SQAT

SOIL QUALITY ANALYSIS TOOL

Deliverable 2.1

Use Case Implementation Plans

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Disclaimer

The author of this document has taken any available measure to ensure that the information contained in this document is accurate, consistent, lawful, and up to date.

Executive Summary

Farms are at the forefront of the data economy, propelled by digitalisation, robotics and smart algorithms. However, these advancements exacerbate societal pressures on soil health, demanding cleaner water, healthier soils, increased carbon storage and biodiversity. Current solutions are costly and unsuitable for farmers. With this in mind, the EU-funded SQAT project will develop a smart soil mapping service. Combining multi-level, multi-technology approaches, SQAT offers high-resolution soil property maps and tailored solutions for farmers. Using autonomous robot-mounted sensors and innovative in situ analysis tools, the SQAT system enhances productivity while reducing costs. Co-developing with SMEs, SQAT aims to commercialise its solutions, empowering farmers with variable-rate applications for liming, fertilisation, seeding, tillage, and carbon farming.

The use case plans are a key managerial and organisational tool for the project. To actualise and implement the project's co-creation approach, it is necessary to structure and order the work in each use case. We apply management best practices to identify and interlink specific objectives, related activities, expected results, and KPIs to measures success, for each use case. These are described separately for each of the seven use cases in SQAT, in: Belgium, Germany, Ireland, Netherlands, Serbia, Switzerland, and Ukraine.

The use case plans in turn will be used to track and evaluate the progress of each use case. They remain a flexible project management tool for the duration of the project and can be altered to address unforeseen issues or to seize upon new opportunities.

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Abbreviations

ABE	Association of Balkan Eco-Innovations
AGRILAB	Agrilab limited liability company
ATB	Leibniz Institute of Agricultural Engineering and Bioeconomy e.V.
BSI	Bare Soil Indices
EC	Electric Conductivity
EV ILVO	Eigen vermogen van het instituut voor landbouw-en visserijonderzoek
HSG-IMIT	Hahn-schickard-gesellschaft fur angewandte forschung ev
ILT-OST	Institute for Lab Automation and Mechatronics
MRV	Monitoring, reporting, and verification
NIR	Near Infrared
OFI	Officine innovazione s.r.l.
PG	“Poljoprivredno gazdinstvo” or agricultural holding in Serbian
TERRATMD	Terra controlling tmd d.o.o
VDBORNE	Van den borne projecten bv
VI	Vegetation Indices
WP	Work Package

1 Introduction

1.1 Aims of The Document

SQAT is an innovation project that aims to develop a smart soil properties mapping system. At the core of this effort is a co-creation approach, which directly involves intended users in the development so as to maximise the value of the innovation results for the users.

This is key to the commercial ambitions of the project. Agriculture is highly heterogeneous – with different cultures (e.g. arable, horticulture), different soil properties, different legislation, different climates and micro-climates, and different socio-economic conditions – all of which impact what soil properties information is needed in what form. The use cases represent the reference in which the project will interact with users, ensuring that the solution delivers value to them within their context. There are significantly different users within use cases as between them.

Since the users are not homogenous, neither can the approach to engage with them be the same. As such, it is important to plan the engagement and testing effort and to ensure that the project makes the best use of the limited project period in the use cases to best contribute to co-creation and valuable results, while avoiding inertia, confusion, and missed opportunities.

It is to this end that the use case plans are key. The aim to provide structure and direction to make the best use of the project opportunity.

This will involve a clear management structure aligned with general best practices (such as for example the European Commission's PM^2) – what do we want to accomplish, who is involved, who is responsible for what, how will we accomplish these aims, when will these activities take place, what are their expected results, and how can we measure those results. This structure will provide a reference more than a prescription – we aim to stay agile and flexible to react to unforeseen developments and to take advantage of new business opportunities that may arise. Nonetheless, this structure will provide a reference that can be reassesses and adjusted as needed in these cases. Such changes will be reflected and presented in the use case reporting (see below).

1.2 Approach and Methodology

The partners involved in each use case drafted their own plans on the basis of a template provided by the task lead, ABE. In turn, ABE provided feedback and support as required.

The template provides key aspects that relate to the organisation of the use case, and the operation of its activities. In specific, it covers:

- Brief context:
- Overall objective and specific aims:
- Partners involved:
- Key stakeholders:
- Smart farming applications involved:

- Criteria for selection of test locations:
- Activities and implementation steps:
- Key performance indicators:
- Expected results:

The content provided in each use case plan in turn provides the basis through which to evaluate the use case on a periodic basis; in particular the objectives, the key performance indicators, and the expected results. The evaluation will take place annually and be presented in D2.2 Annual use case reports.

1.3 Document Content

This document includes the use case plans for each of the seven SQAT use cases, going in alphabetical order of the countries in which they are located, as shown in the figure below.

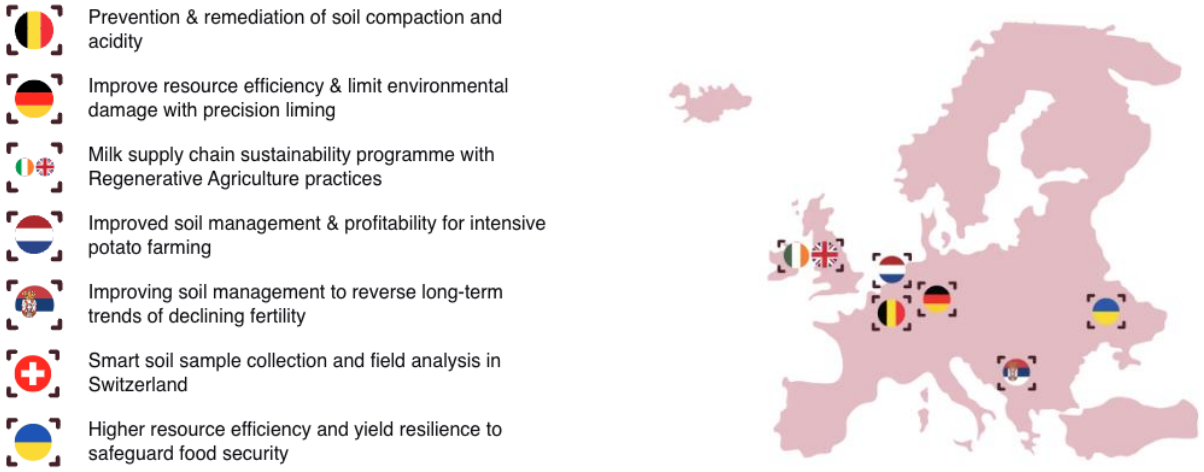

Figure 1. Graphical representation of the SQAT use cases and their locations.

After the presentation of each use case plan, the document provides a conclusion and the next steps.

2 Use case 1 in Belgium: Prevention & remediation of soil compaction and acidity in Flemish soils

2.1 Brief context

In the past decades, working widths of agricultural machinery has increased to optimise labour efficiency. This causes an increase in weight (e.g., Keller and Or (2022) found a steady increase in wheel load of tractors (1.0 to 4.0 Mg) and of combine harvesters (1.5 to 12.0 Mg) in the past 60 years) and thus in the risk of soil compaction, especially with field operations conducted in late-season, mainly for harvesting. The increase of soil pressure and field traffic at conditions with a lower soil strength have a detrimental impact on the soil quality, down to the subsoil. Recent data suggest that between 23-43% of EU arable land is critically compacted (Brus and Van Den Akker, 2018).

For Flanders, a recent field study revealed that 27% of the arable soils were critically compacted in the upper subsoil (30-50cm; Lin et al., 2022). Since soil compaction cannot always be avoided, remediating through (deep) subsoiling is often needed. In current practice, remediation or decompactation is often performed through the use of subsoilers, equipped with several teeth to break through the compacted layers. In current practice, subsoiling is performed throughout the whole field, although significant variation, both spatially and in depth can occur.

To alleviate the compacted soil layer, avoid structure loss in non-compacted regions and optimise fuel efficiency, subsoiling should be performed only where needed and at the correct depth. Adequate and affordable detection methods for mapping soil compaction are lacking, EC and ECa scans can be related to soil compaction, but also to soil salinity, moisture level and texture and thus do not provide fully reliable soil compaction maps.

Manual penetrometer measurements are very time consuming and labour intensive. Automating these measurements using a robot platform, based on remote sensing data (e.g. Copernicus, UAV) overcome current barriers to variable-depth tillage based on precise spatial data.

2.2 Overall objective and specific aims

The overall objective is to apply the novel approach developed in SQAT to optimize (deep) subsoiling applications towards higher efficiency and sustainability in practice

To deliver this objective, the specific aims are:

1. To develop an autonomous mapping of soil compaction in a high spatial resolution as an input for variable depth tillage (subsoiling)
2. To test the device(s) at the ILVO farm comparing results with manual reference measurements
3. To test the device in practice at Belgian farmers' fields
4. To conduct demonstrations and practical workshops towards relevant stakeholders

2.3 Partners involved

The partners involved are shown in the table below.

Table 1. SQAT partners involved in Use case 1 in Belgium, their main contact person, and their specific responsibilities.

Use case role	Organisation	Main contact	Specific responsibilities
Use case lead	EV ILVO	Tommy.dhose@ilvo.vlaanderen.bebe	Overall use case management, testing of the robotic solution in controlled conditions (ILVO testfarm), and in practice conditions (Belgian farmers' fields)
Support	Exobotic	rembrandt@exobotic.be	Testing of robotic platform

2.4 Key stakeholders

We will also involve multiple other stakeholders as externals that will be valuable to achieve the objectives of the use case, presently identified in the table below. Since 2018, EV ILVO has been working on developing adequate and affordable measures for detection, prevention and remediation of soil compaction. A selection of measures was tested on farmers' fields together with farmers, machine constructors and contractors to increase practicality and adoption. This network of stakeholders, as well as potential service providers, advisors and agri-consultants are involved in SQAT. For test fields we use a selection of the 200 ha of EV ILVO's experimental farm, the Experimental Platform for Agroecology in Hansbeke, and select fields in Flanders that include both arable and dairy farming on different soil textures.

Table 2. End-users involved in Use case 1 in Belgium.

	Farmers	Agrifood companies	Agri consultants	Soil mapping company	Other
Involved	✓	✗	✓	✓	✓
Name and description	The EV ILVO testfarm, the Experimental platform for agroecology in Hansbeke, a selection of Belgian farmers		A selection of agri-consultant companies	Regional soil mapping companies	Machine manufacturers (e.g. tillage equipment)

2.5 Smart farming applications involved

Table 3. Applicable smart farming applications in Use case 1 in Belgium.

	Variable-rate liming	Variable-rate macronutrient fertilisation	Variable-rate seeding	Variable-depth tillage	Carbon farming MRV
Involved	✓	✓	✗	✓	✓
Comments if applicable	*If possible*, the penetrometer measurements will be combined with other sensing applications on the robot such as pH and EC measurements	*If possible*, the penetrometer measurements will be combined with other sensing applications on the robot such as NO3 sensing		**This will be the main focus**	*If possible*, the penetrometer measurements will be combined with other sensing applications on the robot such as organic carbon measurements

2.6 Criteria for selection of test locations

The use case will involve several farm locations for various activities of the use case.

- Initial tests will be performed at the robotic testing field of EV ILVO in Merelbeke
- Next, the system will be evaluated on a selection of (experimental) fields of EV ILVO and the Experimental platform for Agroecology in Hansbeke
- In a final step, tests will be conducted on farmers' fields in Flanders (Belgium)

The key criteria for selecting the farmers'fields that will serve as testing locations are:

- Farm size, type and location
- Willingness of the farmer to cooperate
- Soil types: the main soil texture types in Flanders will be included (sand – sandy loam - loam – (clay))
- Crop type, we will focus on arable crops
- Field variability and soil compaction history: clear distinction between compacted and uncompacted zones (e.g. headland)
- Available data to start with (for task planning, the availability of previous data can be used as starting point, e.g. soil scans, harvest maps, telemetry data of heavy machinery, remote sensing data, etc.)

2.7 Activities and implementation steps

Table 4. Activities in use case 1 in Belgium.

Key activities	Sub-activities	Lead	Duration	Required inputs	Outputs
1. Testing in controlled conditions as part of an iterative development cycle	-Preliminary tests at different locations. -Testing at EV ILVO robotic testing field with the developed platform and sensors	EV ILVO	M4 – M28	- SQAT robot prototype - Sensors (penetrometer, soil moisture sensor)	Preliminary test results as input for iterative development cycle to improve the platform before we start with measurements in the field
2. Testing SQAT application on the EV ILVO farm, the Experimental platform for Agroecology in Hansbeke and Belgian farmers' fields	- Comparison of results for our robotic solution and the current state of the art (manual penetrometer measurements or EC(a) scans)	EV ILVO	M20-M34	- EC(a) scanning service	Comparison with SOTA both in resolution, accuracy and labour time
3. Promote	-Conduct demonstrations at EV ILVO and Werktuigendagen -social media posts, articles in farmers magazines, scientific publications	EV ILVO	M25-36	Technology developed and tests conducted	Promotion of the project and project results through various channels
4. Commercial case development	SQAT feasibility analysis Commercial market assessment	FARMEYE	M24-M36	SQAT proof of concept Market research Client beta testing	Commerical plan for SQAT in this use case

The activities above will be implemented in the following steps:

1. The activities above will be implemented in the following steps:
2. M1-12:
    a. Preliminary tests in controlled conditions at EV ILVO robotic testing field (first technology iteration)
    b. Preliminary tests at Belgian farmers' fields using existing EV ILVO robot platform and drone. The results of those preliminary tests will facilitate the selection of the farmers' fields that will serve as testing location for the variable depth tillage
3. M13-24:
    a. Testing new robot application at EV ILVO robotic testing field (multiple technology iterations in iterative development cycle including build, test and evaluate), EV ILVO farm and the Experimental platform for Agroecology in Hansbeke and performing reference measurements
    b. Perform field selections for farmers through analysis of available data, manual penetrometer measurements,drone images and the preliminary tests
    c. Testing the adapted subsoiler for variable depth tillage
4. M26-36:
    a. Testing new robot application at farmers' fields and performing reference measurements
    b. Demonstration at stakeholder event Agritechdag organised by EV ILVO
    c. Demonstration at big outdoor Belgian agricultural engineering fair: Werktuigendagen (Oudenaarde, Belgium)

2.8 Key performance indicators

The key performance indicators (KPIs) for the use case are the following:

Table 5. Key performance indicators for use case 1 in Belgium.

KPI title	Target	Means of verification	Link to specific aims
1. Field demonstration events to engage stakeholders	2 events for stakeholders (farmers, researchers, agri-consultants, advisors)	At least 40 external participants	Iterative development requires stakeholder feedback, both from end-users as well as other stakeholders.
2. Promote	Promotion of the use case results	2 vulgarizing publications 12 social media posts	All of the above
3. Relevant scientific papers on thematic areas	1-2 draft scientific papers, can be combined with other use cases	Dissemination reporting	All of the above

4. More efficient soil compaction management	Positive economic balance for (deep) soiling applications	After scanning, field variability in soil compaction can be determined in a more optimal way compared to the SOTA. Furthermore, fields can be subsoiled in a more optimal way, resulting in a net higher profit for the farmer (input savings: fuel, time).	All of the above
5. Business model assessment	To have financial models that reflect the opportunity for SQAT SOC estimation	Cost analysis	

2.9 Expected results

The expected results of the use case are:

1. More efficient mapping of variability in soil compaction at field scale
2. Optimisation of subsoiling in practice, using the generated data to perform this only where needed and at the correct depth.
    a. Optimum soil conditions for crop growth
    b. Positive economic balance concerning use of resources and/or yield development
        i. increased yields
        ii. reduced sensor mapping costs through autonomous mapping with robot, compared to manual measurements or the use of EC(a) scans

Increasing awareness about the variability of soil compaction at field scale, the importance of tillage depth and further acceptance and implementation of variable depth tillage in Belgian agriculture

3 Use case 2 in Germany: Variable-rate liming to improve resource efficiency and limit environmental damage

3.1 Brief context

Soil acidity is a key factor in soil fertility that concurrently influences several yield-relevant soil properties. For these reasons, farmers regularly apply lime to their fields to strive to obtain and maintain an optimal soil pH to improve crop growth.

However, even in countries with intensive agricultural production, such as Germany, the soil pH of agricultural fields is often not within the optimum range. According to a recent national soil pH survey in Germany, only 35% of the arable soils and 24% of the grassland soils were in the optimum range, whereas the pH of approximately 42% of the mineral soils under arable farming and 57% of the grassland soils was too low. Apparently, lime management on farms in Germany is not sufficient. One reason is that most farmers do not manage soil heterogeneity at field scale.

In Germany, the best management practice for lime requirement calculation is based on the empirical algorithm developed by the Association of German Agricultural Investigation and Research Institutions (VDLUFA). The procedure is based on 30 years of fertilization trials studying the correlation between soil pH and agricultural yield, brought into a simplified management structure.

The approach involves two steps: (i) a soil sampling of one mixed soil sample that is composed of several sub-samples from either the whole field or from sub-plots of 3–5 ha of assumed soil homogeneity and (ii) a look-up table system that defines the target pH value for the management unit from the analysed soil texture, soil organic matter (SOM) content and calculates lime requirement from the mismatch between this target pH and the current pH value.

However, the VDLUFA guidelines for liming are limited because they are based on relatively rough classifications of soil texture and SOM into five and four classes, respectively (Fig. 1). The algorithms that are needed in the context of the present-day requirements of precision farming should be continuous and stepless.

Furthermore, site-specific and variable-rate liming (VRL), which is a precondition for optimizing soil acidity management, requires soil data at a very fine spatial scale. High-resolution maps can therefore help to assess internal field variations in soil properties and reduce the decision uncertainty caused by this unknown spatial variation.

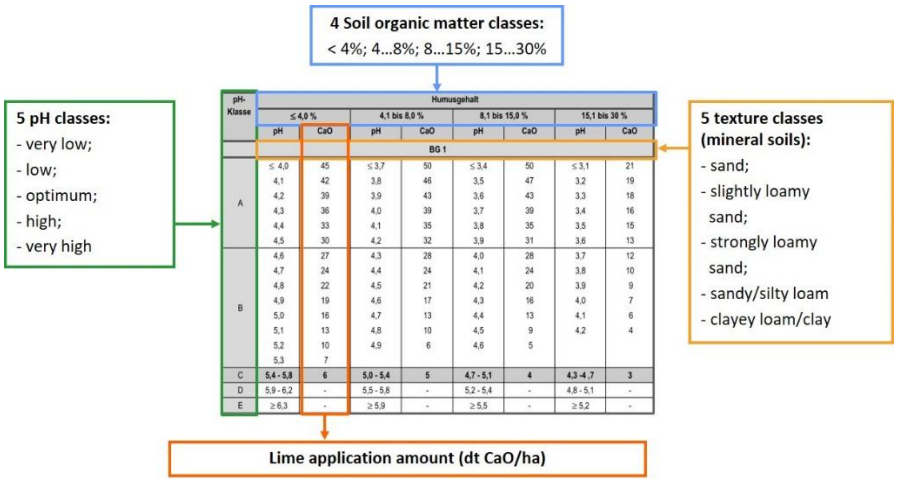

Figure 2. Look-up table system of the VDLUFA for lime requirement calculation in Germany.

As a consequence, SQAT will test autonomous sensor-based soil mapping for generating high-resolution lime requirement maps for variable-rate liming.

Since 2021, ATB is setting up the Leibniz Innovation Farm (InnoFarm) for Sustainable Bioeconomy together with 20 Leibniz institutes and 5 universities from all over Germany, developing and testing innovative concepts and technologies for a sustainable, circular bioeconomy on 940 ha of agricultural land. There are >3.000 visitors per year for trainings, field trips, seminars, etc. and there are long-standing ties with other farms and the research institutions in the region. The entire workflow of autonomous sensor mapping and lime requirement map generation is to be tested on farm scale at the InnoFarm, including the integration of our approach within the operating procedures and practical conditions of a real farm. For transfer of the project results to practitioners, we organise field days and practical workshops with farmers, service providers and agri-consultants.

3.2 Overall objective and specific aims

The overall objective is to test the developed SQAT for generating high-resolution lime requirement maps.

To deliver this objective, the specific aims are:

1. To develop autonomously sensor mapping and soil property map generation of soil pH, texture and soil organic matter in a high spatial resolution for lime requirement calculation.
2. To integrate the algorithm for stepless lime requirement calculation of Rühlmann et al. (2021, https://doi.org/10.3390/agronomy11040785) into the automated data pipeline of SQAT.
3. To test the SQAT on test fields of the Leibniz Innovation Farm and compare the soil mapping results with already existing sensor-based soil property maps
4. To conduct field days and practical workshops for transferring the results to farmers, service providers and agri-consultants

3.3 Partners involved

The partners involved are shown in the table below.

Table 6. SQAT partners involved in Use case 2 in Germany, their main contact person, and their specific responsibilities.

Use case role	Organisation	Main contact	Specific responsibilities
Use case lead	ATB	Sebastian Vogel (svogel@atb-potsdam.de)	Overall management, testing of the robotic solution on the Leibniz Innovation Farm
Support	EV ILVO	Axel Willekens (Axel.Willekens@ilvo.vlaanderen.be)	Development of the robotic platform
Support	ILT-OST	Dejan Šeatović (dejan.seatovic@ost.ch)	Development of the robotic platform
Support	HahnS	Mohamed Bourouah (Mohamed.Bourouah@Hahn-Schickard.de)	Development of the lab-on-the-field module

3.4 Key stakeholders

We will also involve multiple other stakeholders as externals that will valuable to achieve the objectives of the use case, presently identified in the table below.

Table 7. End-users involved in Use case 2 in Germany.

	Farmers	Agrifood companies	Agri consultants	Soil mapping company	Other
Involved	✓	✗	✓	✗	✗
Name and description	Leibniz Innovation Gross-Kreutz (Germany); Landwirtschaft Philipp (Boossen, Germany)		LAB GmbH (Agricultural consulting of the agricultural associations Brandenburg)		

3.5 Smart farming applications involved

Table 8. Applicable smart farming applications in Use case 2 in Germany.

	Variable-rate liming	Variable-rate macronutrient fertilisation	Variable-rate seeding	Variable-depth tillage	Carbon farming MRV
Involved	✓	✗	✗	✗	✗
Comments if applicable					

3.6 Criteria for selection of test locations

The use case will involve several farm locations for various activities of the use case. The key criteria for selecting the use case test location are:

The SQAT approach will be tested on selected arable fields of the Leibniz Innovation Farm that are characterized by a high spatial variability of the soil properties related to liming, i.e., pH value, soil texture and soil organic matter content.

The InnoFarm is being build at the Teaching and Research Institute for Animal Breeding and Animal Husbandry (LVAT e.V.) in Groß-Kreutz (Germany) and is a 940 ha large mixed farm consisting of 579.6 ha arable land and 347.8 ha permanent grassland (270 ha grassland with usage restrictions). The farm and land are predominantly owned by the federal state of Brandenburg and, with their different site conditions, represent typical arable and grassland sites in the state.

The soils of the region developed on morainic landscapes shaped by the Pleistocene glaciation processes as well as by fluvial processes in the river valley of the Havel River. The soils are predominantly sandy. Climatically, the test site is located in the transition zone of the humid oceanic and dry continental climates.

- Altitude: 33-55 m above sea level
- Average annual temperature: Approx. 9.2 °C
- Average rainfall: 500 mm
- Soil type: Light soils (S) – 70 % of the agricultural land; Boggy soils close to groundwater (meadows and pastures) – 30 % of the agricultural land
- Sloping land: 50 % of the agricultural land

3.7 Activities and implementation steps

Table 9. Activities in use case 2 in Germany.

Key activities	Sub-activities	Lead	Duration	Required inputs	Outputs

1. Lime requirement map generation of test fields	- Sensor mapping with SQAT -Reference analysis on pH (lab-on-the-field module), texture and SOM (lab analysis) - Generation of pH, texture and SOM maps - Lime requirement calculation using stepless algorithm	ATB	M24-M36	- Fully autonomously working SQAT (hardware and software)	High-resolution lime requirement / lime application maps for variable-rate liming
2. Testing SQAT on the Leibniz InnoFarm	- Comparison of SQAT outcomes with already existing sensor-based soil property maps	ATB	M24-M36	- SQAT lime requirement maps	
3. Transfer activities	- Conduct field days and practical workshops for transferring the results to farmers, service providers and agri-consultants - prepare factsheets, articles in farmers magazines, scientific publications	ATB, EV ILVO, ILT-OST, HahnS	M36-M40	- Results from practical field tests	Workshops, factsheets, articles
4.Commercial case development	SQAT feasibility analysis Comemrcial market assessment	FARMEYE	M24-M36	SQAT proof of conceopt Market research Client beta testing	Commerical plan for SQAT in this use case

The activities above will be implemented in the following steps:

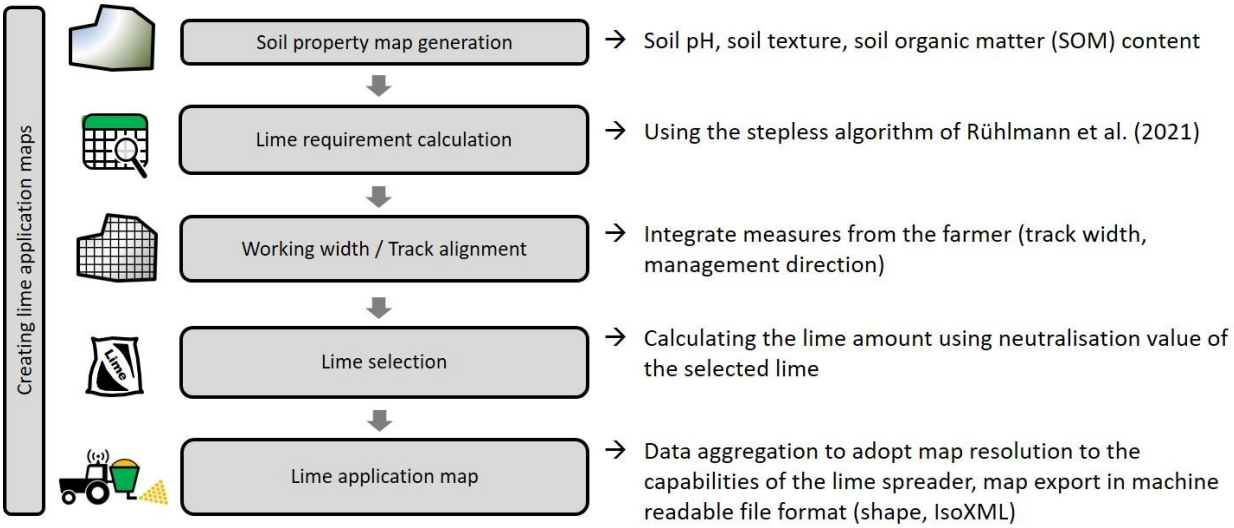

Figure 3. Proposed workflow for variable-rate liming.

3.8 Key performance indicators

The key performance indicators (KPIs) for the use case are the following:

Table 10. Key performance indicators for use case 2 in Germany.

KPI title	Target	Means of verification	Link to specific aims
1. Leverage on field demonstration events to engage customers	1-2 events stakeholders (farmers and agricultural consultants)	At least 50 external participants	All of the above
2. Judicious use of printed materials for promotion	Preparation of fact sheets to stakeholders	Distribution of fact sheets to stakeholders at workshops and online via farmers networks, 1-2 practical articles in farmers magazines	All of the above
3. Relevant scientific papers published on thematic areas	1-2 scientific papers published		All of the above
4. More efficient soil acidity management	Positive economic balance concerning use of resources and/or yield	After the liming cycle of 3 years, all parts of the field are in an optimal pH value	All of the above

	development, harmonization of soil pH value		
5. Business model assessment	To have financial models that reflect the opportunity for SQAT SOC estimation	Cost analysis	

3.9 Expected results

The expected results of the use case are:

1. More efficient soil acidity management:
    a. optimum pH values within fields
    b. positive economic balance concerning use of resources and/or yield development
        i. increases yields
        ii. reduced sensor mapping costs through autonomous mapping with robot
        iii. reduced number of reference lab analysis through lab-on-the-field module
2. Increasing acceptance and implementation of variable-rate liming in practical agriculture

4 Use case 3 in Ireland: Milk supply chain sustainability programme through Regenerative Agriculture practices

4.1 Brief context

Soil health and carbon farming are forming the basis of most regenerative agriculture programmes deployed by agri-corporates through their supply chains. The goal of these programmes is mainly to support scope 3 farmers to reduce the net carbon production emissions of their production operations. Estimation of Soil Organic Carbon (SOC) is a critical component of these programmes and forms the basis of emissions reductions through carbon removals. Measurement of SOC requires intensive infield soil sampling with laboratory bases analysis. A further requirement is to conduct infield bulk density measurements with laboratory-based analysis again required. Overall, this approach to SOC measurement comes at a significant cost to the agri-corporate client. Due to the costs the uptake of this activity is somewhat restricted despite the importance of SOC to both carbon removals and overall soil health and performance.

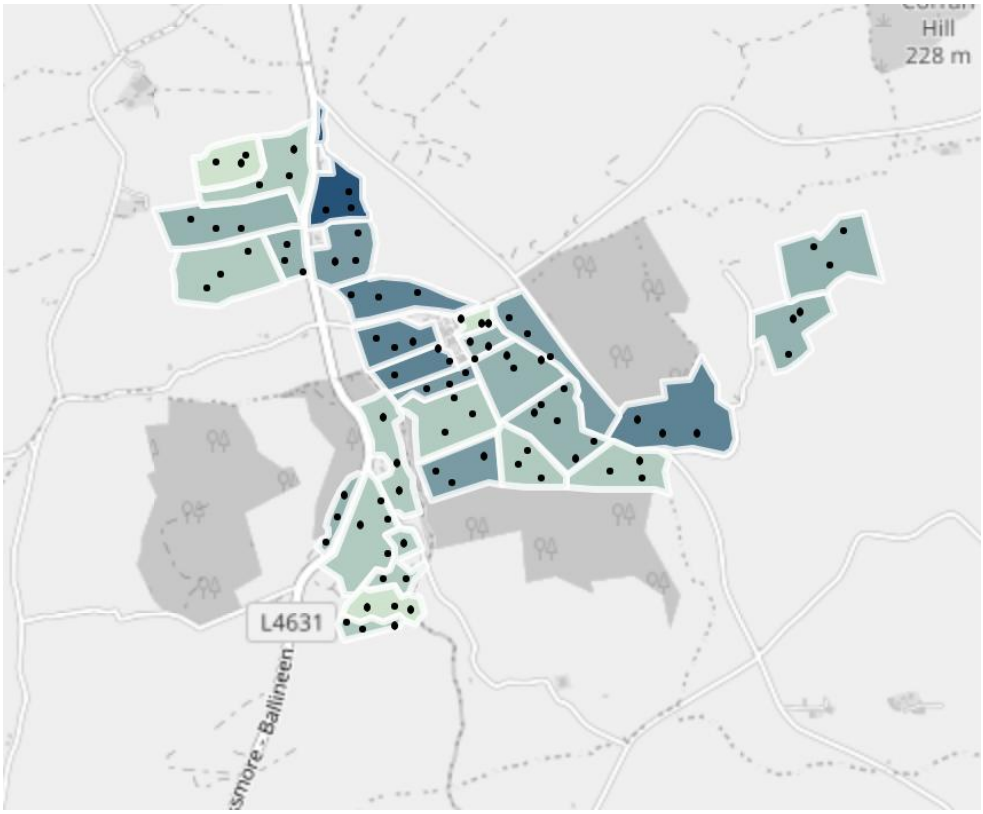

Figure 4. The outcome of SOC point sampling using standard infield sampling and laboratory analysis.

The intention with this use case is to replace standard approaches with the SQAT solution to potentially bring down costs while maintaining or increasing accuracy of the measurement. Near Infrared (NIR) scanning has the potential to replace lab analysis for SOC estimation while the combination of penetrometer and the lab in a box concept would ideally help to estimate in field bulk density in an affordable and scalable manner.

4.2 Overall objective and specific aims

The overall objective is to replace standard approaches with the SQAT solution to potentially bring down costs while maintaining or increasing accuracy of SOC estimation.

To deliver this objective, the specific aims are:

1. To develop an autonomous system to collect infield SOC and bulk density data across farms
2. To determine optimal sampling / data collection resolution based on pre sampling techniques (vegetation indices or soil scanning)
3. Conduct in field validation exercises to validate SQAT techniques to tradition soil sampling

4.3 Partners involved

The partners involved are shown in the table below:

Table 11. SQAT partners involved in Use case 3 in Ireland, their main contact person, and their specific responsibilities.

Use case role	Organisation	Main contact	Specific responsibilities
Use case lead	FarmEye	Jessica Hicks Jessica.hicks@farmeye.ie	Overall management, testing and validation of the robotic solution on the pasture based dairy farms in Ireland, the UK or Western Europe
Support	EV ILVO	Axel Willekens (Axel.Willekens@ilvo.vlaanderen.be)	Development of the robotic platform
Support	ILT-OST	Dejan Šeatović (dejan.seatovic@ost.ch)	Development of the robotic platform
Support	HahnS	Mohamed Bourouah (Mohamed.Bourouah@Hahn-Schickard.de)	Development of the lab-on-the-field module
Use case lead	ATB	Sebastian Vogel (svogel@atb-potsdam.de)	Generation of soil maps to determine sampling resolution

4.4 Key stakeholders

We will also involve multiple other stakeholders as externals that will be valuable to achieve the objectives of the use case, presently identified in the table below.

Table 12. End-users involved in Use case 3 in Ireland.

	Farmers	Agrifood companies	Agri consultants	Soil mapping company	Other
Involved	✓	✓	✗	✗	✗
Name and description	A range of dairy farmers will be involved in the programme. The location and name of the farmers is unknown at present	FARMEYE work with numerous agri-corporates in soil organic carbon measurements.These include Aurvivo, Carbery, Diageo and Tirlan	n/a	n/a	n/a

4.5 Smart farming applications involved

Table 13. Applicable smart farming applications in use case 3 in Ireland.

	Variable-rate liming	Variable-rate macronutrient fertilisation	Variable-rate seeding	Variable-depth tillage	Carbon farming MRV
Involved	✗	✗	✗	✗	✓
Comments if applicable					This use case is aligned to internation MRV protocols. It will be essential that the outcomes of SQAT can comply with GHG protocols or the UNs GSOC MRV protocol

4.6 Criteria for selection of test locations

The use case will involve several farm locations for various activities of the use case. The key criteria for selecting the use case test location are:

1. The farms will be predominantly pasture-based dairy or beef farms (arable farms may also be trialled).
2. The farms must be part of a Sustainable Soil Management programme and members of an agri-corporates Soil Organic Carbon programme.
3. Farms are that are having traditional soil sampling methods carried out on farm. This will support validation objectives within the use case.
4. The farms must be strategically located to ensure variation in soil type, texture and topography to ensure a representative of the overall supply chain of the agri-corporates they supply.

4.7 Activities and implementation steps

Table 14. Activities in use case 3 in Ireland.

Key activities	Sub-activities	Lead	Duration	Required inputs	Outputs
5. Determine SQAT feasibility for SOC estimation (to include bulk densities)	Soil scanning with NIR Soil sampling for bulk density analysis Mapping SOC estimation areas	FARMEYE	M24 – M36	SQAT proof of concept	SOP for SOC extimation at a farm level using SQAT autonomous system
6. Validation	Infield comparison between SQAT and traditional systems	FARMEYE	M24-M36	SQAT system Traditional systems in tangent for comparison	Validation report to determine the feasibility of the SQAT system for SOC estimation
7. Commercial case development	SQAT feasibility analysis Comemrcial market assessment	FARMEYE	M24-M36	SQAT proof of conceopt Market research Client beta testing	Commerical plan for SQAT in this use case

4.8 Key performance indicators

The key performance indicators (KPIs) for the use case are the following:

Table 15. Key performance indicators for use case 3 in Ireland.

KPI title	Target	Means of verification	Link to specific aims
6. Field demonstration	1 test / trial to assess the SOC estimation capabilities	Data made available to partners and external reviewers for assessment	
7. Market engagement	Engage with at least 10 corporate clients on their requirements for SOC measurement	Minutes and report on the client meetings	
8. Business model assessment	To have financial models that reflect the opportunity for SQAT SOC estimation	Cost analysis	
9. Validation of SOC results (SQAT v Traditional)	One test / trial	Data analytics	

4.9 Expected results

The expected results of the use case are:

1. A more affordable and scalable methodology for estimating Soil Organic Carbon stocks in agriculture
    a. SOC estimates using Near Infrared
    b. Infield bulk density using the lab-in-a-box system
2. Affordable SOC measurement systems will enable a wider adoption of Regenerative Agriculture or carbon farming programmes.

5 Use case 4 in the Netherlands: Improved soil management and profitability for intensive potato farming in the Netherlands

5.1 Brief context

The sandy soils around Reusel are characterised by high variability in SOM. Also, parcels are often bordered by forest or lines of trees, creating shadows and competition for nutrients and water. Uniform seeding therefore always causes big differences from place-to-place in crop success – in particular for potato, a rotation crop (once every 3 or 4 years on the same field), which farmers continuously cultivate on different land. Creating soil properties maps helps farmers to make better choices in required crop density. Modern seeding equipment enables this practice. (Kempenaar 2018)[1] The sensors and robot as developed/integrated in this project allows for a more affordable, accurate and actionable soil map.

The use case involves potato farmers (including vdBorne with 500 ha), contractors (including those linked to vdBorne), De Dommel water board, and a potato processor. The result will be to improve crop density tuned to relevant soil conditions, and hence use less seeding material, but with better yield, for an economically more viable operation.

In 2017 vdBorne researched soil properties on his fields in a proof of principle. Properties were measured with a platform made of an autonomous tractor using a combination of sensors to be used as an information source to create VRA maps for planting the seed potatoes.

After learning from these results vdBorne has optimised VRA for planting seed potatoes with a combination of EC, top soil depth and clay/sand ratio. And in a later iteration a correction for shade is added. VRA planting has become a standard practice at vdBorne.

Ideally, SQAT will provide a proof of concept, using as much as possible the legacy from previous experiences at vdBorne. It will make use of only the most relevant sensors on an autonomous platform and guided by satellite data to the right sampling points.

Current environmental restrictions, imposed by regulations like the Water Framework Directive, farmers are increasingly motivated to apply nutrients on a as-needed base. Therefore, based on the SQAT created soil map, the platform will also create task maps for variable rate macro-nutrient fertilisation.

[1] https://link.springer.com/article/10.1007/s11540-018-9357-4

5.2 Overall objective and specific aims

The overall objective is to test and demonstrate the SQAT system for generating high-resolution prescription maps for planting potatoes, based on nutrient carrying capacity.

To deliver this objective, the specific aims are:

1. To develop an autonomous platform in tandem with satellite imaging for mapping of soil properties in a high spatial resolution. To be used as an input for VRA of seed potatoes;
2. To analyse currently used sensors as a viable method of determining appropriate VRA of seed potatoes;
3. To validate remote sensing based maps with existing datasets from other sources;
4. To optimize sampling locations for increased capacity;
5. To test the SQAT system in the field;
6. To conduct demonstrations and field days for transferring results to farmers, service providers and agri-consultants.

5.3 Partners involved

The partners involved are shown in the table below.

Table 16 SQAT partners involved in Use case 4 in Netherlands, their main contact person, and their specific responsibilities.

Use case role	Organisation	Main contact	Specific responsibilities
Use case lead	vdBorne	paul@vdbornecampus.com	Providing background information
Support	vdBorne	luka@vandenborneaardappelen.com	Testing of robotic solution, gathering and managing available datasets
Support	AeroVision	Tamme.vanderwal@aerovision.nl	Overall management

5.4 Key stakeholders

We will also engage other stakeholders that have an interest in the objectives of the use case, presently identified in the table below. vdBorne has been an early adopter of precision agriculture techniques. And has used multiple soil sensors to map fields since 2016.

Table 17 End-users involved in Use case 4 in Netherlands.

	Farmers	Agrifood companies	Agri consultants	Soil mapping company	Other
Involved	✓	✗	✗	✓	✓
Name and description	vdBorne	Processing company, FarmFrites, McDonalds		Soil masters	AeroVision, water board Dommel

5.5 Smart farming applications involved

	Variable-rate liming	Variable-rate macronutrient fertilisation	Variable-rate seeding	Variable-depth tillage	Carbon farming MRV
Involved	✗	✓	✓	✗	✗
Comments if applicable		This will be a 2nd result	This will be the main focus		

5.6 Criteria for selection of test locations

The use case will involve fields that are managed by vdBorne. These are in a wider area around Reusel, The Netherlands. Some fields may be owned by vdBorne, other fields are managed by vdBorne for growing potatoes. The key criteria for selecting the use case test location are:

- Previous datasets including soil information available.
- Heterogeneous fields
- Typical -> translatable for making a business case
- Arable farming, with focus on potatoes
- Potato with 1 in 3 rotation (less than 1 in 3 rotation may have biological factors acting as a moderator on measured chemical and physical properties)
- Test farm: long standing clients from vdBorne

5.7 Activities and implementation steps

Key activities	Sub-activities	Lead	Duration	Required inputs	Outputs
1. Determining SQAT feasibility with existing data	Categorising fields and clients. Analysing legacy data	AeroVision	M06-M12	Datasets previous soil maps vdborne	Overview selected fields and clients for further research
2. Proof of concept	Gathering soil information	vdBorne	M13-M15	Soil sampling data	Requirements for prototype robot
3.Validate	Analysing soil sampling data with satellite imaging	AeroVision	M16-M24	Soil sampling data and satellite imaging	Requirements for SQAT platform
4. Prototype	Testing prototype	vdBorne	M25-M40	Satellite imaging	VRA seedling planting
5. Promote	Demonstrations	AeroVision	M25-M40	Reporting results	Demonstrations, field days
6. Commercial case development?		AeroVision	M25-M40		Commercial plan for SQAT in this use case
7.Commercial case development	SQAT feasibility analysis Comemrcial market assessment	FARMEYE	M24-M36	SQAT proof of conceopt Market research Client beta testing	Commerical plan for SQAT in this use case

5.8 Key performance indicators

The key performance indicators (KPIs) for the use case are the following:

KPI title	Target	Means of verification	Link to specific aims
1. Field demonstration to engage customers	Demonstration during vd Borne precision days and the future food & farming experience	At least 50 external participants	All of the above
2. Policy abstract	A description of the proof of concept as a potential consideration in policy.	Report	
3.Practice abstract	A description of best practices using soil properties for VRA of seedlings and macronutrient fertilizer	Report	
4.Business model assessment	To have financial models that reflect the opportunity for SQAT SOC estimation	Cost analysis	

5.9 Expected results

The expected results of the use case are:

1. A map that helps to plant seedlings optimally, based on soil potential and shade
2. An optimal allocation of macro nutrients based on differences within soils.
3. Less chance of emissions of nitrogen
4. A more cost-effective method of gathering soil information
5. A more accurate method of gathering soil information
6. A more useable result of gathering soil information
7. Increasing awareness about the variability of soil properties at field scale, the importance of VRA for macro nutrients and potato seedlings among farmers in the Netherlands.

6 Use case 5 in Serbia: Improving soil management to reverse negative long-term trends in soil organic matter

6.1 Brief context

Agriculture production in the Republic of Serbia is organised on an area of 3,25M ha of arable land. According to official statistics mainly crops cultivated are corn/maize, wheat, soya beans, sunflower, rapeseed/canola. Due to intensive farming, usage of mineral fertilisers, leak of organic fertilisers and with aim for maximum yields, combined with extreme weather conditions in the past decade, Serbian soils are losing their soil organic matter. At this moment only 1% of soils in Serbia have more than 5% of humus.

Main agricultural part of Serbia is Vojvodina, located on the Pannonian Plain with more than 1,7M ha of arable land based on large predominance of high-quality soils (60% chernozem) and abundant water.

Intensive cultivation has resulted in long-term SOM decline, which together with growing input prices puts farming profitability in jeopardy. Main problem in the past 20-30 years was non adequate sampling methodology which in most cases was done by farmers or farm workers. No additional mapping was done, especially not for bigger plots (>20ha) with aim to have real information of whole plot and at the end to homogenise the plot by using optimum amount of fertilisers for each sample.

Beside our partner list, we use ABE's cluster network to link with the local ecosystem and promote uptake: farmer organisations (SUMP); major land-owning corporations (Matijevic, DeltaAgrar, etc.); national & provincial Agricultural Advisory Services (PSSS, PSSV); independent agri-consultants; etc.

Terra Controlling TMD since beginning is working on the education of farmers when, how and why to take correct samples and what benefits they can get from that. For the farmers who owns parcels/land parts with area bigger then 15ha we offer services, which define the best way for the soil sampling process. Our Soil sampling service was prepared using historical satellite images (minimum four dates per year). With those images we created different vegetation indices (VI) and bare soil indices (BSI) for each date. For each year we have created zones based on VI. or BSI Finaly, we have used those zones to create final zones for soil sampling fields with approximately 5 ha of area. Then we prepare soil sampling locations for each zone/sample (between 15 and 25 per one soil sample), and optimal trajectory for cars.

Sampling is done using automatic probes with depth up to 90cm of soil. For this service we use 2 probes – Bodenprobentechnik Peters mounted on vehicles. Testing is done in an accredited laboratory for soil testing in Novi Sad according to national approved methodology.

The use case works with family farms to improve soil management, with test fields already committed:

- Total area of 50-75 ha of arable land (cereals & oil cultures, vegetables if needed) in repetition of sampling 2-3 times per year which will lead to cca 400 ha totally covered.
- 10 ha of vineyard with 2 sampling per year
- 10-15 ha of orchard with 2 sampling per year

For this Use Case we will communicate with small & medium farmers from all parts of Vojvodina in order to collect as much as needed samplings and results which will be used for further maintenance of SQAT project. Additional changings of fields are possible if needed by other use cases and work packages.

6.2 Overall objective and specific aims

The overall objective is to collect information of soil health parameters which will be used for developing of SQAT and further maintenance and upgrade, and to develop useful services tailored to the Serbian context for multiple cultures which contribute to soil health stewardship.

To deliver this objective, the specific aims are:

- Map chosen fields/plots using VI or BSI.
- Make sampling zones according to results of mapping – processing of satellite images & indices.
- Take samples (15 subsamples for each) from defined zones.
- Test samples in accredited laboratories.
- Combine results and interpolate with mapping results together with SQAT need.

6.3 Partners involved

The partners involved are shown in the table below.

Table 18. SQAT partners involved in Use case 5 in Serbia, their main contact person and their specific responsibilities.

Use case role	Organisation	Main contact	Specific responsibilities
Use case lead	TerraTMD	Dušan Jovanović (dusan.jovanovic@terracontrolling.rs)	Overall management, identification of test fields, testing of the robotic solution on the test fields.
Support	ABE	Srdjan Pavlović (srdjan@balkanecoinnovations.org)	Coordination and communication support, identification of test fields

6.4 Key stakeholders

We will also involve multiple other stakeholders as externals that will be valuable to achieve the objectives of the use case, presently identified in the table below.

Table 19. End-users involved in Use case 1 in Serbia.

	Farmers	Agrifood companies	Agri consultants	Soil mapping company	Other

Involved	✓	✗	✓	✗	✓
Name and description	PG Vasic Agro, PG Milan Tišma, PG Petar Matijević		University of Novi Sad Faculty of Agriculture Laboratory for testing soil, fertiliser and plant material Department of Agrochemistry		Vineyards: PG Frug Orchards: Faculty of Agriculture, Department of Viticulture, horticulture and landscape architecture; PG Srdjan Pavlović

6.5 Smart farming applications involved

Table 20. Applicable smart farming applications in use case 5 in Serbia.

	Variable-rate liming	Variable-rate macronutrient fertilisation	Variable-rate seeding	Variable-depth tillage	Carbon farming MRV
Involved	✗	✓	✓	✗	✗
Comments if applicable		n/a	n/a		

6.6 Criteria for selection of test locations

The use case will involve several farm locations for various activities of the use case settled in different part of Vojvodina. The key criteria for selecting the use case test location are defined by needs of SQAT in order to have as much as can different results as possible.

For this purpose, we will use 3 different geographically and topographical regions of Vojvodina for field and vegetable crops & orchard and vineyard production:

1. Srem, village Ašanja
2. Bačka, village Zmajevo
3. Banat, village Srpska Crnja
4. Šumadija, village Kloka

All regions are different by type of soil, wheatear conditions, used agriculture techniques and type of production.

Farms chosen for this project are individually family farmers and production are done on open field. One of partners in our use case is Agriculture Faculty, Department of Viticulture, horticulture and landscape

architecture with their experimental orchards of cherry. Main culture on farms is corn, wheat, sunflower and rapeseed. Crop rotation is done on yearly basis. Only one culture per year mainly.

Fields or plots are from 5 to 60 ha maximum and for SQAT purpose we will use plots up to 30 ha.

The climatic zone in which Vojvodina resides is Pannonian-continental, characterised by a continental climate. Its features include very warm and dry summers, contrasted by cold winters. Notably, during winter, cold air masses from the north penetrate the region. Transitional seasons are short-lived. The infamous "Košava," a strong, gusty wind, intermittently blows through the region, originating from the Đerdap Gorge and sometimes reaching as far as Subotica. Annual precipitation is low, ranging from 600 to 700mm, with the highest levels occurring in May and June, crucial months for crop growth. Prolonged droughts can occur during the summer months. Insolation, or the duration of sunshine, reaches its peak at Palić with a remarkable 2188 hours per year, while Kikinda receives the lowest precipitation levels at 557mm.

Vojvodina is composed of three main geographical regions intersected by major rivers, the Tisza and the Danube. Banat, stretching across three countries—Serbia (Vojvodina), Romania, and a small portion of Hungary—is delineated from other regions of Vojvodina by the Tisza River to the west (from Bačka), the Danube River to the west (from Srem), and to the south (from Pomoravlje in central Serbia). Banat's terrain is predominantly flat, featuring the Deliblato Sands in the southwest and the Vršac Mountains in the southeast, bordering Romania. Bačka, situated between Hungary (north Bačka) and Serbia (south Bačka), is bounded by the Tisza River to the east (from Banat), the Danube River to the south (from Srem), and by Baranja and Slavonia (regions in Croatia) to the west. Bačka's landscape is mostly flat, with fertile soil for cultivation. Along the Danube, numerous marshes and forests dot the region. In the southeast, at the confluence of the Danube and Tisza rivers, lies Titel Hill, a small elevation with a height of 152 meters. Srem, located between Serbia (eastern border) and Croatia (western border), is delineated by the Danube River to the north (from Bačka) and to the east (from Banat), as well as by Mačva and Šumadija, which lie to the south across the Sava River in central Serbia. Fruška Gora mountain range dominates the relief, boasting the highest peak at 548 meters and standing as the only national park in Vojvodina. The southern part of Srem, or the Posavina region, is predominantly flat.

6.7 Activities and implementation steps

Table 21. Activities in use case 5 in Serbia.

Key activities	Sub-activities	Lead	Duration	Required inputs	Outputs
1a. Macronutrient requirement map generation of test fields	- Copernicus mapping and zoning - Soil sampling - Generation of NPK maps - NPK requirement calculation	Terra	M6-M36	- Data from Copernicus and data from owner of test fields - Fully autonomously working SQAT (hardware and software)	High-resolution macronutrient requirement / macronutrient application maps for macronutrient variable-rate fertilization

	- Sensor mapping with SQAT - NPK requirement calculation				
1b. Seeding requirement map generation of test fields	- Copernicus mapping and zoning - Soil sampling - Generation of NPK maps - Yield mapping - Seeding requirement calculation - Sensor mapping with SQAT - Seeding requirement calculation	Terra	M6-M36	- Data from Copernicus and data from owner of test fields - Fully autonomously working SQAT (hardware and software)	High-resolution seeding requirement / application maps for variable-rate seeding
2. Testing SQAT on test fields	- Comparison of SQAT outcomes with already existing sensor-based soil property maps	Terra	M24-M36	- SQAT fertilization and seeding requirement maps	
3. Transfer activities	- Conduct field days and practical workshops for transferring the results to farmers, service providers and agri-consultants - prepare factsheets, articles in farmers magazines, scientific publications	All partners	M36-M40	- Results from practical field tests	Workshops, factsheets, articles

4.Commercial case development	SQAT feasibility analysis Comemrcial market assessment	FARME YE	M24-M36	SQAT proof of conceopt Market research Client beta testing	Commerical plan for SQAT in this use case

The activities above will be implemented in the following steps:

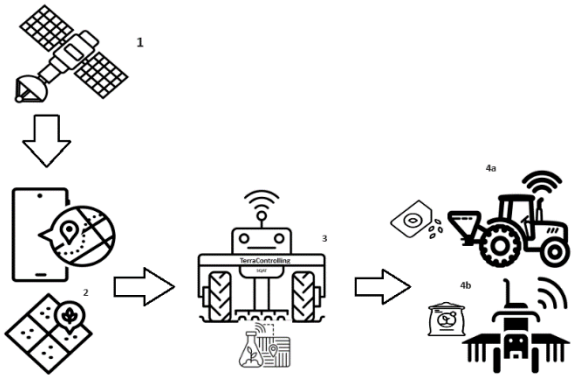

Figure 5. Schematic representation of the steps to be used to generate services for farmers in Serbia.

1. Zoning is based on VI and BSI (*Copernicus).
2. Define final zones and locations for soil sampling.
3. Soil sampling and laboratory results via robotic platform (SOC, Bulk density, pH, Soil texture, Hydrogen, NPK).
4. Based on data from laboratory and from customers – creating maps for variable fertilisation and variable seeding

*Data from Copernicus satellites are going to be used (likely Sentinel-2) due to its availability and resolution (10-20m for visible and NIR bands). Sentinel data can be adequate for generating macronutrient requirement maps when combined with high-quality ground-truth data and advanced interpolation methods. However, if sub-field level precision is needed, especially for macronutrient variability within smaller zones (e.g., <5 ha), complementary high-resolution commercial satellite data (like PlanetScope with 3 m resolution) or drone imagery may be necessary. The adequacy depends on: Spatial resolution: To capture detailed variability. Temporal frequency: Ensuring timely imagery during critical growth stages. Spectral bands: For calculating indices like NDVI, BSI, and other vegetation-related metrics.

6.8 Key performance indicators

The key performance indicators (KPIs) for the use case are the following:

Table 22. Key performance indicators for use case 5 in Serbia.

KPI title	Target	Means of verification	Link to specific aims
1. Leverage on field demonstration events to engage customers	1-2 events stakeholders (farmers and agricultural consultants)	At least 20 external participants	
2. Judicious use of printed materials for promotion	Preparation of fact sheets to stakeholders	Distribution of fact sheets to stakeholders at workshops and online via farmers networks, 1-2 practical articles in farmers magazines	
3. Relevant scientific papers published on thematic areas	1 scientific papers published		
4. Business model assessment	To have financial models that reflect the opportunity for SQAT SOC estimation	Cost analysis	

6.9 Expected results

The expected results of the use case are:

1. More efficient soil management:
    a. optimum NPK values within fields
    b. positive economic balance concerning use of resources and/or yield development
        i. increases yields
        ii. reduced number of reference lab analysis through lab-on-the-field module
2. Increasing acceptance and implementation of variable-rate fertilization and variable rate seeding in practical agriculture

7 Use case 6 in Switzerland: Automatic soil sample collection and field analysis

7.1 Brief context

ISF has secured the commitment of FENACO, the Swiss farmer cooperative, and will engage government/private agri. advisors. The quadrupedal robot is deployed in a number of farmer fields with high-value crops and with high intra-field heterogeneity: apple orchards and berry fields (strawberries, raspberries). The experiment will test and compare a novel lightweight drilling and soil-sample compartmentalisation (spring, mid-summer and autumn with high density of samples, 2 per 5m2) to state-of-the-art soil-sampling manual soil sampling tools. Farmers will provide input on their fertilisation procedures and be involved in the experiment design process.

7.2 Overall objective and specific aims

The primary objective of this use case is to advance soil sampling techniques in agricultural fields by implementing control software for a state-of-the-art quadrupedal robot featuring a groundbreaking drilling device. The project will involve designing and constructing a robotic system capable of independently traversing diverse agricultural terrains, identifying optimal sampling locations, and executing precise soil sample collection while minimising environmental disruption. Furthermore, the project will entail extensive research and development efforts to optimise the drilling device for various soil compositions and environmental conditions, including integrating advanced sensors for real-time data acquisition and analysis. The aim is to establish a highly dependable and efficient tool for conducting meticulous soil monitoring and analysis tailored to the specific requirements of agricultural settings.

The project's next phase will focus on developing a novel container for the soil samples. This container will be designed to securely store and preserve the collected soil samples while allowing easy retrieval and analysis. The goal is to create a container that can maintain the integrity of the soil samples during transportation and storage, ensuring that the data obtained from the samples remains accurate and reliable. Additionally, the container will be equipped with tracking and labelling capabilities to streamline the organisation and cataloguing of the samples, facilitating efficient data management and analysis in agricultural research and monitoring.

Furthermore, the robotic system will have an automatic delivery mechanism to transport the soil samples from the collection site to the field lab for analysis. This feature will enable seamless and timely transfer of the samples, reducing the risk of contamination or degradation and expediting the overall soil analysis process. The automatic delivery system will be designed to ensure the safe and efficient transportation of the soil samples, maintaining the integrity of the data throughout the entire sampling and analysis workflow. This integrated approach aims to revolutionise soil sampling practices in agricultural fields, offering a comprehensive solution for precision agriculture and environmental monitoring.

7.2.1 Aims

The specific aims are:

1. To develop and test lightweight drilling devices for a magnitude of soil types. The drilling and soil sample collection depth is 0.9 m… The drilling device and its components, particularly the mechanical structure, must be as lightweight as possible to maximise the entire system's efficiency. Thus, typical lightweight materials offering high stiffness (and strength) combined with low density will be used. This might be a pure composite solution or a combination of composites and aluminium/steel as a hybrid structure. To obtain an optimal stiffness/weight ratio, structural optimisation based on Finite Element Simulation (coupled with, e.g. genetic algorithms) will be used. The available construction space determines the envelope for this optimisation; thus, different geometries (e.g. tubes, framework, and beams) will be evaluated. Concerning composite and hybrid solutions, it is necessary to characterise all the materials (typically, no or only insufficient material data is available) and finished products (verification of simulation, failure analysis, fatigue life). A suitable manufacturing process must also be evaluated, as different methods (e.g. prepreg-autoclave, infusion, hybrid moulding) are feasible.
2. Implement software to control the quadrupedal robot and enable automatic and collaborative system behaviour during sampling.
    a. Robot executes preplanned routes for the individual sampling process
    b. The robot manages its energy levels and plans charging stops for autonomous operation.
    c. The robot reports system status and exceptions to the user via a predefined interface.
3. Path planning is performed on high resolution, and an actual map is created through a camera-equipped UAV.
4. Logging of sample acquisition location with 3 cm accuracy.
5. Simultaneously with the soil sampling, a UAV will collect high-resolution multispectral images of the field.
6. Collected samples are stored individually on the robot in containers without cross-contamination.
7. Specific containers will be delivered to the field lab.

In addition to the automatic soil sampling, a generative deep learning method will be refinded / developed to increase the resolution of the soil homogeneity maps. A UAV-mounted multispectral sensor will collect data from experimental fields, and a training data set will be created.

To create a training dataset for increasing the resolution of Sentinel satellite images using close-proximity multispectral UAV data, high-quality, high-resolution ground-truth images will be collected, and the sensor will match the spectral bands of Sentinel images. This dataset will be used to train generative models, such as GANs or super-resolution networks, to enhance e the Sentinel data.

Steps to Create a Training Dataset

1. **Define Objectives and Study Area**: Select representative farming fields within Sentinel satellite coverage, considering diverse soil types and conditions.
2. **Select UAV and Sensor**: Use a UAV with a multispectral camera matching Sentinel-2 bands (e.g., Blue, Green, Red, Red Edge, NIR) and high spatial resolution.
3. **Plan and Collect Data**:
    - Plan flights with sufficient overlap (60-80%) and at various altitudes.
    - Conduct flights under consistent lighting, ideally during Sentinel-2 overpasses.
    - Use Ground Control Points (GCPs) for accurate georeferencing.
4. **Preprocess Images**:
    - **UAV Data**: Georeference, orthorectify, calibrate, and create high-resolution mosaics.
    - **Sentinel Data**: Apply atmospheric correction and co-register with UAV images.
5. **Create Paired Patches**: Divide both datasets into matching patches (e.g., 256x256 pixels) to form paired high-res (UAV) and low-res (Sentinel) data for training.
6. **Data Augmentation**: Use techniques like rotation, flipping, and noise addition to increase dataset size and variability.
7. **Train the Super-Resolution Model**: Choose a generative model (e.g., SRGAN, EDSR), train it using paired patches, and evaluate performance with metrics like PSNR and SSIM.
8. **Validate and Refine**: Test the model on new data, refine it by collecting more samples, and experiment with different architectures as needed.
9. **Document and Share**: Organize data and models in a repository and share results to foster collaboration and further research.

This streamlined approach will help enhance the resolution of Sentinel-2 images using high-resolution UAV multispectral data.

7.2.2 Automatic sampling project

Based on a map containing soil homogeneity indicators derived from satellite images, route planning for soil sample acquisition is a strategic process that optimizes where and how soil samples are collected. This approach uses spatial data to ensure that samples are taken from representative locations, maximizing the accuracy and efficiency of soil analysis.

Sections 1.2.2 to 1.2.4 are for a forward understanding of the process but are not part of the use case.

7.2.3 Data preparation and analysis – refer to other work packages

Satellite Image Analysis:

Satellite images are processed to extract soil homogeneity indicators. These indicators may include variations in soil moisture, vegetation health (NDVI), and other spectral signatures that correlate with soil properties like texture, organic matter, or mineral content.

The data is then mapped, showing areas of similar and dissimilar soil characteristics. This map will highlight zones of homogeneity (where the soil is relatively uniform) and heterogeneity (where there are significant variations).

Overlaying the Homogeneity Map:

The soil homogeneity map is overlaid on a geographic map of the area to be sampled. The map visually represents where the soil conditions are consistent and where they vary.

In WP 3, data preparation will be performed; the results will be used for an automatic soil sampling system.

7.2.4 Determining sample locations

Identifying Representative Areas:

Fewer samples are required in homogeneous areas because the soil properties are expected to be similar. The sampling locations can be spaced further apart, reducing the number of samples needed.

More frequent sampling is necessary in heterogeneous areas to capture the variability in soil properties. These areas will require a denser sampling grid.

Stratified Sampling Approach:

The field is divided into strata or zones based on the homogeneity map. Within each stratum, samples are taken from locations that best represent the average conditions of that zone. Multiple samples may be taken in highly heterogeneous zones to cover the different conditions.

7.2.5 Route planning

Optimization Algorithms:

Once the sample locations are identified, route planning algorithms (such as the Traveling Salesman Problem or other path optimization algorithms) determine the most efficient path between sample points. The goal is to minimize travel time and distance while covering all necessary sampling locations.

Incorporating Field Constraints:

The route is adjusted for field conditions, such as accessibility, terrain, and obstacles (e.g., water bodies infrastructure). This ensures that the sampling process is practical and feasible.

Dynamic Route Adjustment:

The route can be dynamically adjusted during sampling if real-time data is available (e.g., from drones or on-the-ground sensors). For example, if unexpected soil conditions are detected, additional samples might be collected, or the route might be modified to explore these variations further.

7.2.6 Execution

Navigation and Sampling:

- The optimized route is uploaded to the sampling robot with GNSS devices used by field personnel. The sampling process follows the planned route, ensuring samples are collected efficiently from the predetermined locations.
- The samples are sealed airtightly for delivery to the field lab
- The sample preparation for the chemical analysis is not automated, and a human operator will perform it.

Data Logging:

As samples are collected, their exact GPS coordinates and relevant field observations are recorded. This data is crucial for later analysis and correlating lab results with specific locations on the homogeneity map.

7.2.7 Post sampling analysis in the field

Once the soil samples are analysed, the results are integrated back into the homogeneity map. This updated map provides a more detailed and accurate representation of soil conditions, which can be used for further decision-making or future sampling.

7.3 Partners involved

The partners involved are shown in the table below.

Table 23 SQAT partners involved in Use case 6 in Swiss, their main contact person, and their specific responsibilities.

Use case role	Organisation	Main contact	Specific responsibilities
Use case lead	ISF-OST		Overall management, testing of the robotic solution on the
Soil sampling	ILVO	Axel Wilkens	Commercial, heavy-duty soil sampling
Homogeneity Map	Aerovision	Tamme van der Wal	Homogeneity map from satellite images

7.4 Key stakeholders

We will also involve multiple other external stakeholders that will be valuable to achieve the use case's objectives, presently identified in the table below.

Table 24 End-users involved in Use case 6 in Swiss.

	Farmers	Agrifood companies	Agri consultants	Soil mapping company	Other
Involved	✓	✗	✓	✗	✗
Name and description	Swiss Future Farm (SFF)		Swiss Future Farm (SFF)		
Hydraulic samples			ILVO		

7.5 Smart farming applications involved

	Variable-rate liming	Variable-rate macronutrient fertilisation	Variable-rate seeding	Variable-depth tillage	Carbon farming MRV
Involved	✓	✗	✓	✗	✗

7.6 Criteria for selection of test locations

The use case will involve several farm locations for various activities. The key criteria for selecting the use case test location are:

The average farm size in Canton Thurgau is approximately 20 to 30 hectares. However, there is a range in farm sizes, with some smaller family-owned farms and larger commercial operations. The diverse agricultural landscape of Canton Thurgau accommodates a variety of farming practices, from small-scale fruit orchards to more extensive vineyards and arable land. We will use the experimental area belonging to Canton Thurgau. There are more than 80 hectares available for the experiments.

In the experiment, we aim to cover open arable crops from our experimental farm and two to three orchards.

The specific fields and municipalities for the experiment will be determined after consultation with Agroscope and Fenaco to ensure the selection aligns with their expertise and recommendations.

The dominant soil types in Canton Thurgau are generally characterised as fertile and well-suited for agricultural activities. The region features a mix of loamy and sandy soils, which are ideal for fruit orchards and vineyards. These soil types provide good drainage and nutrient retention, contributing to the success of agricultural production in the area. Additionally, the presence of fertile loess soils further enhances the agricultural potential of Canton Thurgau, making it a prime region for fruit cultivation and wine production.

Canton Thurgau in Switzerland boasts a diverse climate that is influenced by its proximity to Lake Constance. The region experiences a temperate climate with mild summers and relatively mild winters compared to other parts of Switzerland. The lake has a moderating effect on the climate, leading to milder temperatures and less extreme weather conditions.

Agriculture plays a significant role in the economy of Canton Thurgau. The fertile soils and favourable climate make it an ideal region for agricultural activities. The area is known for its fruit orchards, particularly apples, pears, and cherries. Additionally, vineyards thrive in the mild climate, producing high-quality wines. The agricultural landscape of Canton Thurgau contributes to its scenic beauty and economic prosperity.

The combination of a diverse climate and fertile land makes Canton Thurgau a thriving region for agriculture, particularly in fruit cultivation and wine production. It's important to note that the exact geolocations of these sites will be provided in year two of the study. This approach allows us to ensure that the experiment encompasses a diverse range of agricultural settings and conditions, contributing to a more comprehensive understanding of the performance and adaptability of the robotic soil sampling system. By incorporating varied locations, we can gather data representative of different agricultural terrains and practices, thereby enhancing the applicability of the study's findings to a broader range of farming scenarios.

7.7 Activities and implementation steps

The primary objective of this mission is to ensure that proximity sensing, soil sampling, and Copernicus satellites converge to cover the same area simultaneously.

This approach to mission preparation is crucial, as it can potentially use GAN to create super-resolution soil maps from coarse Sentinel data. We aim to obtain comprehensive and near real-time insights into the targeted geographical areas by aligning these critical components.

Figure 6 lightweight drill

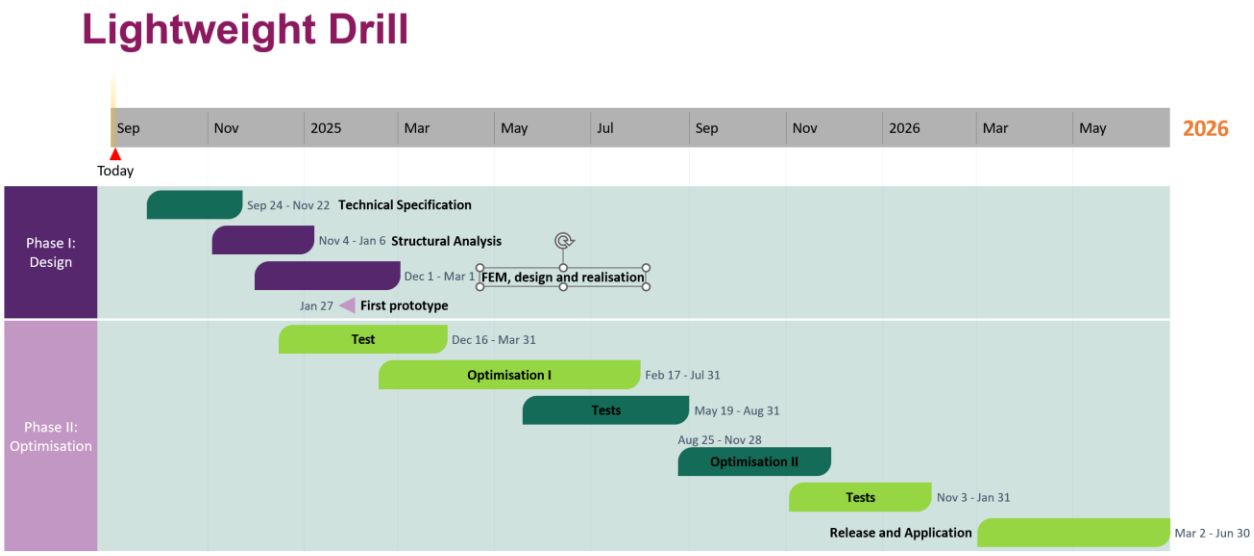

Figure 7 sample delivery and carrier platform

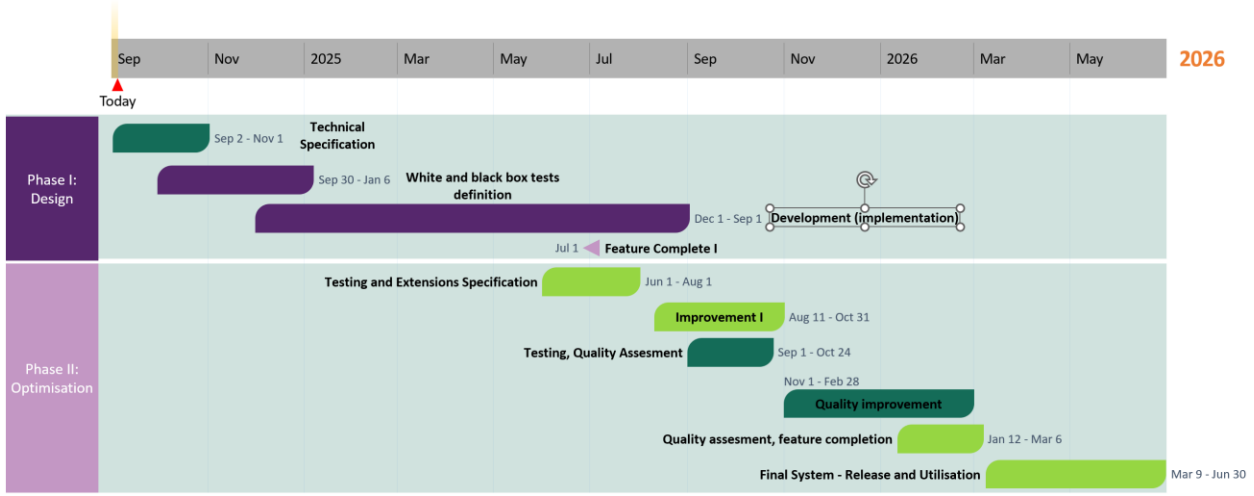

Table 25 Implementation phases

Key activities	Sub-activities	Lead	Duration	Required inputs	Outputs
Phase I: Design	1. Technical Specification	ISF (former ILT)	M07 – M09	- Sample Packaging requirements - Sample Volume - Sample Weight - Sample Labeling definition	- Technical specification sheet - System Design
	2. White and black box test definitions	ISF	M09 – M12		- System review - Acceptance by consortium
	3. Development (Implementation)	ISF	M12 – M18		Functional System
	4. Feature Complete	ISF	M18		Feature complete implementation of the system
Phase II: Optimisation	1. Testing and extensions Specification	ISF	M18 – M20		Successful system tests in the lab environment
	2. Improvement I	ISF	M20 – M22		Improved system based on test inputs
	3. Testing, Quality Assessment	ISF	M22 – M24		Successful system tests in the field environment
	4. Quality Improvement	ISF	M24 – M26		Improved system based on field tests
	5. Quality assessment, feature completion	ISF	M26 – M30		All defined features implemented, tested and fully functional.
	6. Final System	ISF	M30 – M42		Final optimised system

Figure 8 Supraresolution training data set and generative AI

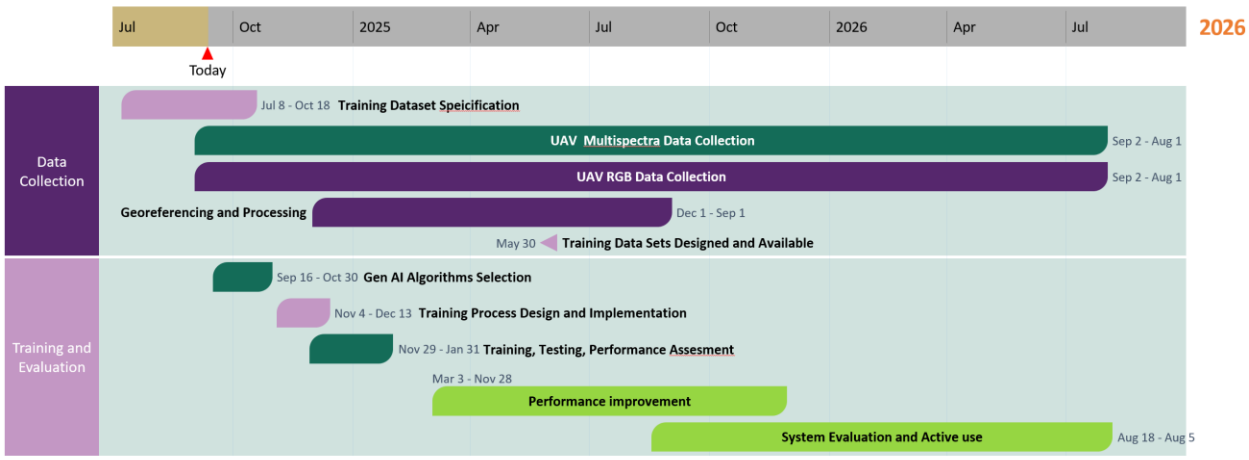

Table 26 Implementation phases

Key activities	Sub-activities	Lead	Duration	Required inputs	Outputs
Data Collection	1. Training Dataset Specification	ISF (former ILT)	M05 – M08	- Needed resolution on ground - Size of training set - Definition of soil types	Specification for Training dataset
	2. Data collection with UAVs	ISF	M07 – M30		RGB and multispectral images of fields and soil, according to specification
	3. Georeferencing and Processing	ISF	M10 – M19		Fully georeferenced images (RGB and multispectral) of different fields/soils
	4. Training Datasets Designed and available	ISF	M15		Fully georeferenced dataset available for partners

Training and Evaluation	1. Gen AI Algorithm Selection	ISF	M07 – M08		Selection of AI Algorithms for further usage
	2. Training Process Design and Implementation	ISF	M09 – M10		- Fully defined architecture for training - Implementation of training system
	3. Training, Testing, Performance Assesment	ISF	M09 – M11		Performance numbers of AI System
	4. Performance Improvement	ISF	M13 – M21		Improved AI System
	5. System evaluation and active use	ISF	M18 – M30		Evaluation paper on capabilities of trained AI System

Figure 9 Robot interface drilling machine

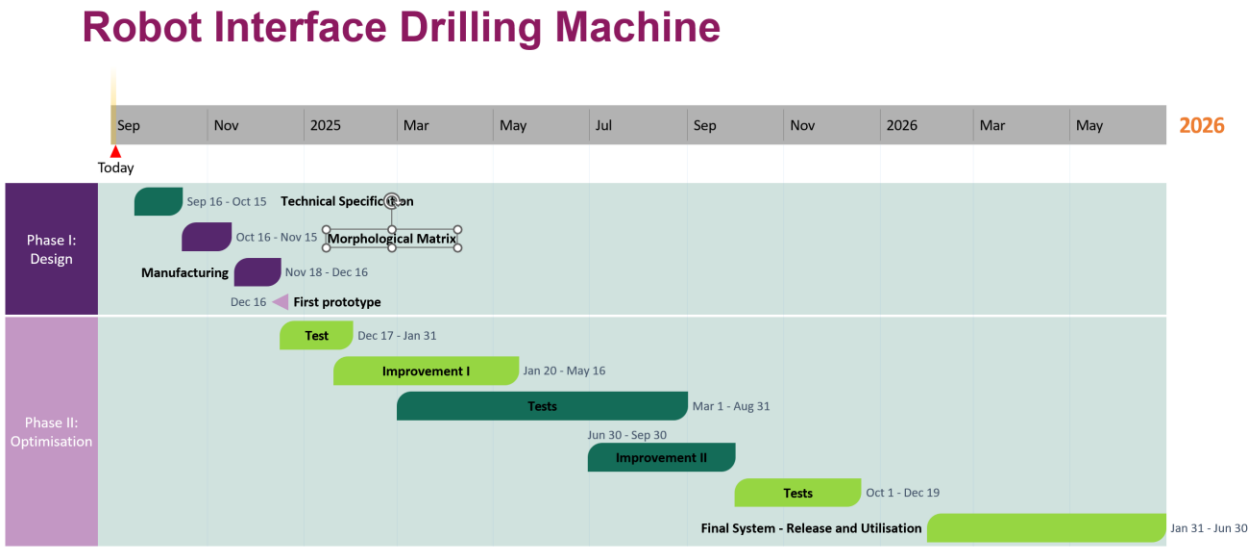

Table 27 Implementation phases

Key activities	Sub-activities	Lead	Duration	Required inputs	Outputs
Phase I: Design	1. Technical Specification	ISF (former ILT)	M07 – M09	- Drill depth - Environment conditions - Sample Type - Sample Amount	Technical specification sheet
	2. Conceptual development	ISF	M09 – M11		- Concepts for lightweight drilling system - Defined interfaces for drilling system
	3. Manufacturing	ISF	M10 – M11		Manufactured parts for the drilling system
	4. First Prototype	ISF	M11		Drilling system prototype to be mounted on existing robot
Phase II: Optimisation	5. Testing	ISF	M10 – M13		List of optimisations for initial prototype
	6. Improvement	ISF	M11 – M15	Updated requirements from testing feedback	Weight, stiffness and control optimisations based on tests
	7. Testing II	ISF	M13 – M18		List of optimisations for second iteration
	8. Improvement	ISF	M19 – M22		Weight, stiffness and control optimisations based on tests
	9. Test III	ISF	M22 – M23		Final tests with lightweight soil sampling system
	10. Final System	ISF	M23 – M28		Optimised lightweight soil sampling system

The activities above will be implemented in the following steps: The development of the lightweight system is divided into four sub-systems

1. Lightweight Drill and Structure
2. Robot Interface for the drilling system
3. Soil sample containers and labelling system
4. Sample delivery and carrier system

Each sub-system has a separate timeline. The continuous integration will ensure the system's operational state at any stage of the development.

7.8 Key performance indicators

The key performance indicators (KPIs) for the use case are the following:

KPI title	Target	Means of verification	Link to specific aims
1. Sample Area	Robots can sample 10 h in 1 hour	Time for sampling: Single sample collection takes 30s – 2 minutes.	
2. Sample Volume	25 kg of sorted soil volume per 10 ha	The system collects 25 kg for 10 ha	
3. Sample Containers	Each sample is collected, sealed and labelled individually	Containers are airtight under normal atmosphere pressure Containers contain an equal amount of soil predetermined by a user Each container has a unique identifier enclosed with a soil probe or attached to the hull.	
4. Delivery System	The delivery system transports labelled samples to the field lab for analysis	All containers are delivered to the proximity (1-2m distance) of the field lab within a session time frame. The operator will feed the samples for analysis into the field lab analyser	
5. Business model assessment	To have financial models that	Cost analysis	

	reflect the opportunity for SQAT SOC estimation		

7.9 Excepted results

The expected results of the use case are:

1. Automatic sampling system with lightweight sampler.
2. The sampling system can acquire up to 30cm deep soil samples and compartmentalise them in 10 cm containers.
3. The sampling system can acquire up to 60 cm depth soil samples and compartmentalise them in 15 cm containers.
4. The system can deliver sealed samples to the field lab
5. The soil samples have equal quality to the manually acquired soil samples.

8 Use case 7 in Ukraine: Higher efficiency for higher yields to safeguard food security

8.1 Brief context

Sown areas in spring 2023 will be reduced by ≥20%, resulting from direct damage of Russian aggression on agricultural resources and the linked economic effects (cost of production increased by 60%). To ensure Ukraine's food security and its role as a leading exporter for int'l agricultural markets, it is necessary to leverage appropriate agro-technological solutions to boost yields: maximising resource use and minimising risks. Agrilab will optimise use of inputs (20-50%) by providing farmers with: (i) soil analysis using the System, (ii) weather and climate alerts, (iii) determine effective productivity, (iv) develop task maps for variable fertiliser application, (v) develop task maps for variable sowing rates, (vi) digitalise field data in proprietary MyAgrilab software. Agrilab uses its own experimental fields those of select customers, working with agri-advisors, the All-Ukrainian Agrarian Council, and charitable recovery/ reconstruction funds. We include recently demined fields to demonstrate return to cultivation.

For 10 years of work on the territory of Ukraine, Agriab can offer the following competencies and apply them in the SQAT project.

1) Algorithm for calculating the average perennial potential yield of crops (the list of crops is limited)
2) Algorithm for calculating the crop nutrition system
3) Algorithm for calculating the need for amelioration measures for crops
4) Competences in the development of maps of the tasks of differentiated application of fertilizers, differentiated application of ameliorants, differentiated sowing of crops
5) Analytical database for more than 2,000,000 hectares of survey with geo-data of each selected soil sample, soil type, climatic data, crops in the field, etc.
6) Staff and competencies of specialists in the process of formation: soil selection routes, soil mixing and delivery methods, soil storage methods, soil preparation methods for analysis, evaluation of soil maps of fields, evaluation of agrochemical data, evaluation of technological features in the direction of crop nutrition
7) There is an own research base more ten hectares where tests of technologies, equipment, etc. can be carried out.
8) More than 600 agricultural companies. Among them are dozens of companies that can be participants for testing equipment, software and other products within the framework of the project.
9) Advertising activity about the project SQAT platform within the framework of demo fields that are held at the experimental fields of the head office (Kyiv, Boryspil) and of agricultural partners of Ukraine.
10) Advertising activity about the project SQAT platform within the framework of educational seminars held in the main office (Kyiv, Boryspil) and agricultural partners of Ukraine.

8.2 Overall objective and aims

The overall objective is to test the developed SQAT to create: - (program module) algorithm / logic for calculating the crop nutrition system depending on the indicators of soil analysis, climate, soil maps, predecessors, etc. - (program module) site specific management nutrients, considering the level of the crop yield and the possibilities of the field area - (program module) site specific management of amelioration - (program module) site specific management of seeding SQAT advertising and educational activities

To deliver this objective, the specific aims are:

1. Competences and analysis in the development of the above modules of the SQAT
2. Testing of modules in the demo-fields of the head office and partners / farmers
3. Analysis and adaptation of the algorithm and calculation modules based on the current Agrilab database of Ukraine
4. More than three own demo-fields for advertising and educational activities of the SQAT platform.

8.3 Partners involved

The partners involved are shown in the table below.

Table 28 SQAT partners involved in Use case 7 in Ukraine, their main contact person, and their specific responsibilities.

Use case role	Organisation	Main contact	Specific responsibilities
Use case lead	AgriLab	1) Yevhenii Predchenko yevhenii.predchenko@agrilab.com.ua 2) Iaroslav Boiko, iaroslav.boiko@agrilab.com.ua	Overall management or the use case, coordinating with farmers and other participants, in charge of field activities

8.4 Key stakeholders

We will also involve multiple other stakeholders as externals that will valuable to achieve the objectives of the use case, presently identified in the table below.

Table 29 End-users involved in Use case 7 in Ukraine

	Farmers	Agrifood companies	Agri consultants	Soil mapping company	Other
Involved	✓	✗	✗	✗	✗
Name and description	Up to 10 farmer locations among existing customers. FG Svitanok LLC POLTAVA-SAD AGROBUD LLC AGRO-REGION LTD Yatran FG etc				

8.5 Smart farming applications involved

	Variable-rate liming	Variable-rate macronutrient fertilisation	Variable-rate seeding	Variable-depth tillage	Carbon farming MRV
Involved	✓	✓	✓	✗	✗
Comments if applicable	Focusing on ameliorants to bring down soil pH rather than liming				

8.6 Criteria for selection of test locations

The use case will involve several farm locations for various activities of the use case. The key criteria for selecting the use case test location are:

We use experimental demo fields, currently there are three of them in Ukraine and farmers and their fields involved in testing.

We aim to cover agricultural fields for the cultivation of the main oil and grain crops

The average size of a farmer who is our client and can be involved in the project is from 300 hectares. This is a private business, including possible educational projects of state importance.

The key goal and task is to test modules and elements with different equipment and under different climatic and soil conditions.

As of today, Agrilab has a client base of 2 million hectares and research.

Over 600 agricultural companies with a land bank of more than 1,000 hectares.

It is important to understand the variety of soil and climatic features of all areas. On average, both the test field and the farmer have from 3 to 10 different soil conditions.

The demo field at the main office has the following parameters:

- Altitude: 120-130 m above sea level
- Average annual temperature: Approx. 9.5 °C
- Average rainfall: 640 mm
- Soil type: Light soils (S) – 100 % of the agricultural land
- Sloping land: 0%

8.7 Activities and implementation steps

Key activities	Sub-activities	Lead	Duration	Required inputs	Outputs
1. Selection of demo test fields	Search for a potential model and rules for evaluation and correlation of wet chemistry and equipment sensors	Agrilab	Year 1	Agreed list of proposed fields Working equipment for testing and comparing indicators of sensors and wet chemistry	Report on evaluation and correlation or lack thereof of sensor data to wet chemistry indicators
2.Calibration of sensor readings based on testing more reliable wet chemistry readings	Interim dual analysis and adjustment of sensor readings to wet chemistry readings. followed by calibration	Agrilab	Year 2	*Access to wet chemistry accounting data (local samples) and indicators transmitted by sensors*	models of qualitative interpretation of sensor data based on wet chemistry correction
3. Development and adjustment of yield calculation algorithms and elements of variable application rates	Based on the existing experience of the company and the team, testing the proposed algorithm of variable norms -	Agrilab	Year 2-3	Access to the algorithm. Access to fill data. agreed list of test fields	Conclusions - which should be implemented as before the implementation of the algorithm in the public. so including its calibration and adjustment based

(meliorants, fertilizers, seeds)	and their adjustment as necessary				on the accumulation of the database in the following
4. SQAT advertising and educational activities	Conducting advertising events	Agrilab	Year 2-3	The event was planned and carried out	Demo field - from 20 participants turnout. list of participants and photo / video report. Training seminars - from 30 participants. list of participants and photo / video report.
5.Commercial case development	SQAT feasibility analysis Comemrcial market assessment	FARMEYE	M24-M36	SQAT proof of conceopt Market research Client beta testing	Commerical plan for SQAT in this use case

The activities above will be implemented in the following steps:

Evaluation of the proposed model (variable application rates) or participation in its creation. and system testing and calibration based on wet chemistry readings to sensor readings.

8.8 Key performance indicators

The key performance indicators (KPIs) for the use case are the following:

KPI title	Target	Means of verification	Link to specific aims
1. Test fields	3 or more locations for equipment testing and evaluation	Use case reporting	
2. Model of evaluation of algorithms of variable application rates	Sensors tested on demo fields and the corresponding conclusion of the correlation of indicators	Use case reporting	

3. Algorithm for calculating variable application rates	The current algorithm is tested on demo fields and there is a comparison to the performance of wet chemistry	Use case reporting	
4. Leverage on field demonstration events to engage customers	3+ events with 60 stakeholders (farmers)	Use case reporting	
5. Judicious use of printed materials for promotion	Preparation and distribution of fact sheets to stakeholders	Use case reporting	
6. Advertising publications on Facebook, YouTube, and LinkedIn platforms	6+ publications devoted directly or indirectly to the platform and its activities	Use case reporting	
7.Business model assessment	To have financial models that reflect the opportunity for SQAT SOC estimation	Cost analysis	

8.9 Expected results

The expected results of the use case are:

1. More efficient soil acidity management:
    a. optimized yields
    b. change in the cost of unproductive expenses for the use of an incorrect distribution of resources across the field
    c. demand-oriented and resource-efficient ameliorants application
    d. demand-oriented and resource-efficient nutrients application
    e. demand-oriented and resource-efficient seeds application
    f. reduced sensor mapping costs through autonomous mapping with robot
    g. reduced number of reference lab analysis through lab-on-the-field module
2. Increasing acceptance and implementation in practical agriculture

9 Conclusion

The use cases in the SQAT project are instrumental to the project's overall co-creation approach.

Each use case has its own aims and represents different contexts/users. All the use cases have a clear value that the SQAT smart soil properties mapping system will deliver, in large part via the smart farming applications. To this end, we also involve a large number of commercial partners in the use cases that will support the exploitation of project results after the end of the project period.

The use case plans represent a structured approach to organise the co-creation effort in each use case, and to make the best use of the project resources and the project opportunity – and thus to maximise the commercialisation potential and social impact after the project.

Common expected results for all use cases:

1. Reduction in Soil Sampling Costs
    a. Achieve a **20% decrease** in the overall cost of soil sampling and analysis compared to traditional methods, through the use of autonomous robotic platforms and modular components.
2. Improvement in Input Efficiency
    a. Enable a **15% reduction** in the use of fertilizers and lime per hectare by providing more precise soil mapping and tailored input application recommendations.
3. Decrease in Operational Time
    a. Achieve a **20% reduction** in the time required for soil sampling, data analysis, and input application through automation and streamlined processes.
4. Increase in Crop Yield
    a. Facilitate a **5-10% increase** in crop yield per hectare by optimizing soil health and nutrient management based on accurate data insights.
5. Reduction in Environmental Impact
    a. Lower the environmental footprint of farming operations by achieving a **10% reduction** in greenhouse gas emissions related to fertilizer application and machinery use.

The expected results outlined in this document represent targets to strive for; however, a more detailed business modelling analysis, supported by reliable data, will be conducted as part of another deliverable "Periodic business & exploitation plan".

The plans remain a flexible reference for all project activities and may be adapted to address unforeseen changes or new opportunities.

The progress of the use cases will be reported annually, in D2.2, on the basis of the content in the use case plans presented herein.

End of document