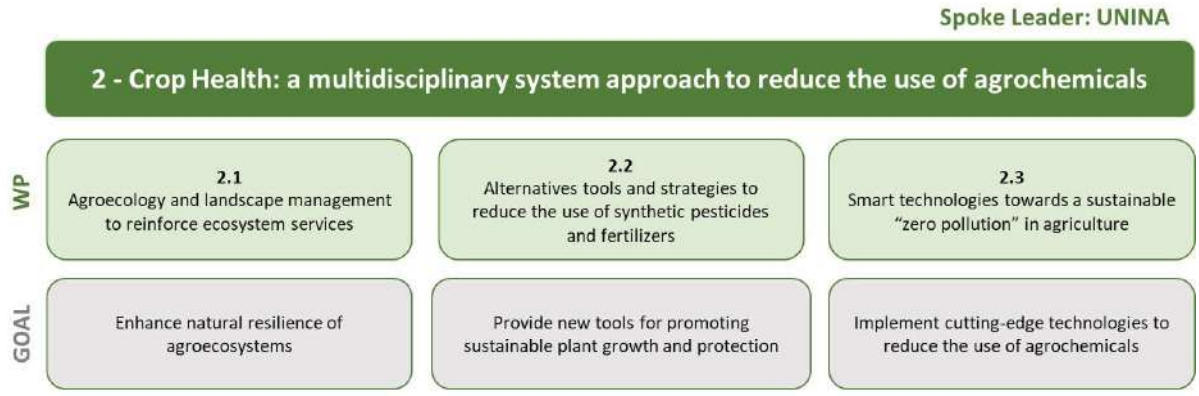
SPOKE 2



Work package number	2.1	**Lead beneficiary**	UNIPD
Work package title	Agroecology and landscape management to reinforce ecosystem services		
Start month	1	**End month**	36

Objectives

- To evaluate the role of different managed and un-managed habitat types in supporting agrobiodiversity and related ecosystem services key to crop production
- To elucidate mechanisms underpinning the relationship between agrobiodiversity and ecosystem services key to crop production
- To develop cost-effective and expeditious (bio)monitoring tools and protocols for indicators of agroecosystem health
- To develop a Decision Support System (DSS) supporting farmers and policy makers in the adoption of management strategies promoting functional biodiversity and ecosystem services

Description of work

Task 2.1.1 *Farm and landscape management strategies promoting functional biodiversity at multiple spatial scales* **(M1-M36; task leader:** UNINA; **partners involved:** UNINA, UNIBO, UNIPD, UNIBAS**)**

European agriculture often adopts a land sharing approach that integrates both biodiversity conservation and food production on the same landscapes. Here, we will apply a multi-habitat sampling approach to evaluate the role of different habitat types (both crop and non-crop) in supporting below- and above-ground biodiversity and related ecosystem services key to crop production. In particular, we will test how different agro-ecological strategies can affect multiple taxa across different trophic levels and how different landscape compositions and configurations can support biodiversity and ecosystem services.

Methods: several regional observational studies across representative landscape gradients will be performed. Farms will be selected along statistically orthogonal gradients in local management (e.g. IPM vs. organic farming), landscape composition (e.g. crop diversity) and landscape configuration (e.g. edge density). In each farm, biodiversity and ecosystems services will be sampled and quantified using traditional and modern techniques (e.g. DNA metabarcoding, soil respiration etc.).

***Initial TRL*:** 2

***Final TRL*:** 4

Task 2.1.2 *Mechanisms underpinning the relationship between biodiversity, above and below-ground services sustaining primary production and crop health* **(M1-M36; task leader:** CREA; **partners involved:** UNINA, UNITO, CREA, UNICT**)**

In the first place, this task will investigate understudied biodiversity-ecosystem service relationships. In particular, soil harbours a substantial fraction of the Earth's biodiversity, whose role in contributing to many crucial ecosystem

functions is largely unknown. Subsequently, we will unravel the potential interactions between below-ground and above-ground ecosystem services (e.g. primary production, biocontrol, pollination). Such context dependency and interactions among services will have important practical implications in defining a virtuous management of multiple services in complex systems, such those represented by the Italian agroecosystems.
Methods: first, the actual biotic drivers of soil ecosystem services (and their interplay) will be investigated at the mesocosm-level by manipulating soil communities and by adopting a multifaceted approach relying on innovative technologies (e.g., genomics and transcriptomics), as well as non-invasive technologies, such as X-ray tomography. Second, semi-field, plot, or mesocosm experiments will be performed by manipulating several below-ground and above-ground ecosystem services. In these experiments, additive, synergistic and antagonist effects of multiple services will be investigated and their contribution to crop yield quantified under realistic field conditions.
***Initial TRL*:** 3
***Final TRL*:** 5

Task 2.1.3 *Technologies of environmental monitoring and biomonitoring to assess the impact of agroecological strategies* **(M1-M36; task leader:** UNIBO; **partners involved**: UNINA, UNIBO, UNITO, e-GEOS, ENG)
Innovative strategies for the (bio)monitoring of agricultural areas are fundamental for a better understanding of the individual and cumulative effect of different farmland management systems on the environment. Such strategies can guarantee benefits to food, health, water and climate, all aspects which are deeply interconnected with biodiversity. While previous monitoring efforts have mostly focused either on habitat type and above-ground biodiversity, there is now the need to have a holistic understanding and to capture the complexity of biodiversity responses to land-use intensification. Within this framework, T2.1.3 aims to develop and validate cost-effective and expeditious tools and protocols for monitoring key farmland-associated species, from both above-ground and soil communities, and soil functionality, which can be used as indicators of agroecosystem health.
Methods: the new generation of biodiversity assessment tools (e.g., eDNA metabarcoding, DNA microarray-based technologies, acoustic stations, proximal sensing such as time-lapse cameras and remote sensing) have been proposed as reliable methods for measuring and tracking changes in biodiversity. In this task, the accuracy of such types of approaches in detecting the selected bioindicators, targeting both aspects of farmland biodiversity (taxa diversity and functionality), will be validated in selected case-study areas representative of the Italian agroecosystems. These technologies can be used for a non-destructive and non-invasive monitoring of a variety of species and the associated ecosystem services (such as for pollinators and parasitoids).
***Initial TRL*:** 4
***Final TRL*:** 6

T2.1.4 *Modelling the impact of agroecological strategies on functional biodiversity and on ecosystem services* **(M6-M36; task leader:** Engineering; **partners involved**: UNINA, UNIBO, UNIPD, UNIBAS, UNITO, CREA, UNICT, e-GEOS, ENG**)**
Developing spatially-explicit models for assessing the impact of agroecological strategies on ecosystem services and implementing the achieved information into an integrated Decision Support System, will guide farmers and policy makers in the adoption of management strategies promoting functional biodiversity and ecosystem services at multiple spatial scales. This will allow us to shape resilient agroecosystems and preserve the current natural capital. The DSS will give the possibility of forecasting different scenarios resulting from the individual farmer choices across real landscapes and from different policy contexts (e.g. CAP). The empirical data from the previous three tasks will be used as inputs for the DSS .
Methods: starting from the data collected in the previous tasks, spatially-explicit predictive models will be estimated and implemented into a GIS environment (QGIS). These statistical models will be regionally validated and will feed data into a decision support system (DSS) that will help coordinate private and public interventions across heterogenous landscapes. To guide policy and stakeholder decision-making, land-use scenario analyses will also be performed.
***Initial TRL*:** 4
***Final TRL*:** 6

Deliverables
D2.1.1 Report on the effect of farm and landscape agroecological strategies on multiple taxa and associated ecosystem services (M36)

D2.1.2a Report on key biodiversity-ecosystem functioning relationships supporting crop production and health (M36)
D2.1.2b Report on the interactions between ecosystem services supporting crop production and health (M36)
D2.1.3 Protocols, advanced methods and new bioindicators for evaluating the impact of agroecological strategies on farmland functional biodiversity (M36)
D2.1.4 Development of a preliminary DSS tool supporting farmers and policy makers (M36)

Milestones
M2.1.1 Definition of study case areas (2 to 3) and establishment of sampling protocols (M6)
M2.1.2 Establishment of mesocosms (15 to 25 for each tested condition) in walk-in climatic chambers, and setup of semi-field experiments in experimental farms (2 to 4 within each study case area) in which biodiversity and ecosystem services will be manipulated (M8)
M2.1.3 Establishment in two to five experimental farms of (bio)monitoring devices targeting different components of above and below ground biodiversity (M18)
M2.1.4 Establishment of spatially-explicit models for assessing the impact of agroecological strategies on ecosystem services within the study case areas (M24)

Interactions with other Spokes
The experimental approach developed will be used to analyze data generated by observations carried out by Spoke 3 (*WP3.2 - Innovative strategies to protect natural resources and reduce agriculture environmental impact*), Spoke 4 (*WP4.2 - Smart climate agriculture and forestry: from sustainable products to the bioeconomy*), Spoke 6 (*WP6.1 - Farm management models to enhance sustainability and resilience in different agricultural scenarios*) and Spoke 7 (*WP7.1 - Integrated models to develop marginal areas*) in relevant environments, characterized by different management strategies and landscape composition.

Work package number	2.2	**Lead beneficiary**	UNITO
Work package title	Alternatives tools and strategies to reduce the use of synthetic pesticides and fertilizers		
Start month	1	**End month**	36

Objectives
- To provide alternative tools for plant protection and nutrition/growth promotion that can replace the use of synthetic agrochemicals.
- To enhance plant defense and nutrition/growth through genetic improvement, the use of microorganisms and plant signaling molecules.
- To use biocontrol agents both as organisms and as source of biopesticides and biostimulants, which will be also obtained from different biomasses.
- To develop formulation nanotechnologies that will allow safe and efficient delivery of biopesticides and biostimulants.
- To develop non-chemical pest control strategies.

Description of work

Task 2.2.1: Improved genetic materials to reduce the use of agrochemicals (M1-M24; task leader: UNICT; **partners involved**: UNINA, UNIPD, UNITO, CREA, UNICT, CAI)
Protocols for assessing the level of resistance/tolerance and nutrition/growth performance of plant genetic materials made available by Spoke 1 will be developed. This will be done at laboratory, semi-field, and field level. Moreover, to assess the risk associated with the use of new genetic material, protocols for measuring the impact on non-target organisms (selected representatives of different ecological functions and trophic guilds) will be also developed.
Methods: bioassays will be developed to assess the nutrition/growth performance of plant genetic materials and their impact on fitness of pests and pathogens, focusing also on the underlying mechanisms of action. The effects on non-target organisms, such as biocontrol agents, pollinators and beneficial microorganisms will be also assessed

with both *in vitro* and *in vivo* protocols, at individual and population level, integrating biological, behavioural and *omic* data.
***Initial TRL*:** 3
***Final TRL*:** 5

Task 2.2.2: Plant multitrophic interactions underlying agroecosystem stability and resilience (M1-M24; task leader: UNINA; **partners involved**: UNINA, UNIBO, UNIPD, CREA**)**
Several fungal and bacterial strains that occur naturally as part of the root microbiota have a nutrition/growth promoting effect, or are used for biocontrol but have also an indirect effect against pests via the plant, by activating defense response pathways. We will study the impact of beneficial microorganisms inhabiting rhizosphere soil and/or associated with plants on plant nutrition/growth and on pest/pathogen control; we will elucidate the molecular mechanisms underlying these interactions. In addition, the effect of the use of beneficial microorganisms will be evaluated along the trophic chain. These studies will provide the background knowledge for a targeted manipulation of these multitrophic interactions, using selected microorganisms and/or natural molecules modulating these interactions, to enhance the plant nutrition/growth and defense barriers while reducing the risk to which non-target species can be exposed.
Methods: the induction of plant growth and defense responses by microorganisms and their metabolites, as well as by plant signalling molecules will be characterized at functional and molecular level, using both *in vitro* and *in vivo* bioassays, complemented by multiple *omic* analyses and functional studies aiming at defining targeted application strategies.
***Initial TRL*:** 3
***Final TRL*:** 5

Task 2.2.3: Biological control (M1-M36; task leader: CREA; **partners involved**: UNINA, UNIBO, UNIPD, UNITO, CREA, UNICT, CAI**)**
The diffusion of biocontrol agents largely relies on the availability of high-quality products and of adequate technologies for their use, aiming to reduce the production cost and to enhance their efficacy. This can be achieved by implementing cutting edge technologies for their selection, production, quality control, storage, and distribution in the field. Moreover, to facilitate the authorization for importing biocontrol agents from foreign countries for classical biological control, it will be crucial to define new risk assessment schemes that can provide a holistic evaluation of the impact that these organisms can have on non-target species.
Methods: protocols for scaling-up the production and storage of beneficial organisms and microorganisms will be developed and quality control methodologies, based on genetic analysis and targeted bioassays, will be established. The impact of biocontrol agents on non-target species will assessed also with the use of landscape specific modelling approaches.
***Initial TRL*:** 4
***Final TRL*:** 6

Task 2.2.4: Biopesticides and biostimulants (M6-M36; task leader: UNIBAS; **partners involved**: UNINA, UNIBO, UNIPD, UNITO, CREA, UNIBAS, UNICT, CAI, ENI**)**
Biopesticides and biostimulants will be identified by functional studies of multitrophic interactions in T2.2.2 and by screening for biological activity of the natural compounds obtained from biomass processing in Spoke 8. Specific bioassays will be developed to assess their efficacy and ecological sustainability. For the selected bioactive compounds/strains formulation strategies will be developed, aiming to increase their shelf-life, resistance to environmental degradation and to facilitate, when appropriate, the uptake by plant tissues or target organisms. Novel tools for risk assessment will be developed for this category of "low risk agrochemicals".
Methods: molecules of different origin will be tested to assess their impact on nutrition/growth and against selected pests and pathogens, as well as on non-targets, using both *in vitro* and *in vivo* experimental approaches, complemented by *omic* analyses to identify functional biomarkers. For the most promising candidates, tailored formulation strategies will be developed, to promote efficacy and sustainability. Among others, biocompatible humo-pectic hydrogels for soil delivery will be considered, while microparticles (MPs), nanoparticles (NPs) and carbon quantum dots (CQDs) will be considered for products to be sprayed on plants. Semi-field and field trials will be designed for selected formulations of effective molecules.
***Initial TRL*:** 4
***Final TRL*:** 6

Task 2.2.5: Non-chemical methods of pest control (M6-M30; task leader: UNITO; **partners involved**: UNINA, UNIBO, UNITO, CREA, UNIBAS)
Here we will focus on the development of alternative control strategies largely based on a wealth of physical methods of pest suppression and/or able to disrupt reproduction and alter the behaviour. This will include the technical devices based on physical cues (i.e., light, sound, microwaves, heat, pressure, etc.), or on selective trapping systems. The efficacy of the proposed methods will be assessed along with the impact that they may have on non-target organisms, to ensure the ecological sustainability of the proposed pest control method.
Methods: starting from already established background knowledge on the role that specific physical cues have on pests and pathogens, research work will be designed to develop application methods that are both ecological and economically sustainable, considering both greenhouse and field environment.
Initial TRL: 4
Final TRL: 6

Deliverables
D2.2.1 Protocols for assessing plant resistance/tolerance to pests and disease agents (M18)
D2.2.2 Report on mechanisms regulating plant multitrophic interactions (M24)
D2.2.3 Report on cutting-edge technologies for selection, production and distribution of biocontrol agents (M36)
D2.2.4 Report on developed biopesticides and biostimulants (M36)
D2.2.5 Report on non-chemical innovative tools and strategies for pest control (M36)

Milestones
M2.2.1 List of selected model crops (at least 3), pests and pathogens (one or two for each selected crop) to be used for plant bioassays and multitrophic interaction studies (M6)
M2.2.2 Selection of at least 2 promising technologies/tools from each of the three applied tasks (i.e. T2.2.3-5) as candidates for developing products with a high TRL (7-8) (M18).

Interactions with other Spokes
Plant genetic materials made available by Spoke 1 (*WP1.3 - Developing advanced genotypes with improved resilience*) will be screened for resistance/tolerance to pests and pathogens; the role of plant microbiota in the modulation of plant growth and defense, and the underlying mechanisms of action, will be studied in collaboration with Spoke 1(*WP1.1 - Plant, animal and microbial genetic resources: mining for resilience* and *WP1.2 - Dissecting morpho-physiological and molecular mechanisms of adaptation*), focusing the attention on pests, pathogens and their natural antagonists; the effect of biopesticides and biostimulants obtained from different sources and types of biomasses by Spoke 8 (*WP8.1 - Producing new products to upgrade waste value, WP8.3 - Nutrient and organic matter recovery from wastes to reduce the use of agrochemicals and closing waste cycle*) will be assessed, or the protocols defined will be shared in a coordinated research effort.

Work package number	2.3	**Lead beneficiary**	UNINA
Work package title	Smart technologies towards a sustainable “zero pollution” in agriculture		
Start month	1	**End month**	36

Objectives
- To develop accurate environmental monitoring protocols, predictive models for crops, pests and fertilizers management
- To promote precision agriculture for a timely and targeted environmental delivery of agrochemicals
- To use deterministic models and artificial intelligence (AI) to drive the definition of sustainable Integrated Pest Management (IPM) plans and fertilization strategies
- To develop a geoSpatial CyberInfrastructure for a Decision Support System (DSS) to reduce the use of agrochemicals and environmental pollution

Description of work

Task 2.3.1 *Monitoring technologies at different spatial scales* **(M1-M36**; **task leader**: UNIPD; **partners involved**: UNINA, UNIBO, UNIPD, UNITO, CREA, UNIBAS, e-GEOS**)**
Here a panel of monitoring technologies, tailored towards different spatial scales, will be produced. The task will include the following activities:
- metanalysis of scientific literature evaluating crop health monitoring technologies with reference to varying spatial scales and to a range of stakeholder's requirements (e.g. farmers, Public Authorities);
- selection of a panel of best proximal and remote sensing approaches along with plant phenotyping techniques with reference to their cost-benefit ratio;
- performing crops health monitoring by proximal sensing, remote sensing and plant phenotyping in experimental farms and over a range of pedoclimates in selected landscapes;
- analytical and Integrated Evaluation of the performance of all the applied monitoring technologies with respect to the different spatial scales and different stakeholder requirements.
Methods: metanalysis. Test of proximal sensing including EMI, Electrical Resistivity, Gamma Ray Spectrometry. Test of cost benefit ratio between satellite images from Copernicus, NASA, RapidEye. Geoeye,Worldview Test of drones and other low cost platforms for plant phenotyping in experimental farms.
***Initial TRL*:** 3-4
***Final TRL*:** 4-7

Task 2.3.2 *Modelling crops and environmental health* **(M1-M30**; **task leader**: IBF; **partners involved**: UNINA, e-GEOS, IBF**)**
This task will address crops health and environmental protection models. These models will address pest, weed prediction, and control models. They will include the following features: crop growth, plant-pathogen interactions, agrochemical leaching and climate change.
The task is divided in the following activities:
- metanalysis of scientific literature evaluating crop health models considering type of pest, spatial scales, and different user requirements;
- selection of the best crop health models considering the following features: type of pest, accuracy, reliability, quality of output, spatial scales, transferability, cost-benefit ratio, availability of open-source code, potentiality of web-based model implementation (e.g. on-the-fly modelling);
- model implementation and model testing for a selection of pests over a range of experimental farms and pedoclimate in different landscapes and for climate change scenarios.
Methods: metanalysis. Testing - including calibration and validation - of the selected crop health, Crop growth, pesticide and nitrate leaching models and sensitivity analysis. Testing are performed also by using existing datasets from experimental farms.
***Initial TRL*:** 4
***Final TRL*:** 6

T2.3.3 – *Precision agriculture and smart technologies for application of agrochemicals* **(M1-M36**; **task leader:** Engineering; **partners involved**: UNIBO, UNIPD, UNITO, UNIBAS, UNICT, ENG, IBF**)**
This task will focus on the use of precision agriculture and smart technologies for reducing the agrochemicals use. The task will be organized in the following activities:
- metanalysis of scientific and technical literature addressing both (i) smart automation systems for precision spraying and (ii) multicriteria DSS app supporting crop health farming activities (including monitoring and plant disease identification) for specific pest;
- selection of the best smart automation systems and multicriteria DSS app for crop health (such as those available through IPM decision (https://www.ipmdecisions.net) on the base of their cost-benefit ratio and type of pest;
- implementation and field testing of the selected smart automation systems for precision spraying also considering their effectiveness, design, implementation cost and potential incentivation actions;
- implementation and field testing of a range of simplified multicriteria DSS app supporting farmers in (i) selecting the best suite of monitoring approach for their needs and (ii) identifying main plant pests and diseases.
Methods: metanalysis. Field testing in experimental farms.
***Initial TRL*:** 3-4
***Final TRL*:** 4-7

T2.3.4 – *Development and validation of sustainable IPM plans* **(M1-M36**; **task leader:** CAI; **partners involved**: UNINA, UNIPD, UNITO, CREA, UNICT, CAI**)**
This task will will deliver a panel of integrated tools and strategies structured in plans for plant protection which are both ecologically and economically sustainable and accepted by the society. Optimal IPM plans for major crops in different pedoclimatic areas will be defined using modeling approaches, on the basis of characteristics of the landscape where the plans will be implemented. The strategies defined will be validated under relevant field conditions, in different pedoclimatic areas.
Methods: deterministic models based on a thorough landscape modelling for context specific prediction of the optimal integration of different tools will be adopted. This will allow to identify the most appropriate plans for a specific area, where field experiments for validation will be carried out.
***Initial TRL*:** 4
***Final TRL*:** 7

T2.3.5 – *Development of a geoSpatial CyberInfrastructure (GCI) for a Decision Support System to reduce the use of agrochemicals and environmental pollution* **(M1-M36**; **task leader:** e-GEOS; **partners involved**: UNINA, UNIBO, UNICT, e-GEOS, ENG, IBF**)**
This task will be fed by all the above 2.3 tasks and will release a set of multidisciplinary S-DSS tools to reduce the use of agrochemicals.
- An analysis of all findings obtained from all 2.3 tasks relevant for the development and for tuning T2.3.5 activities.
- Building the IT infrastructure including datacube, and a pool of well-focused HPC services (e.g., GPU, COMPs)
- Building the dataset (pests' distribution and biology, proxies of pesticide use, historical and current climate, climate change, soil, land use, landscape, hydrogeology) to be used by the GCI
- Implementing and/or developing of web-based modelling aiming to (i) crop health modelling (for selected pests) and (ii) reducing environmental pollution. The models will be fed by the dataset and have to be implemented over the GCI.
- Developing the Geospatial Decision tools supporting (S_DSS) both crop health and reducing environmental pollution by building for each of these tools the data-modelling- Graphical Use Interface pipeline.
- Testing - from both a scientific and end-user viewpoint - of Geospatial Decision Supporting tools to reduce the use of agrochemicals and the environmental pollution.
Methods: building the IT infrastructure including datacube and HPC services (e.g., GPU, COMPs), databases, Development of the GeoSpatial CyberInfrastructure to produce SDSS tools.
Initial TRL: 4
Final TRL: 7

Deliverables
D2.3.1 Report on monitoring results obtained after 1st year remote and proximal sensing and plant phenotyping (M12)
D2.3.2 Report on model testing concerning pest and weed prediction and control including crop growth, plant-pathogen interactions, agrochemical leaching also considering climate change (M20)
D2.3.3.1 Report on design, testing, implementation and incentivation of smart automation systems for precision spraying (M28)
D2.3.3.2 A simplified multicriteria DSS app supporting farmers in (i) selecting the best suite of monitoring approach for their needs and (ii) identifying main plant disease (M30)
D2.3.4 Delivery of strategies for increasing (i) IPM, BCAs, (ii) user uptake and (iii) the socio-economic impact of IPM plans (M28)
D2.3.5 Release of multidisciplinary S-DSS tools to reduce the use of agrochemicals (M30)

Milestone
M2.3.1 Protocol in place for monitoring by remote and proximal sensing (M8)
M2.3.2 List of predictive models for crops, pests and fertilizers management are finalised (M8)
M2.3.3 Targeted approaches towards smart technologies for application of agrochemicals and IPM have been established (M18)
M2.3.4 First groups of S-DSS tools are ready for testing (M22)

Interactions with other spokes

Monitoring technologies, crop modelling and precision agriculture technologies will be developed in close collaboration with Spoke 3 (*WP3.1 - Smart solutions for precise and sustainable management of agricultural systems*); strategies for IPM and reduced use agrochemicals will be developed in collaboration with Spoke 5 (*WP5.2 - Livestock management for improving resilience to climate change*), Spoke 6 (*WP6.1 - Farm management models to enhance sustainability and resilience in different agricultural scenarios*) and Spoke 7 (*WP7.1 - Integrated models to develop marginal areas*), defining tailored protocols for sustainable food and feed production in specific areas; the *geoSpatial CyberInfrastructure (GCI) for* DSS to reduce the use of agrochemicals will be developed by considering all smart technologies and strategies generated by Spoke 3 (*WP3.1 - Smart solutions for precise and sustainable management of agricultural systems*) and Spoke 4 (*WP4.2 – Smart climate agriculture and forestry: from sustainable products to the bioeconomy*) in relevant production scenarios.