompeting pathogenic ones Non-pathogenic soil bacterium (Rhizobium rhizogenes, strain K1026) is applied by spraying or soaking. It colonizes wounded plant tissue and blocks infections by the predominant crown gall-causing pathogenic agrobacteria that infect nut trees (almonds, walnuts), stone fruit trees (peach, plum, apricot, cherry), roses, euonymus and many other horticultural crops.

	Example 6 name **Example 6 description**	Grafting Plants with a higher resistance to pest and diseases are produced by grafting seedlings onto resistant root stocks of other plants (e.g. courgette onto wild eggplant).
82	**AMP** **AMP description**	**Phytoremediation** Phytoremediation (including phytostabilization, phytodegradation, phytoextraction and phytovolatilization) is the practice of using living green plants to immobilize or adsorb contaminants from polluted soil. It is a cost-effective and environmentally friendly approach to tackling contamination issues.
	Example 1 name **Example 1 description**	Phytoextraction using Indian mustard Indian mustard (Brassica juncea) is planted in areas contaminated with heavy metals. It produces high quantities of biomass in which a range of heavy metals are hyperaccumulated or volatilized. Aboveground parts can be removed (phytoextraction) while roots contribute to phytostabilization.
	Example 2 name **Example 2 description**	Phytoextraction and phytodegradation using willow short-rotation coppice Willow (Salix sp.) is grown to remediate soil contaminated with heavy metals including zinc, nickel and cadmium. It is a fast-growing species that is also effective for phytodegradation of organic pollutants and as a bio-energy crop.
	Example 3 name **Example 3 description**	Phytoextraction and phytodegradation using poplar short-rotation coppice Poplar (Populus sp.) is grown in a short-rotation coppice. Due to its extensive root system, high water uptake, rapid growth and large biomass production it is effective for phytodegradation of organic pollutants, as a phytoextraction strategy for most heavy metals and is a valuable bio-energy crop.
	Example 4 name **Example 4 description**	Phytodegradation of pesticides using Indian grass Indian grass (Sorghastrum nutans) is grown with other grass species on contaminated soil. Indian grass is tolerant of most herbicides and of climatic extremes. In mixed stands it develops a rhizosphere with microflora that can readily detoxify pesticide residues and reduce rates of pesticide leaching.
	Example 5 name **Example 5 description**	Phytoextraction using sunflower Sunflowers (Helianthus Annuus) are grown to remediate soils contaminated with heavy metals such as cadmium, chromium, lead and zinc. The plants accumulate the metals in their shoots and leaves (phytoextraction).
	Example 6 name **Example 6 description**	Phytostabilization using Miscanthus Miscanthus is a perennial grass grown on soils contaminated with heavy metals. Revenue can be obtained with this green-energy crop without presenting a risk to human or animal health while heavy metals are stabilized.
	Example 7 name **Example 7 description**	Phytovolatilization of arsenic using Pteris vittata The Chinese ladder brake fern (Pteris vittate) is grown to rehabilitate soil contaminated with arsenic. The fern is a hyperaccumulator of arsenic, volatizing 90% of what it takes up so no removal of plant parts is needed. It requires subtropical growing conditions.
83	**AMP**	**Integrated pest and disease management**

	AMP description	Integrated pest and disease management is a broad-based approach that considers all available pest and disease control techniques and integrates appropriate measures. The aim is to discourage the development of pest populations and diseases, keeping interventions to levels that are economically justified, and reducing or minimizing risks to the environment, soil and aquatic life and human health.
	Example 1 name	Pest and disease monitoring
	Example 1 description	Several tools are available for pest and disease monitoring including apps for disease recognition and sticky traps for insect monitoring. Monitoring is the basis for integrated pest and disease management.
	Example 2 name	Push-Pull integrated pest and soil fertility management
	Example 2 description	In an area affected by stemborer moths, maize is intercropped with a repellent “push” plant (e.g. desmodium). The plot is surrounded by an “pull” plant (e.g. napier grass), attractive to the moths but which secretes a sticky substance trapping their larvae.
	Example 3 name	Pheromone dispensers
	Example 3 description	Pheromone dispensers are used to disrupt the mating of certain insects (e.g. moths in vineyards) in order to increase yield while at the same time preserving biodiversity and the sensitive balance of the ecosystem. Pheromone use diminishes the need for insecticides.
	Example 4 name	Winter food fields
	Example 4 description	Winter food fields are not harvested and ploughed until the following spring. They serve as an important food source of grains and herbs and provide refuge for wintering field birds and mice. A more complete food web develops, ensuring lower sensitivity to pests and diseases.
	Example 5 name	Tree buffer zones
	Example 5 description	Indigenous trees are used to create a buffer zone between fields, preventing the spread of diseases. The trees also enhance the biodiversity of the area.
	Example 6 name	Flower strips for biological pest control
	Example 6 description	Flower strips are planted in rice fields as habitats for beneficial arthropods which control pests. This prevents pest outbreaks and limits the need for chemical control.
	Example 7 name	Grafting
	Example 7 description	Plants with a higher resistance to pests and diseases are created by grafting seedlings onto resistant root stocks of other plants (e.g. tomatoes onto wild eggplant).
	Example 8 name	Optimal timing of pesticide applications
	Example 8 description	The timing of herbicide and pesticide applications is optimized to reduce the amount applied. Multiple factors (including the time of day, season, stage of crop growth and local weather conditions) should be taken into account in order to make most efficient use of the products and reduce unnecessary pollution.
84	**AMP**	**Integrated nutrient management**
	AMP description	Integrated nutrient management utilizes soil, nutrient, water, crop, and vegetation management practices with the aim of improving and sustaining soil fertility and land productivity and reducing environmental degradation.
	Example 1 name	Replacing mineral fertilizers with organic matter input

	Example 1 description	Mineral fertilizers are (partly) replaced by organic fertilizers in order to increase organic matter input and improve soil quality in general, reduce wind erosion, reduce nitrate leaching, increase soil biodiversity and make the soil more resilient to stress factors like drought or excessive rainfall.
	Example 2 name	Balanced fertilization
	Example 2 description	Different types of fertilizer (such as compost, mineral fertilizers, gypsum and micro-nutrients) are applied at adjusted, balanced rates to improve soil nutrient status, prevent nutrient mining and increase water holding capacity and crop productivity.
	Example 3 name	Manure separation to better distribute organic matter at farm level
	Example 3 description	Slurry manure is fed through a separator into a thick fraction (rich in P and used in maize fields or as a substrate in cow stables) and a thin fraction (rich in N and used on other parts of the farm or exported from the farm to be treated for discharge in the environment).
	Example 4 name	Foliar fertilizer applications
	Example 4 description	Essential plant nutrients are applied as corrective foliar fertilizer based on visual symptoms or plant tissue tests to complement initial soil application. Nutrient concentration and day temperature should be optimal to avoid leaf burning.
	Example 5 name	Manure management plan
	Example 5 description	A simple manure management plan is drawn up identifying fields (or parts of fields) where spreading restrictions apply and crops that most efficiently use manure.
	Example 6 name	Carbon farming
	Example 6 description	Practices are implemented that are known to improve the rate at which CO_2 is removed from the atmosphere and converted to plant material and/or soil organic matter. Such carbon farming practices can be holistically inventoried using a carbon farm plan.
85	**AMP**	**Automated targetting**
	AMP description	Automated targeting is the application of smart farming techniques offered by artificial intelligence for implementing agronomic activities only where they are needed, saving on energy consumption and use of chemical inputs.
	Example 1 name	Weed mapping
	Example 1 description	Weed distribution and density are photographed from ground level or from a drone. The images are uploaded to an app that displays weed density maps at field and farm level that can be used to prioritize and target weed control.
	Example 2 name	Targeted weed spraying
	Example 2 description	Plant recognition technology is mounted on a crop spraying system to identify and target particular weed species. This enables a vast reduction in herbicide use.
	Example 3 name	Robotic weeder
	Example 3 description	Robotic weeders that orientate themselves in the field by means of GPS, cameras and sensors are used to target weed species. The robot arm sprays minimal amounts of herbicides on the identified weeds, leading to vast reductions in herbicide use.
	Example 4 name	Automated pest monitoring

	Example 4 description	Camera-equipped pheromone insect traps are used for automated pest monitoring. Pictures from traps are uploaded to a website where image processing and analytical software are used to recognize and monitor pests and provide recommendations.
	Example 5 name	Greenhouse plant disease predictions
	Example 5 description	Ambient monitoring sensors are combined with weather forecasts and other data to accurately predict the risk of disease outbreak and enable targeted intervention. Plant diseases can be difficult to control because once the signs have manifested, it is too late to take preventive action.
	Example 6 name	Satellite imagery-based recommendations
	Example 6 description	High resolution satellite imagery is analyzed together with agronomic data to provide recommendations for variable fertilizer or plant protection applications that can be imported to computer-managed farm equipment for implementation.
86	**AMP**	**Controlled and rotational grazing**
	AMP description	Controlled grazing is the practice of regulating the amount of grazing time and consumption levels in a pasture in order to prevent overgrazing and soil degradation. It can be applied in a rotational system, whereby livestock is allowed periodically on fields enabling effective recovery and maintaining pasture in good condition.
	Example 1 name	Rotational grazing
	Example 1 description	The grazing area is subdivided into a number of enclosures that are successively grazed by the animals. This rotational grazing ensures that not all the area is grazed simultaneously.
	Example 2 name	Split ranch grazing
	Example 2 description	Livestock is concentrated on half the available land for a full year, allowing the other half to recover. This split ranch grazing requires less fencing than more complex systems, without compromising sustainability or ecological function.
	Example 3 name	Ecograzing
	Example 3 description	Two herds are rotated on three paddocks adjusted according to climate and the state of the native perennial, productive and palatable grasses. In this ecograzing scheme all paddocks get wet season rest for 2 years out of 3.
	Example 4 name	Combined herding for planned grazing
	Example 4 description	Livestock from all households is combined each day into a single herd that is driven to designated portions of the communal grazing area. Two adaptable grazing plans are developed each year, one for when perennial grasses are growing and the other when they are dormant.
	Example 5 name	Fast rotational intensive grazing
	Example 5 description	Grazing land is divided into many small paddocks using electric fences. The paddocks are intensively grazed for short times before the animals are moved on according to a grazing plan. This holistic management approach increases productivity and improves soil health and pasture cover and species composition. Long recovery periods also provide an opportunity for the natural regeneration of tree cover.
	Example 6 name	Ecosystem-wide seasonal grazing management in community land
	Example 6 description	Grazing is community-governed to maintain spatial and temporal heterogeneity of pasture, improving pasture quality and quantity. This is

		achieved through tight controls on settlement areas, grazing patterns and water points and local knowledge of herders.
	Example 7 name **Example 7 description**	Daily and seasonal rotation on grassland A rotation system is used whereby the herder moves with the grazing animals staying between one week and one month in a different base. From each base, different directions are taken daily.
87	**AMP** **AMP description**	**Area closure** Area closure is the practice of enclosing and protecting an area of degraded land from human use and animal interference to permit natural rehabilitation. It can be enhanced by additional vegetative and structural conservation measures.
	Example 1 name **Example 1 description**	Rangeland resting Rangeland is protected by excluding grazing for 2-3 years (depending on ecosystem resilience and climatic conditions) to allow the plant cover to recover.
	Example 2 name **Example 2 description**	Area closure with enrichment planting Degraded land is protected from human and animal interference for 3-5 years. This area closure is complemented with maintenance of terraces, enrichment and overseeding of grasses to enhance growth of natural vegetation and biodiversity.
	Example 3 name **Example 3 description**	Area closure for fodder and alternative income An area of degraded land is enclosed and protected from human and animal interference for natural rehabilitation, enhanced by additional vegetative and structural conservation measures. Enclosed areas provide fodder and timber after 7-8 years.
	Example 4 name **Example 4 description**	Dry-season fodder reserves (Ngitili) Ngitili are traditional enclosures used for in-situ conservation and rehabilitation of vegetation. For initial regeneration of denuded land exclusion for up to 5 years is needed. Thereafter seasonal exclusion from the onset of the rainy season till the peak of dry season is practiced.
	Example 5 name **Example 5 description**	Sand dune stabilisation Three measures are combined to stabilize sand dunes over a number of years: enclosure; millet stalk palisade construction; and regeneration and planting of native vegetation.
	Example 6 name **Example 6 description**	Area closure and reforestation Degraded arid lands are reforested with Acacia (A. tortilis, a native drought-tolerant species) by planting the trees in pits and protecting the area with fencing. The aim is to restore and rehabilitate the forest-steppe ecosystem.
	Example 7 name **Example 7 description**	Summer resting During summer, when rangelands suffer from seasonal water stress, Mediterranean pastoralists move their flocks to deciduous forest where the animals can still find green grass. This action prevents excessive pressure on the rangelands.
88	**AMP** **AMP description**	**Pasture monitoring** The practice of pasture monitoring enables timely detection of changes in the condition and productivity of pastures caused by both anthropogenic and climatic factors. It also facilitates assessment of such changes in order to prevent and control pasture degradation.

	Example 1 name **Example 1 description**	Grazing Response Index The Grazing Response Index is calculated by managers to evaluate the frequency and intensity of pasture grazing and periods of recovery. This enables them to determine which pasture to use next and to estimate intensity of use.
	Example 2 name **Example 2 description**	Monitoring vegetation cover index A Vegetation Cover Index is calculated annually, derived from measurements of woody and herbaceous cover and woody species diversity. The index is used to monitor changes in ecological status with reference to an initial benchmark.
	Example 3 name **Example 3 description**	Monitoring the condition of pastures Georeferenced monitoring of pasture condition is carried out in 1 m2 sample plots. The plots are photographed and soil threat severity, vegetation height and cover (of palatable and non-palatable species) and fodder yield are recorded. The purpose is to detect and assess changes in condition and productivity to prevent pasture degradation.
	Example 4 name Example 4 description	
	Example 5 name Example 5 description	
	Example 6 name Example 6 description	
89	**AMP** **AMP description**	**Avoiding pugging of paddocks** Avoiding animal grazing on wet soils minimizes the structural damage (or pugging) that is easily caused by treading and trampling. Soil pore space is destroyed, reducing infiltration rates, increasing waterlogging, compaction and erosion and degrading the pasture quality.
	Example 1 name **Example 1 description**	Sacrifice paddock A sacrifice paddock (usually one with a run-down pasture) is selected to move cows onto during wet conditions. After the winter, summer fodder crop may be grown to level and restore the soil, and pasture is re-sown the following autumn.
	Example 2 name **Example 2 description**	On-off grazing In on-off grazing, cows are allowed to graze in 1-2 short periods (2-4 hours) per day and are then moved off the pasture to a stand-off area. Grass of good length and density is needed to reduce susceptibility to pugging.
	Example 3 name **Example 3 description**	Selecting pasture with tall grasses When soils are wet, pastures with tall fescue and other sod-forming perennials are grazed. Tall grasses have a flotation effect and greater root mass that help limit soil damage and expedite regrowth. Cows need to walk less far to obtain enough grazing, reducing pugging.
	Example 4 name **Example 4 description**	Slow pasture rotation A slow pasture rotation is used. If the rotation is too fast, pasture cannot reach optimum growing height, more supplementary feed is needed in winter and livestock will return to the wet paddock sooner, causing greater damage.

Example 5 name	Block grazing with temporary fencing
Example 5 description	Grazing in square or rectangular areas is used instead of elongated strips to help avoid cows walking up and down the fence line. Shifting fences and back fencing are additional strategies to avoid trampling.
Example 6 name	Stand-off pad
Example 6 description	A purpose-built, drained stand-off pad is constructed where livestock can be held for long periods when it is not suitable for them to be on pasture.
Example 7 name	Feedpad
Example 7 description	A feedpad is used for regular supplementary feeding and loafing of cattle on an area of land that is either formed with a solid foundation and/or concreted to establish a permanent facility.
Example 8 name	Visual soil assessment of pugging to support management
Example 8 description	Visual soil assessment, monitoring of soil moisture and weather forecasts are used to decide on grazing management.