**DETAILED PROPOSAL**

The ***H****ybrid Machine Learning for Multi-Stressor Crop* ***D****isease and Pest Detection Using high-resolution Hyperspectral, Thermal with* ***R****adiative transfer* ***A****nalysis and exploitation of Next Generation* ***E****arth* ***O****bservation missions* (HYDRA-EO)

The HYDRA-EO project aims to develop a hybrid machine learning (ML) framework for the detection of crop diseases under multiple biotic and abiotic stress conditions. By integrating high-resolution hyperspectral and thermal remote sensing, radiative transfer modelling, and multi-scale Earth Observation (EO) data, the project addresses critical challenges in monitoring plant stress responses across spatial and temporal scales. HYDRA-EO will leverage a combination of ESA’s upcoming missions—CHIME, FLEX, and Copernicus LSTM—alongside existing platforms such as PRISMA, EnMAP, ECOSTRESS, Sentinel-3 OLCI , Sentinel-2, and Landsat, to enhance agricultural resilience monitoring and disease detection capabilities. This multi-sensor, multi-scale approach will enable robust, scalable solutions for early disease detection, supporting precision agriculture and sustainable crop management across diverse agroecosystems.

**Key Objectives**

* **Conceptual framework for integrating high-resolution imagery across scales**: The project will develop a scalable framework to integrate high-resolution hyperspectral and thermal data acquired at the leave and canopy levels, and assess how spectral and spatial degradation affects the extrapolation of plant traits and stress indicators to larger spatial scales, such as orchards, landscapes, and satellite observation footprints. This involves coupling remote sensing observations with radiative transfer modelling (RTM) to assess the impact of spectral bandset reduction and spatial resolution on the detection of biotic (fungal, viral, insect, and bacterial) and abiotic (e.g., water stress) stressors. Special attention will be given to retrieving functional plant traits, including biochemical (e.g., chlorophyll, leaf water content), biophysical (e.g., leaf area index (LAI), leaf structure), and photosynthetic indicators such as solar-induced fluorescence (SIF), which are critical for tracking stress responses. These plant traits will be linked to evapotranspiration dynamics to better understand multi-stressor impacts on crop functioning. The integration strategy combines high-resolution EO data from ECOSTRESS, PRISMA, and EnMAP with simulated datasets for upcoming missions, including Copernicus LSTM (thermal) and CHIME (hyperspectral). These simulations are derived from airborne thermal and hyperspectral (e.g., Headwall) sensors used in aerial campaigns. Combined with broader-scale, time-resolved imagery from Sentinel-2 and Landsat, this approach ensures consistent multi-sensor monitoring across spatial scales.
* **Trial setup and aerial campaigns implementation**: To support biotic stress detection and trait-based EO product validation, HYDRA-EO will establish dedicated field trials and execute coordinated aerial campaigns across major cropping systems, including olive, pistachio, potato, alfalfa, and grapevine. Each trial site has been selected to capture relevant agronomic and ecological gradients, particularly in relation to water availability and pest/disease incidence. Field monitoring will prioritize high-impact pathogens and pests, including several listed in the EU quarantine register. In grapevine systems, trials in Tuscany will monitor *Flavescence Dorée*, caused by *Candidatus Phytoplasma vitis,* a regulated pathogen of major concern in European viticulture. Potato field trials in the Netherlands, will be used to assess the response to Potato Virus Y (PVY), *Erwinia* spp. (bacterial soft rot), and Leaf Curl Virus—pathogens of high priority to the European Commission due to their threat to food security and productivity.

In olive systems located in semi-arid regions of Spain, trials will focus on *Pseudomonas savastanoi* (olive knot), *Spilocaea oleagina* (peacock spot), and *Bactrocera oleae* (olive fruit fly), all under variable water regimes. In Spanish pistachio orchards, emphasis will be placed on *Septoria* spp., *Botryosphaeria* spp., *Alternaria alternata*, and *Botrytis cinerea*, especially under drought-prone scenarios. Large-scale alfalfa fields in Italy affected by different insects, such *as Acyrthosiphon pisum, Phytodecta fornicata, Phytonomus punctatus* will provide an optimal scenario for tracking insect impact and the management strategies for reducing their impact.

At all trial sites, detailed leaf physiological measurements will be conducted to support trait retrieval and EO model calibration. These include assessments of chlorophyll content, fluorescence emission, leaf water content, leaf conductance, and macro- and micronutrient composition, using portable sensors and laboratory assays. These measurements will provide ground-truth data for validating EO-derived stress indicators and plant functional traits. Phytopathological assessments will be carried out through visual disease scoring, supported by advanced molecular diagnostics, including qPCR-based pathogen detection. To ensure rigorous and accurate phenotyping, all trial sites will be periodically visited by experienced phytopathologists from stress detection and precision agriculture. These experts will conduct disease scoring, validate EO-derived indicators, and support traits calibration for each crop-pathogen interaction. Special attention will be given to how water stress and climatic conditions modulates disease severity and spectral signatures, enabling refined development of EO-based monitoring algorithms and bandset reduction strategies.

* **Integration of aerial and satellite data for monitoring stress dynamics**: Field trial data, aerial campaign observations, and satellite EO data will be integrated to comprehensively monitor crop stressors across spatial and temporal scales. High-resolution UAV and aircraft sensor data will be combined with satellite imagery from PRISMA, and EnMAP, along with simulated datasets from the forthcoming CHIME and FLEX missions. Acquisitions from PRISMA and EnMAP will be requested during and shortly after key field campaigns to effectively monitor spectral changes in crops under various biotic and abiotic stressors. Continuous time-series data from multispectral and thermal satellites, including Sentinel-2, Landsat, and ECOSTRESS, will further support assessments of crop health, ensuring accurate monitoring of stress-related spectral variations from local to global scales. Nevertheless, integrating SIF data from coarse-resolution missions such as FLEX (~300 m) presents challenges in heterogeneous cropping systems like olive orchards and vineyards. At this scale, SIF signals are diluted by mixed land cover within each pixel, reducing their reliability for crop-specific stress monitoring. For this reason, the integration with this satellite will be performed in the large-scale and homogenous field of alfalfa through hyperspectral airborne campaigns and continuous SIF monitoring at ground level. This scenario will allow understanding how FLEX mission capture plant stress responses and further enhancing the project's ability to monitor perturbations in crop health. In addition, the HYDRA-EO project aims to understand and quantify the signal degradation by combining UAV-based SIF reference data with RTMs to generate synthetic spectrally FLEX datasets. This approach will allow the project to assess how SIF signals degrade across scales and define the practical thresholds and conditions under which FLEX data can be effectively used for plant trait retrieval and stress detection over time and across regions.
* **Development of Hybrid machine learning framework**: The project will develop a hybrid machine learning framework that integrates hyperspectral, thermal, and RTM outputs with multi-scale EO data. The framework will utilize RTM-derived plant traits—including biochemical compounds (e.g., chlorophyll), leaf and canopy water content, structural properties (e.g., leaf area index), and photosynthetic indicators (e.g., solar-induced fluorescence)—to provide physically-based inputs for ML algorithms. A key methodological step will be spectral bandset reduction, selecting optimal wavelengths sensitive to specific stress-related plant responses identified through RTM sensitivity analyses. This approach enables robust and scalable detection of stress indicators, allowing for the accurate upscaling of detailed airborne and field-level observations to satellite-derived data from current missions—hyperspectral (PRISMA, EnMAP), thermal (ECOSTRESS), and SIF (FLEX, Sentinel-3 OLCI)—as well as simulated datasets from upcoming missions, including hyperspectral (CHIME) and thermal (Copernicus LSTM). The integration of these functional plant traits with evapotranspiration modelling will further strengthen the physiological interpretation of stress responses, ensuring compatibility and forward compatibility with future ESA missions and operational agricultural monitoring system.
* **Validation and Intercomparison of Detection Models:** To ensure scientific robustness and operational relevance, the validation will leverage independent ground-based datasets acquired by experienced plant pathologists, who will conduct detailed field assessments—including visual disease scoring, physiological trait measurements, and, qPCR-based pathogen identification. Their expertise ensures that the ground reference data accurately reflect infection severity, pest incidence, and plant physiological status across diverse cropping systems. High-resolution airborne hyperspectral and thermal imagery, along with satellite-derived observations, will be integrated with these field datasets to enable robust validation. Model performance will be rigorously evaluated across the crops, environmental conditions, and stressors studied in field trials and aerial campaigns. This comprehensive validation strategy will assess the consistency of spectral trait retrieval and the accuracy of stress detection during the scaling-up process from plant-level to satellite observations. Outcomes from this effort will enhance the reliability of EO-based disease detection tools, laying the groundwork for validated, operationally-ready products suited to large-scale agricultural monitoring and warning systems.

By achieving these objectives, the project will deliver significant advancements in EO-based crop disease detection capabilities, providing scientifically validated tools and data products for operational use by the agricultural and scientific communities, and contributing to improved resilience in future Earth Observation missions.

* **BACKGROUND AND** **TECHNOLOGIES, DATA AND INSTRUMENTS/TOOLS.**
  1. Background of the company(ies)

The consortium assembled for this project brings together leading research institutions specializing in remote sensing, plant physiology, radiative transfer modelling, and crop stressor detection. The consortium is led by Wageningen University, Department of Environmental Sciences (WU-DES), a global leader in environmental sciences, precision agriculture, and Earth observation. WU-DES plays a central role in the integration of remote sensing methodologies for crop stress detection. Specifically, the Geo-Information Science and Remote Sensing Group (GRS) in the Environmental Sciences Department, specializes in hyperspectral and thermal imaging, RTMs, and ML algorithms for vegetation analysis. Their expertise in developing hybrid models enhances the detection of crop stress and enables the retrieval of key plant traits, facilitating a more accurate understanding of crop health under varying conditions.

GRS's strong background in international and ESA projects underscores its commitment to advancing Earth observation methodologies. Notably, their involvement in ESA's QA4EO initiative focuses on establishing quality assurance frameworks for Earth observation data, ensuring the reliability and accuracy of satellite-derived information. Additionally, the SEN4LDN project aims to develop robust and automated EO methods to map land cover changes and land productivity dynamics, contributing to high-resolution monitoring of land degradation neutrality Additionally, GRS hosts the Unmanned Aerial Remote Sensing Facility, established in 2012, which supports environmental management by providing timely, accurate, and detailed information on land through UAV technology. This facility enables high-frequency observations and flexibility in sensor use, bridging the gap between satellite-based and ground-based geo-sensing systems. Through these research initiatives, GRS demonstrates its capacity to lead complex, multidisciplinary projects that align with ESA's objectives, particularly in the realms of crop stress detection, land degradation monitoring, and the development of open-source tools for the EO community.

In addition to **WU-DES**, the consortium is strengthened by the expertise of several key partner institutions, each of which brings unique capabilities to the project. Together, they ensure the successful execution of the proposed research, particularly in detecting multiple crop stressors through various EO satellite missions. These partners include:

* **Stichting Wageningen Research, Wageningen Environmental Research (WENR)** is a leading European research and development organisation offering a combination of practical, innovative and interdisciplinary scientific research across many disciplines related to the sustainable use of the living environment. With its interdisciplinary expertise at the intersection of Earth Observation (EO), agriculture, and environmental monitoring, WENR has a long-standing track record in applying remote sensing, geospatial analysis, and data-driven modelling to address complex challenges in agricultural and environmental systems. It will focus on integrating thermal and hyperspectral data, enhancing the precision of early crop stress detection and informing targeted intervention strategies.
* The **Consiglio Nazionale delle Ricerche – Institute of BioEconomy (CNR-IBE)**, Florence, Italy, plays a pivotal role in this project, contributing its extensive expertise in Earth Observation, hyperspectral remote sensing, and environmental monitoring. As Italy’s largest public research institution, CNR has been at the forefront of scientific and technological innovation for over a century. Within CNR, the Institute of BioEconomy (IBE) focuses on the integration of agro-environmental monitoring, micrometeorology, and remote sensing applications for sustainable land and crop management. CNR-IBE has played a leading role in the development and operational deployment of the **PRISMA** (PRecursore IperSpettrale della Missione Applicativa) satellite, an advanced hyperspectral Earth Observation mission developed by the Italian Space Agency (ASI). The CNR-IBE has played a crucial role in sensor calibration, validation, and data applications. Its efforts ensure the highest standards of spectral analysis, enabling advanced environmental and agricultural monitoring, with a particular focus on early stress detection and precision agriculture.
* The **Chaparrillo Agro-Environmental Research Center** (CIAG-IRIAF), Ciudad Real (Spain), is a reference institution in agricultural and environmental research, strongly focused on plant breeding across agronomic and genetic crop resilience, precision agriculture, and remote sensing applications. As part of the Instituto Regional de Investigación y Desarrollo Agroalimentario y Forestal de Castilla La Mancha (IRIAF). The CIAG-IRIAF has been pivotal in the development and expansion of pistachio tree cultivation in Spain, providing essential research on plant stress physiology, genetic and agronomic adaptation, and environmental factors affecting crop’s productivity. Since the late 1980s, CIAG-IRIAF has not only pioneered pistachio research, but also handled the European Pistachio Varieties Certification Centre. Within this project, CIAG-IRIAF will leverage its experience to monitor pistachio crop health, integrating genetic and spectral data by Genome-Wide Association Analysis (GWAS), to dissect and improve disease resilience strategies and remote sensing-based stress detection.

By combining the expertise of WU-DES and its partners, the project will develop cutting-edge methods to detect and manage crop stressors across a variety of crops, leveraging advanced remote sensing and ML techniques. Although these institutions represent diverse areas of expertise, their contributions are intricately connected to the project’s overarching objectives. Each partner’s specialized knowledge plays a crucial role in overcoming the challenges involved in fluorescence measurements, sensor integration, and validation activities, ensuring the success of this ambitious project.

* 1. Technical achievements relevant to the activity and/or to be used

Several achievements of the Contractor and Subcontractor(s) are directly relevant to their

experience and capability to successfully perform the tasks of this project:

**Wageningen University, Department of Environmental Sciences (WU-DES)**

The WU-DES has extensive expertise in remote sensing, multispectral and hyperspectral imaging, fluorescence emission analysis, and advanced data processing techniques. With a strong background in precision agriculture, WU-DES applies remote sensing and ML approaches to assess crop physiology and monitor abiotic and biotic stress factors, including plant stress and disease progression. t is a leading reference in the scientific community for developing algorithms related to passive fluorescence retrievals, canopy reflectance modelling, and thermal-based stress indicators—key components for advancing plant health monitoring and ensuring the project’s success.

In addition, WU-DES has extensive experience in developing machine learning-driven models for monitoring crop physiological responses, facilitating early pathogen detection and the assessment of both biotic and abiotic stress factors. WU-DES has pioneered hybrid ML approaches, integrating radiative transfer models with deep learning and statistical techniques to improve stressor classification and plant trait retrieval.

WU-DES also leads the development of open-source spectral analysis software such as ToolsRTM and SCOPEinR, which are extensively used for radiative transfer simulation and inversion across multiple EO platforms. The university has extensive experience in high-resolution UAV campaigns, SIF measurement systems, and trait-based disease mapping, supported by in-field calibration and validation protocols. These technological and methodological assets make WU-DES a central contributor to EO scaling strategies in HYDRA-EO.

**Stichting Wageningen Research, Wageningen Environmental Research (WENR)**

WENR applies advanced EO techniques, including thermal and hyperspectral imaging, to enhance early crop stress detection and support sustainable agriculture. By linking temperature variations with physiological responses and disease progression, WENR improves crop monitoring accuracy and enables timely interventions. Its expertise in data fusion, sensor calibration, and remote sensing plays a key role in addressing both biotic and abiotic stressors. WENR also has extensive experience with ESA and Copernicus projects, emphasizing user engagement and co-designing solutions tailored to diverse stakeholder needs. A few examples of projects showing WENR's capabilities in EO-based crop stress monitoring, co-design of services, and stakeholder collaboration:

* [Monitoring Agricultural Resources System (MARS)](https://ec.europa.eu/jrc/en/mars): Operational use of EO for crop yield forecasting, by monitoring weather and crop conditions during the growing season, and estimate final yields by harvest time, at large-scale (Europe, China, India, Russia). The project also aligns with policy-level users like FAO, and among its users are the European Directorate General for Agriculture and Rural Development and the EuropeAid Office.
* Copernicus C3S\_422\_Lot1\_WENR and C3S2\_415\_Lot1\_WENR, Copernicus Global Agriculture (2017-current): This contract developed operational services using high-impact climate-derived information for the agricultural sector to enable informed decisions.
* Sustainable Development Goals - Enhanced monitoring through Copernicus Services (SDGs-EYES, 2023-2025): Leading user engagement and the co-design of EO-based products for monitoring selected SDGs.
* Copernicus C3S\_430 and C3S\_520, Sectoral Information System - Support Disaster Risk Reduction & Evaluation and Quality Control Function (2019-2021): A climate change service for assessing risks from extreme weather. WENR was leading the user needs & scope definition of the service, and eensured the delivery of high-quality data and proposed service evolutions.

**The Consiglio Nazionale delle Ricerche – Institute of BioEconomy (CNR-IBE)**

Members of the CNR-IBE are active members in European Space Agency (ESA) and Italian Space Agency (ASI) projects. Among their contributions to ASI projects, CNR-IBE is coordinating since 2019 the "Activity of Scientific CAL/VAL of PRISMA mission (PRISCAV PROJECT) that enabled to deploy and maintain 12 CAL/VAL sites representatives of different land-use and developing a cal/val strategy based on ground and airborne match-up. CNR-IBE is also contributing since 2016 to the preparatory experiments for the ESA-FLEX mission (Atmoflex, Surfsense, Flexsense, Deflox, FRM4FLUO). Within the framework of SIF retrieval is also coordinated the field experiments in the ASI-funded FLEX-ITA project. CNR-IBE is also involved in the ESA's CalVal Park project phase1 dedicated to the definition of the technical specification of a calibration and validation playground in Italy for VHR satellites.

The CNR-IBE’s work in integrating hyperspectral and thermal datasets to assess vegetation health and stress is directly relevant to the project, particularly for monitoring plant health across ecosystems affected by pathogens. Their experience in campaign logistics, sensor calibration, and algorithm development will be critical for the successful execution of the aerial and satellite campaigns in vineyards and alfalfa, supporting effective site selection, data collection and analysis. Additionally, CNR-IBE’s extensive expertise in vineyard, alfalfa and forest monitoring, including multi-sensor (RGB, thermal, multispectral and hyperspectral cameras) UAV campaigns for Flavescence Dorée detection in Chianti Classico domain (Italy), directly supports the project’s objectives for plant disease monitoring and early detection in diverse agricultural systems.

**Chaparrillo Agro-Environmental Research Center (CIAG- IRIAF)**

CIAG-IRIAF manages two extensive field sites where pistachio and olive trees are cultivated under drought conditions following standard agricultural practices. These sites are located at: Location 1 (39º 01’ 47” N, 3º 56’ 26” W) and Location 2 (39º 2’ 10.21’’ N, 3º 56’ 18.48’’ W). Field trials will be carried out across six distinct parcels distributed between these two locations.

At Location 1, three parcels are devoted to pistachio trials, targeting fungal pathogens of economic importance: *Septoria spp*. (leaf spot), Botryosphaeria spp. (panicle and shoot blight), *Alternaria alternata* (alternaria leaf and fruit spot), and *Botrytis cinerea* (gray mold).

* Parcel 1 includes 334 pistachio trees representing 67 varieties and 11 rootstocks, all grown under rainfed conditions. These will be phenotyped for disease symptoms and genotyped for Genome-Wide Association Studies (GWAS).
* Parcel 2 spans 2 hectares and is planted with a commercial pistachio variety grafted onto four different rootstocks. Trees are managed under both rainfed and irrigated regimes and will undergo the same disease assessments.
* Parcel 3, covering 2.8 hectares, contains eight female commercial varieties, each grown on four rootstocks under rainfed conditions, also to be evaluated for the same fungal infections.

Additionally, two olive parcels at Location 1 are dedicated to biotic stress trials, focusing on key pathogens and pests: *Pseudomonas savastanoi pv. savastanoi* (olive knot or olive tuberculosis, bacterial infection), *Spilocaea oleagina* (olive leaf spot or repilo, fungal infection), and *Bactrocera oleae* (olive fruit fly, insect pest). Both olive parcels will be assessed for disease symptoms and pest infestation.

* Parcel 4 consists of 3.17 hectares of the Cornicabra variety under rainfed conditions.
* Parcel 5 includes 3.24 hectares planted with the Arbequina variety, also rainfed.

At Location 2, Parcel 6 comprises 1.61 hectares of olive trees encompassing eight different varieties, all cultivated under rainfed conditions. These trees will be assessed for the same biotic stressors identified at Location 1.

CIAG-IRIAF addresses research in pistachio cultivation, focusing on the improvement against biotic and abiotic stresses, through 3 main lines of research focused on the agronomic and genetic selection and improvement by using new tools and technologies. The GWAS analyses will correlate and integrate genetic, agronomic and hyperspectral datasets and will allow to develop and genomic and agronomic tools, including remote sensing approaches to assess diseases and pests mentioned before. The CIAG-IRIAF researcher group experience in using hyperspectral, thermal, and chlorophyll fluorescence data for crop resilience analysis is crucial for monitoring plant health and developing multi-sensor approaches to disease detection and management. This group has an expert plant pathologist who will carry out the verification of the phenotyped diseases using sequencing analysis by qPCR. Data integration will significantly enhance the project’s ability to assess plant resilience and disease susceptibility, contributing to more targeted and effective crop management strategies.

The combined expertise of these partners, spanning hyperspectral sensor development, data processing, field campaigns, product validation, and airborne data acquisition, provides a strong foundation for achieving the project’s objectives. Their contributions will ensure effective integration of advanced remote sensing technologies with plant trait retrieval, disease monitoring, and stress detection across diverse crop systems.

* 1. Overall Team composition, Proposed Key Personnel

The HYDRA-EO consortium brings together a multidisciplinary team of internationally recognized experts in EO, plant physiology, physically-based radiative transfer modelling, thermal imaging, and machine learning approaches. The consortium is led by Wageningen University, Department of Environmental Sciences (WU-DES) as Prime Contractor, with key institutional partners: Stichting Wageningen Research, Wageningen Environmental Research (WENR, NL), Consiglio Nazionale delle Ricerche – Institute of BioEconomy (CNR-IBE, IT), and Chaparrillo Agro-Environmental Research Center (CIAG-IRIAF, ES). The team is structured to cover all technical, experimental, and operational needs of the project, ensuring alignment with ESA objectives in remote sensing for plant trait monitoring and crop stressor detection.

The following Key Personnel are included in the proposal with allocated budgets:

* Dr. Carlos Camino (WU-DES) – Project Coordinator and WP1–2, WP5-6 and WP10 Lead: Responsible for scientific integration, trait retrieval modelling, and EO scaling strategies.
* Prof. Lammert Kooistra (WU-DES) – Scientific Advisor: Oversees scientific quality, RTM scaling, and spectral harmonization.
* Ms. Annemarie Klaasse (WENR) – WP8 and WP9 Lead: Coordinates stakeholder integration, dissemination, and the development of operational EO tools.
* Dr. Rosa Mérida García (CIAG-IRIAF) – WP2 co-lead: Leads field trials in pistachio and olive, responsible for site design and in-situ validation activities.
* Dr. Jose Luis Pancorbo (CNR-IBE) – WP3–WP4 and WP7 Lead: Coordinates spectral validation, sensor intercalibration, and hyperspectral scaling.
* Dr. Lorenzo Genesio (CNR-IBE) – WP3–WP4 and WP7 Lead: Expert in data integration and hyperspectral and SIF spaceborne missions.
* Postdoctoral Researcher (WU-DES) – Full-time, 12 months: Dedicated to model development and data integration across WP2–WP5.
* Dr. Allard de Wit (WENR) – Senior researcher in crop modelling and remote sensing; specializes in integrating remote sensing with agrometeorological models, with a focus on crop yield forecasting and regional model scaling. He supports WP5 through the development of model-informed trait prediction workflows and contributes to WP7 by advising on crop model integration and operational monitoring strategies.
* Dr. Ángel de Miguel García (WENR) – Senior researcher in water, soil, and land management; expert in hydrology and water footprint assessments. He contributes to WP2 and WP6 by supporting the integration of soil and water condition measurements into the stress monitoring framework, helping to contextualize EO indicators within broader sustainability and water use efficiency metrics.

Additional personnel will contribute scientifically or technically as supporting team members, without direct personnel budget allocation in the proposal. Their contributions are ensured through institutional co-funding and are essential to the scientific excellence and continuity of HYDRA-EO:

* Dr. Nandika Tsendbazar (WU-DES) – Specialist in EO validation and spatial upscaling methodologies; advises WP3 and WP7.
* Dr. Dainius Masiliunas (WU-DES) – Expert in time series analysis and crop growth stage modelling; supports WP2 and WP6.
* Dr. Harm Bartholomeus (WU-DES) – Specialist in LiDAR and UAV-based remote sensing; contributes to aerial data acquisition design in WP2.
* Dr. Marc Rußwurm (WU-DES) – Expert in deep learning and hybrid ML architectures; advises on model development and scaling strategies in WP5.
* Dr. Salvatore Filippo Di Gennaro (CNR-IBE) – Hyperspectral data analyst and UAV remote sensing campaign specialist; supports sensor calibration and QA/QC workflows.
* Dr. Aldo Dal Prà (CNR-IBE)– Agronomic systems expert; contributes to field logistics and sensor-trial interface design in WP4 and WP5.
* Dr. Julián Guerrero Villaseñor (CIAG-IRIAF) – Specialist in pistachio and olive agronomy; advises on genotype trials and WP4 phenotyping.
* Dr. Raquel Martínez Peña (CIAG-IRIAF) – Expert in plant physiology and remote phenotyping; contributes to trait calibration and in-field assessments.
* Dr. David Fariña Flores (CIAG-IRIAF) – Agronomic and disease monitoring expert; supports the integration of biotic stress diagnostics with EO data in WP2 and WP4.

**External Advisory Board and Collaborating Experts (no CVs):**

These senior advisors provide external validation, expert feedback, and strategic linkage to other EU and ESA initiatives:

* Dr. F. Rovira-Mas – Professor at the Polytechnic University of Valencia; Coordinator of the CERBERUS Project (EU Grant 101134878); provides technical guidance on robotics and sensor integration for EO crop monitoring.
* Dr. Pablo J. Zarco-Tejada – Internationally recognized leader in imaging spectroscopy, with roles in BEXYL, XF-ACTORS, and POnTE; advises on early detection methodologies and SIF modelling.
* Dr. Corne Lugtenburg – Expert in potato field trials and phenotyping; supports trait validation and UAV experimental logistics in Dutch sites.
* Dr. Sergio Vélez Martín – UAV systems expert at the University of Burgos; advises on drone-based thermal and spectral data acquisition and campaign execution.
* Dra. Laura Mugnai – Senior plant pathologist at the University of Florence with over 25 years of experience in grapevine and olive tree pathology.

Each WP is led by one or more of the listed Key Personnel, ensuring strong governance, scientific continuity, and alignment with deliverables. The overall structure is described in detail in Section 3.1 and supported visually by the team diagram.

A complete list of CVs for Key Personnel has been submitted under Section 1.4 in the ‘Curricula Vitae’ folder on esa-star. The table below provides the list of Key Personnel and institutional contributors, including their roles in the project and contact details for ease of reference.

|  |  |
| --- | --- |
| Prime Contractor and Partners | Key Personnel and Main Advisor |
|  | Project responsible - Professor  Dr. Lammert Kooistra  Email: [lammert.kooistra@wur.nl](mailto:lammert.kooistra@wur.nl)  Project responsible – Assistance Professor  Dr. Carlos Camino  Email: [carlos.caminogonzalez@wur.nl](mailto:carlos.caminogonzalez@wur.nl)  ----- Advisors -----  Assistance Professor  Dra. Nandika Tsendbazar  Email: [nandin.tsendbazar@wur.nl](mailto:nandin.tsendbazar@wur.nl)  Assistance Professor  Dr. Dainius Masiliunas  Email [dainius.masiliunas@wur.nl](mailto:dainius.masiliunas@wur.nl)  Assistance Professor  Dr. Harm Bartholomeus  Email: [harm.bartholomeus@wur.nl](mailto:harm.bartholomeus@wur.nl)  Assistance Professor  Dr. Marc Russwurm  Email: [marc.russwurm@wur.nl](mailto:marc.russwurm@wur.nl) |
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* 1. Curricula Vitae of Key Personnel

**Carlos Camino** (WU-DES)

Dr. **Carlos Camino** received his Ph.D. from the University of Córdoba (2019). He worked at the State Meteorological Agency (2010–2015), the Institute for Sustainable Agriculture (2015–2019), and the Joint Research Centre of the European Commission (2019–2024). During his time at the JRC, he played a significant role in several European-funded projects targeting *Xylella fastidiosa*, including POnTE and XF-ACTORS. In these projects, he contributed to developing methods with remote hyperspectral data for the early detection of plant pests, integrating spread modelling approaches with remote sensing and machine learning. Since 2025, he has been an Assistant Professor at Wageningen University, Department of Environmental Sciences, specializing in hyperspectral imaging, radiative transfer modelling, and ML for plant trait retrieval and stress detection.

**Lammert Kooistra** (WU-DES)

Dr. **Lammert Kooistra** is a Professor of Remote Sensing at Wageningen University, Department of Environmental Sciences and Scientific Advisor for the HYDRA-EO project. He has over 20 years of experience in vegetation monitoring, radiative transfer modelling, and EO-based trait retrieval. Prof. Kooistra has coordinated and contributed to numerous ESA, Horizon2020, and national projects related to agriculture, biodiversity, and environmental sensing. He is one of the lead developers of the SCOPEinR and ToolsRTM packages and a key contributor to the integration of optical, thermal, and LiDAR data. In HYDRA-EO, he provides scientific oversight on trait modelling and spectral harmonization across platforms.

**Annemarie Klaasse** (WENR)

Ms. **Annemarie Klaasse** is a senior researcher Water Management at Stichting Wageningen Research, Wageningen Environmental Research. She has a MSc in Erosion, Soil and Water Conservation from University (2001) and has since worked on satellite earth observation applications for the assessment of forest fires, wetlands, agriculture, irrigation and water productivity. She built a strong background in surface energy balance algorithms to estimate actual evapotranspiration and biomass production. Before joining Wageningen University & Research she guided part of the eLEAF team to align data production, projects, research and service development. Her research focus is on combining Earth Observation data products with other datasets and models and translate them into actionable information to improve water and food security from global to field scale.

**Rosa Mérida García** (CIAG-IRIAF)

Dra. **Rosa Mérida García** is a scientist specialized in plant breeding using genomic and bioinformatic tools, with experience in the integration of hyperspectral indices with plant genetics using Genome-Wide Association Studies (GWAS) focused on biotic and abiotic stresses plant’s adaptation. She possesses experience in phenotyping, applied research and knowledge transfer. She completed her PhD on integrating agronomic and genomic approaches for wheat adaptation at IAS-CSIC, publishing in high impact journals. Currently at CIAG-IRIAF, she leads research on woody crops combining genomic and hyperspectral in association mapping models.

**Lorenzo Genesio** (CNR-IBE)

Dr. Lorenzo Genesio is a Senior researcher at CNR-IBIMET with 25+ years of experience in eco-physiology, land–atmosphere interactions, and remote sensing. He has coordinated national and EU-funded research in climate impacts on Mediterranean agroecosystems and EO-based monitoring of land degradation. He supports flux and EO integration in HYDRA-EO.

**Jose Luis Pancorbo** (CNR-IBE)

Dr. **Jose Luis Pancorbo** received his M.S. in Forest Engineering (2017) and Ph.D. in Agro-Environmental Technology (2023) from Universidad Politécnica de Madrid (UPM). Currently, he works at the Aerolab Department of the Institute of BioEconomy, Consiglio Nazionale delle Ricerche (CNR-IBE) in Florence, Italy. His research expertise lies in the development and application of radiative transfer models for the retrieval of vegetation biophysical and biochemical traits. He has contributed to validating remote sensing approaches for assessing crop status, evaluating agricultural practices, detecting plant diseases, and differentiating between nutritional and water stress.

**Allard de Wit** (WENR)

Dr. **Allard de Wit** is a senior researcher on crop modelling and remote sensing. He received a PhD degree from Wageningen University in 2007 and has been involved in several projects on the use of agrometeorological and remote sensing techniques for operational crop yield forecasting on a European and global scale. His research focuses on improving the regional application of crop models and the uncertainties involved in moving from point scale to regional scale. His interests particularly focus on the use of remote sensing to improve the output of crop models by applying data assimilation techniques..

**Ángel de Miguel García** (WENR)

Dr. **Ángel de Miguel García** is a senior researcher in the Soil Physics and Land Management team at Wageningen University, Department of Environmental Sciences and in the Water & Food team at Stichting Wageningen Research, Wageningen Environmental Research (The Netherlands) since 2015. His aim is to promote environmental sustainability across agriculture by improving water, soil, and land management in a changing environment through the application of science-based knowledge in several private and public initiatives. His activities are focused on the application of the Integrated Water and Land management approach and the assessment of Water Footprint and Water security Assessment at different scales (farm, basin, or national level) through the integration of water related data. Angel has a PhD in Hydrology and Water Management Resources from the University of Alcalá (2013).

**External Supervision & Expert Contributions (Non-Budgeted)**

In addition to the core Key Personnel formally budgeted in the proposal, the HYDRA-EO consortium is supported by a select group of senior researchers and scientific advisors who contribute their domain expertise, institutional coordination, and strategic oversight without financial compensation under this contract. These individuals play a critical role in ensuring scientific excellence, interoperability with parallel projects, and alignment with institutional capacities:

**Nandika Tsendbazar** (WU-DES)

Dr **Nandika Tsendbazar** is an assistant professor at the Laboratory of Geo-information Science and Remote Sensing at Wageningen University, Department of Environmental Sciences. She represents the land cover focus area in the CEOS Working Group on Calibration and Validation- Land Product Validation subgroup. She also represents the Land monitoring community in the Dutch Earth Observation community. She has strong experience in the validation of EO products related to land and forest cover through her leading role in map validation via ESA and EU-funded projects such as Copernicus Global Land Service and ESA-Worldcover. She is actively involved in statistical validation and area estimation for land and forest cover change through the World Resources Institute and FAO. She obtained her PhD (2016) from Wageningen University and her MSc (2011) from the University of Twente. Her research focuses on advancing the value of EO through improved fit-for-purpose and quality assessments as well as advancing land and vegetation cover change monitoring through time series analysis of high-quality ground truth data on land dynamics.

**Dainius Masiliunas** (WU-DES)

Dr. **Dainius Masiliūnas** is a lecturer and land cover change scientist, focusing on land cover fraction estimation, change detection in time series and big earth observation data analysis at the global scale. He received his MSc and PhD degrees from Wageningen University in 2017 and 2024, respectively. He was a member of the Horizon 2020 openEO project, and is currently leading the task on openEO integration of the Horizon Europe project Open Earth Monitor Cyberinfrastructure. He was responsible for integrating change detection into the Copernicus Global Land Cover Operations project, and is the maintainer of the BFAST package in R. He was a member of the Digital Europe Green Deal Data Space preparation project (GREAT).

**Harm Bartholomeus** (WU-DES)

Dr. **Harm Bartholomeus** Associate Professor at Wageningen University, Department of Environmental Sciences with expertise in airborne LiDAR, thermal, and hyperspectral remote sensing. He leads UAV flight design and sensor integration in multiple ESA-funded campaigns. In HYDRA-EO, he advises WP2 on campaign planning and 3D canopy trait retrievals.

**Marc Rußwurm** (WU-DES)

Dr. **Marc Rußwurm** is Assistant Professor of Machine Learning and Remote Sensing at Wageningen University, Department of Environmental Sciences. His background is in Geodesy and Geoinformation, and he obtained a Ph.D. in Remote Sensing Technology at TU Munich. During his Ph.D., he could visit the European Space Agency and the University of Oxford as a participant in the Frontier Development Lab in 2018, the Obelix Laboratory in Vannes, and the Lobell Lab in Stanford. As a postdoctoral researcher, he joined the Environmental Computational Science and Earth Observation Laboratory at EPFL, Switzerland. His research interests are developing modern machine learning methods for real-world remote sensing problems, such as classifying vegetation from satellite time series and detecting marine debris in the oceans. He is interested in domain shifts and transfer learning problems naturally arising from geographic data.

**Raquel Martínez Peña** (CIAG-IRIAF)

Dr **Raquel Martínez Peña** is a scientist specialized in plant biology and agronomy, with experience in applied research, innovation, and knowledge transfer. She completed her PhD on carbon and nitrogen efficiency in durum wheat under stress at ITACyL, publishing in top journals. She has worked on field experimentation and remote sensing for pistachio and almond adaptation in Castilla y León. Currently at CIAG-IRIAF, she leads research on woody crops using technologies like hyperspectral imaging and machine learning. She has international collaborations and has published over 30 scientific and outreach works.

**Julián Guerrero Villaseñor** (CIAG-IRAF)

Dr. **Julián Guerrero Villaseñor** is a scientist specialized in experimentation and dissemination of the main agronomic and phenological aspects of pistachio cultivation and the rootstock/cultivar interrelationship with the soil and biotic and abiotic stresses derived from climate change. He had an important professional stage in agrotechnical consultancy for different companies related to the agricultural sector. Currently at CIAG-IRIAF, he leads research on woody crops focused on the cultivation of pistachio and olive trees.

**David Fariña Flores** (CIAG-IRIAF)

Dr **David Fariña Flores** is a scientist specialized in plant pathology. He completed his PhD on the interaction between Pinus pinaster and *Fusarium circinatum*, with particular emphasis on the plant's defense mechanisms, such as the production and regulation of oleoresin. Additionally, he studied the spatio-temporal variation of the F. *circinatum* population in Spain. Both lines of research involved the use of molecular biology, biotechnology, and genetic tools. Currently at CIAG-IRIAF, he works at woody crops department focused on conducting Distinctness, Uniformity, and Stability tests at the examination center for new pistachio varieties and rootstocks, and he also contributes to various pistachio-related research projects, including assisted pollination, phenological monitoring, and cover crop management.

**S.F. Di Gennaro** (CNR-IBE)

Dr. **Salvatore Filippo Di** **Gennaro** is a remote sensing and agronomic systems specialist at CNR, with a focus on UAV multi-sensor crop monitoring (multispectral, thermal, hyperspectral and RGB photogrammetry), vineyard management, and phenotyping. He has coordinated precision agriculture activities and supports airborne data quality assurance and vineyard campaign logistics in HYDRA-EO.

**Aldo Dal Prà** (CNR-IBE)

Dr**. Aldo Dal Prà** is a researcher at IBE-CNR with a Ph.D. in Animal Science from the University of Florence, where he also held a postdoctoral position. He has worked at CREA-ZA and the Animal Production Research Center. He has served as an adjunct professor at the Universities of Brescia, Modena-Reggio Emilia, and Florence, Italy. He coordinated 9 Operational Groups and contributed to 60 research projects, including 7 EU-funded. His expertise focuses on animal production and sustainable agriculture.

These advisors enhance the project’s capacity to deliver high-impact, interoperable, and policy-relevant outcomes. While they are not costed in the current budget, their contributions represent significant in-kind institutional support and long-term commitment to the HYDRA-EO objectives.

**External Supervision & Expert Contributions (non CVs) :**

 Dr. **F. Rovira-Mas**– Professor at the Polytechnic University of Valencia, Spain, and Founder & Director of the Agricultural Robotics Laboratory – serves as the Coordinator of the CERBERUS Project (Grant 101134878). He provides as external collaborator,  technical guidance and strategic advice on integrating remote sensing methodologies into broader European initiatives within the CERBERUS Project, which focuses on advancing sensing and automation technologies for sustainable agricultural management across Europe.

 Dr. **P.J. Zarco-Tejada** is a leading expert in hyperspectral remote sensing and precision agriculture, with extensive experience in early plant stress detection using thermal and imaging spectroscopy. He has played a key role in major EU projects such as BEXYL (Grant No. 101060592), POnTE (Grant No. 635646), and XF-ACTORS (Grant No. 727987), focusing on the early detection of *Xylella fastidiosa* through advanced remote sensing techniques. His work integrates radiative transfer modeling, airborne imaging, and AI-driven analytics to support plant health monitoring. He is currently based at the Institute for Sustainable Agriculture (IAS-CSIC) in Spain and also serves as an Honorary Professorial Fellow at the University of Melbourne, Australia. Dr. Zarco-Tejada has held research and leadership roles across Europe, Canada, and Australia, and is internationally recognized for his contributions to quantitative remote sensing.

Dr. **Corne Lugtenburg** is a senior researcher specialized in precision agriculture and crop phenotyping, with extensive field experience in large-scale potato trials in the Netherlands. His work focuses on integrating proximal and remote sensing technologies—such as multispectral imaging and UAV-based monitoring—for evaluating crop performance, disease resistance, and variety selection under real farm conditions. He plays a key role in coordinating experimental field trials and translating research into practical applications for sustainable potato production. He is currently based in the Netherlands and actively collaborates with growers and research institutes on crop innovation projects.

Dr. **Sergio Vélez Martín** is a specialist in drone technology and remote sensing applications for environmental monitoring and precision agriculture. At the University of Burgos, he leads initiatives on UAV-based data acquisition, integrating multispectral and thermal sensors for high-resolution crop stress detection. His work focuses on flight planning, sensor calibration, and image processing pipelines, with extensive experience supporting large-scale agricultural trials and interdisciplinary EO campaigns.

Dra. **Laura Mugnai** is a senior plant pathologist at the University of Florence with over 25 years of experience in grapevine and olive tree diseases. She is a leading expert in Flavescence dorée epidemiology, diagnostics, and sustainable control, and has coordinated major EU and national projects in viticulture pathology. Her research includes fungal pathogens (Botryosphaeria, Esca complex), bacterial infections, and biotic stress phenotyping. Within HYDRA-EO, she advises on disease diagnostics, supports field protocols, and contributes to the validation of EO-based biotic stress indicators. She brings extensive experience in vineyard health monitoring across Tuscany and Northern Italy.

* 1. Tenderer’s technologies, data and instruments/tools for the execution of the work

In this section the facilities relevant to the project which will be used during the execution of it are reported according to the different partners.

**Wageningen University, Department of Environmental Sciences (WU-DES)**

Wageningen University, Department of Environmental Sciences (WU-DES) provides state-of-the-art infrastructure and extensive expertise in remote sensing, plant trait analysis, and stress detection. Its technological resources include UAV-mounted hyperspectral and thermal sensors, high-performance computing (HPC) facilities for processing large datasets, and tools for the use of advanced radiative transfer models. These tools allow WU-DES to integrate UAV, ground-based, and satellite data to enhance both spatial and temporal resolution for environmental monitoring. The WU-DES also has a strong foundation in SIF research, employing field spectrometers, hyperspectral systems, and LiDAR to develop and refine robust SIF retrieval methodologies. This expertise supports the evaluation of photosynthetic efficiency and the analysis of environmental stress impacts.

To ensure the highest quality data acquisition and processing, WU employs advanced airborne remote sensing platforms, including the DJI S1000+ octocopter UAV equipped with the FluorSpec system for detailed SIF measurements, and the Headwall High-Precision LiDAR & Hyperspectral System, capturing spectral data from 400–1000 nm. These sophisticated sensors offer high-resolution spatial and spectral data, critical for precise stress detection and analysis in plants. WU-DES uses a wide range of calibration instruments, including the ASD FieldSpec 3 for radiance and reflectance measurements and thermal calibration devices such as thermal guns and infrared thermometers. Ground-based measurements complement aerial campaigns, incorporating advanced equipment like the LiCOR LAI-2200C Plant Canopy Analyzer for LAI assessments, handheld chlorophyll and nitrogen meters, and portable photosynthesis systems (e.g., LI-6800) for detailed gas exchange and transpiration studies. By integrating these diverse resources, WU-DES enables precise retrieval of plant traits and stress indicators across multiple environmental conditions.

Software and modelling tools developed by WU-DES include the ToolsRTM and SCOPEinR R packages, freely available via GitLab (https://gitlab.com/users/caminoccg/). These are used to simulate spectral reflectance and SIF emissions, perform band selection, and analyze sensor degradation. The packages are fully integrated into a Shiny interface and form the basis of trait retrieval pipelines across the project.

WU-DES’s extensive array of UAV platforms, calibration instruments, and analytical software provides a state-of-the-art resource base for the project. With the support of a dedicated technical team, WU-DES ensures smooth execution of the entire workflow—from data acquisition and preprocessing to advanced analysis and validation. These capabilities make WU-DES a key contributor to the project’s success, delivering innovative solutions that enhance environmental monitoring, sustainable agriculture, and crop resilience in the face of multiple stressors.

Following the establishment of a potato trial in 2022, WU-DES is facilitating the acquisition and processing of spectral datasets from aerial campaigns conducted in 2025, with a follow-up campaign planned for 2026 at a centrally located field in the Netherlands (52.545163°N, 5.53998°E). The site is naturally affected by major biotic stressors—including Potato Virus Y (PVY), Erwinia spp. (bacterial rot), and Leaf Curl Virus—and serves as a unique testbed for evaluating EO-based disease detection methods. In collaboration with the Dutch General Inspection Service for Agricultural Seeds and Seed Potatoes, infected plants will be identified and geo-referenced using RTK GNSS to support accurate ground-truthing. These campaigns aim to generate high-resolution spectral and thermal datasets for trait retrieval and stress detection under field-realistic conditions. UAVs equipped with hyperspectral sensors, LiDAR, RGB, and thermal cameras will be used throughout the season. Ground-based SIF measurements and leaf-level biochemical sampling (e.g., pigments, nitrogen, water, dry matter, micronutrients) will complement the remote sensing data and support RTM and ML validation.

Importantly, the potato trial is conducted in collaboration with private sector partners involved in breeding and agronomic research. All data sharing complies with existing Non-Disclosure Agreements (NDAs), intellectual property rights, and confidentiality clauses. Outputs relevant to the ESA contract—such as algorithms, processing pipelines, and non-sensitive, aggregated results—will be openly shared. Publication of results involving commercial data will occur only with partner approval. Alternative open-access trial sites (e.g., CIAG-IRIAF in Spain, CNR-IBE in Italy) will be used to ensure full transparency, reproducibility, and compliance with ESA’s open science requirements.

In addition to the potato-focused trials, the WU-DES team will also support experimental activities on other key crops, including olive, alfalfa, pistachio, and grapevine—each affected by different pathogens and environmental stressors. For example, olive crops will be monitored for *Pseudomonas savastanoi* (olive knot), *Spilocaea oleagina* (olive leaf spot), and *Bactrocera oleae* (olive fruit fly) under several water regimes. Alfalfa will be assessed for pests such as *Aproaerema albipunctella*, while pistachio will be examined for fungal pathogens like *Septoria* spp., *Botryosphaeria* spp., *Alternaria alternata*, and *Botrytis cinerea* in rainfed conditions. Grape vines, in turn, will be evaluated for diseases including *Flavescence Dorée.*

The main objective of these activities is to generate high-resolution spectral and thermal datasets that can support the development of EO-based plant trait retrieval models and stress detection methods under field-realistic conditions. UAVs equipped with hyperspectral sensors, LiDAR, thermal cameras, and RGB imagers will collect radiometric, geometric, and temperature data across the growing season. These measurements will be complemented by visual inspection, ground-based SIF observations and detailed biochemical sampling of leaf material, capturing pigments, water content, dry matter, and macro- and micronutrient composition. The integration of these datasets will support the validation of radiative transfer models and machine learning algorithms used to detect and classify crop stress with high spatial and spectral precision.

By leveraging their expertise in disease detection, spectral data analysis, and plant stress monitoring, the WU-DES team will help tailor methodological approaches and calibrate severity scales for each crop–pathogen system. This ensures that data collection, processing, and analysis workflows are robustly adapted to capture the full range of physiological responses, ultimately enabling accurate and scalable EO-based stress detection across diverse agroecosystems.

**Stichting Wageningen Research, Wageningen Environmental Research (WENR)**

WENR applies a comprehensive set of methodologies and technologies to address the research objectives of this project. Its expertise spans remote sensing, geospatial analysis, and data-driven modelling, with a specific focus on monitoring crop health, estimating yields, detecting stressors, and managing land effectively and sustainable. Key scientific tools and approaches include:

* Remote sensing applications: Analysis of thermal, hyperspectral and multispectral data to detect early physiological responses of crops to biotic and abiotic stress factors.
* Experimental and modeling work: Contributing to the understanding of crop responses to drought, heat, nutrient stress, and pest and disease pressure through physiological modeling and field-based validation.
* Data fusion and integration: Combining datasets from various sources, including satellite platforms such as ECOSTRESS, Landsat, Sentinel-2 and Sentinel-3, and potentially VIIRS, alongside for example data from UAV-mounted thermal sensors and ground-based infrared measurements for calibration and validation.
* Machine learning and statistical models: Automated pattern recognition and predictive analytics for classification and anomaly detection in agricultural monitoring and for improving the spatial and temporal resolution of stress indicators. Like WU-DES, WENR has access to the High Performance Computing Cluster (WUR HPC) on the WUR campus to facilitate data science and AI applications.
* Evapotranspiration and temperature dynamics: Modelling crop evapotranspiration and temperature variations to better understand the interactions between physiological processes and external stress factors, including pest and disease progression.
* Custom analytical tools: Development of software for integrating and processing large-scale datasets, enabling detailed assessments of plant health indictors across scales.

WENR’s expertise includes the interpretation of canopy temperature dynamics in relation to evapotranspiration and disease progression, as well as the scientific modelling of physiological responses to stressors. In addition, WENR actively collaborates with partner organizations across Horizon Europe and ESA-funded projects, fostering synergies that facilitate the sharing of methodologies, data, and insights to enhance research outcomes. The use of field-validated approaches and interdisciplinary methods enable early detection of crop stressors and provide actionable insights for optimizing water use, improving crop yield, and ensuring long-term sustainable agricultural practices.

**The** **Consiglio Nazionale delle Ricerche – Institute of BioEconomy** (CNR-IBE)

The Consiglio Nazionale delle Ricerche (CNR-IBE), Italy’s premier public research institution, is widely recognized for its leadership in Earth observation, remote sensing, and environmental monitoring. With a strong collaboration history with the European Space Agency (ESA), CNR-IBE has played a crucial role in the PRISMA satellite mission, particularly in sensor calibration, hyperspectral data validation, and the application of remote sensing technologies to vegetation monitoring. For this project, CNR-IBE will contribute advanced technological resources and multidisciplinary expertise.

CNR’s airborne remote sensing capabilities include the T-MOTOR MX860 multirotor UAV platform equipped with state-of-the-art VNIR and SWIR hyperspectral sensors, as well as LiDAR technology. The VNIR sensor provides high-resolution data across 340 bands from 400–1000 nm, while the SWIR sensor extends the spectral range to 2500 nm with 267 bands. Together, these instruments offer exceptional spectral resolution and spatial detail, critical for detecting and mapping vegetation stress responses. LiDAR further enhances these capabilities, offering three-dimensional canopy structure information and supporting comprehensive vegetation analysis. In addition, the DJI Mavic 3T equipped with an RGB and a 640×512 px thermal camera will allow individualizing the plant canopy for extracting temperature.

Complementary ground-based sensing systems will be deployed to capture high-resolution spectral and fluorescence data. The RS-5400 Portable Field Spectroradiometer will be used for in-field spectral measurements across the 350–2500 nm range, combining three high-density photodiode array detectors to achieve high spectral accuracy and resolution. This instrument provides 1 nm spectral sampling across 2151 channels, enabling detailed characterization of vegetation optical properties relevant to plant traits characterization, photosynthetic efficiency and stress indicators. To support controlled and repeatable measurements at the leaf level, the system is equipped with a leaf-clip sensor, allowing precise contact-based spectral acquisition under standardized illumination and geometry. This setup minimizes the influence of ambient light and enables consistent data collection across time and locations, ensuring reliable estimation of key physiological traits. The availability of high-quality leaf-level spectra is particularly critical as reference data for benchmarking airborne and satellite observations, which are often affected by atmospheric noise, sensor limitations, and canopy-level heterogeneity. By establishing this fine-scale reference, we can better interpret remotely sensed signals, correct for potential artefacts, and ultimately strengthen the linkage between physiological traits and large-scale spectral indicators. This comparison is essential for validating EO-derived products and improving the robustness of models estimating plant traits, crop health and stress.

In addition, a FloX system will be installed at ground-level for continuous, high-frequency measurements of SIF and radiometric signals. The system integrates two spectrometers—Ocean Optics FLAME-S and QEPro—optimized respectively for broadband reflectance and narrow-band SIF emission between 650–800 nm. Each spectrometer is fed by dual fibber optics for simultaneous capture of incoming irradiance and target radiance. Placed in a temperature-controlled enclosure, the system ensures measurement stability under variable field conditions. Operating autonomously and with minimal power requirements, FloX provides robust temporal monitoring of SIF dynamics and related vegetation traits, supporting integration with satellite-based proxies.

In 2026, CNR-IBE will undertake aerial campaigns using these UAV-mounted sensors to monitor Flavescence Dorée in vineyards and insect damage in alfalfa fields, specially affected by *Acyrthosiphon pisum*. These campaigns will collect detailed hyperspectral and thermal data, along with ground-based spectral and radiometric measurements and leaf samples for biochemical analyses. The ground-based measurements will be used to measure SIF, chlorophyll content, protein content, leaf water content, nitrogen levels, and other key physiological traits and canopy properties. Advanced optical instruments will allow for precise leaf- and canopy-level measurements, while biochemical sampling will assess pigments, water content, and nutrient status across different crop systems. This comprehensive data collection will serve as vital ground-truth information for refining remote sensing models and improving the accuracy of vegetation stress assessments.

CNR-IBE’s coordinated approach involves the integration of UAV, satellite, and ground-based observations. By combining these data sources, CNR-IBE will produce high-quality datasets and validated methodologies that enhance modelling approaches for plant trait retrieval, improve disease detection methods, and contribute to a better understanding of vegetation stress dynamics and agricultural ecosystem resilience. The involvement of phytopathologists from the University of Florence will further enhance the process by providing expert symptom interpretation, ensuring robust connections between remote sensing data and real-world field conditions. Their assessments will support rigorous calibration and validation, ultimately resulting in a more accurate and reliable remote sensing framework.

In addition to the aerial and ground-based campaigns, CNR-IBE will coordinate the acquisition of satellite imagery from the PRISMA mission. These observations will be carefully scheduled to coincide with in-situ campaigns conducted at study sites in Italy, the Netherlands, and Spain. This alignment will enable detailed temporal monitoring and robust validation of remote sensing-based detection models, supporting a comprehensive assessment of vegetation health and stress responses across multiple spatial scales. The resulting framework will also provide valuable insights into the capabilities of the new generation of hyperspectral satellites for detecting crop stress and retrieving plant traits across diverse cropping systems.

**Chaparrillo Agro-Environmental Research Center (CIAG- IRIAF)**

CIAG-IRIAF is a recognized leader in pistachio and olive orchard management, with a solid track record in precision agriculture, crop resilience research, and remote sensing applications. The centre contributes to agronomic research, orchard certification, and disease monitoring, enabling the development of innovative strategies for sustainable crop management.

In this project, CIAG-IRIAF will provide pistachio and olive orchards at dedicated test sites to support aerial campaigns. Their expertise in agronomy, multi-sensor data acquisition, and stress assessment ensures that plant responses are evaluated under practical field conditions. CIAG-IRIAF will carry out UAV-based hyperspectral and thermal surveys, using these data to validate remote sensing methods for early stress and disease detection.

CIAG-IRIAF’s efforts extend to integrating genetic and spectral datasets, applying GWAS to analyze crop health and identify traits that improve disease resilience. By combining genetic insights with hyperspectral and thermal data, the center aims to refine disease resistance strategies and improve remote sensing-based stress detection approaches. GWAS analyses will be supported by tools such as genomic DNA extraction kits, PCR thermocyclers, SNP genotyping platforms, qPCR systems, and bioinformatics workflows for variant calling and association mapping.

Underpinning these activities is CIAG-IRIAF’s robust field and laboratory infrastructure. This includes essential agricultural equipment, imaging and sensing instruments, and environmental monitoring systems. Field measurements will be conducted with advanced tools like the SC-1 leaf porometer, NDVI Field Scout CM1000, and Scholander Chamber. Drone platforms (such as the DJI Mavic 2 Enterprise and Mavic 3 Multispectral) will complement these capabilities. Data collection is further enhanced by systems like Crop View Panoramica and HOBO temperature and humidity loggers. This infrastructure supports field campaigns, and the implementation of cutting-edge GWAS analyses and precise stress assessments.

In 2026, CIAG-IRIAF will conduct field and aerial campaigns on pistachio and olive orchards to measure the effects of inoculated diseases. Trials on pistachio will target fungal pathogens such as *Septoria* spp., *Botryosphaeria* spp., *Alternaria alternata*, and *Botrytis cinerea*. Olive trials will examine stresses caused by Pseudomonas *savastanoi pv. savastanoi*, *Spilocaea* *oleagina*, and *Bactrocera oleae* under varying water regimes. These campaigns will include leaf sampling for biochemical and optical measurements to monitor physiological responses. CIAG-IRIAF phytopathologists will perform visual inspections to document disease symptoms, ensuring accurate data collection and validation. This work will involve analyzing solar-induced fluorescence, chlorophyll content, nitrogen levels, and other physiological indicators, providing a detailed understanding of plant health.

As part of these efforts, CIAG-IRIAF has subcontracted the Sustainable Agriculture Institute (IAS-CSIC) in Córdoba, Spain, to carry out additional aerial campaigns. Using a Cessna aircraft equipped with high-resolution hyperspectral and thermal sensors, IAS-CSIC will conduct an aerial campaign in olive and pistachio orchards affected by the studied plant pathogens under different water regimes. Two hyperspectral sensors—one covering the visible-near infrared range and another capturing the near-infrared to shortwave infrared range—will operate alongside a thermal infrared camera. This sophisticated setup will produce high-quality data, helping to refine disease detection methods and enhance stress assessment models.

With access to these resources, CIAG-IRIAF will ensure the effective integration of field expertise and remote sensing techniques. Their efforts will enhance multi-sensor approaches for plant trait analysis, disease detection, and stress quantification, ultimately contributing to improved resilience and sustainability in tree crop systems.

1. **TECHNICAL PART** 
   1. Understanding of the main technical objectives of the ITT

The **HYDRA-EO** project directly addresses the objectives of the ESA call by developing a robust, transferable EO framework for detecting and monitoring multiple stressors—both biotic (e.g., pathogens, pests) and abiotic (e.g., drought)—across diverse agricultural systems. The project combines high-resolution hyperspectral and thermal remote sensing, radiative transfer modelling, and hybrid ML techniques to improve the detection, tracking, and interpretation of plant stress dynamics at multiple spatial and temporal scales.

A key innovation of HYDRA-EO lies in its multi-sensor, multi-scale architecture, which integrates UAV-mounted, aircraft-based, and satellite EO data to monitor stress responses in five target crop systems: pistachio, olive, alfalfa, potato, and grapevine. These crops represent a spectrum of structural complexity, from homogeneous canopies (alfalfa, potato) to heterogeneous woody systems (olive, pistachio, vineyard), enabling comprehensive analysis of stress signals and sensor limitations across agricultural landscapes.

To support this framework, HYDRA-EO will conduct coordinated aerial campaigns in 2026 using high-resolution hyperspectral and thermal sensors to monitor crop responses to both biotic and abiotic stressors. Priority targets include the EU-regulated pathogens Potato Virus Y (PVY) in potato and *Flavescence Dorée* in grapevine. Additional stressors will cover fungal pathogens (*Septoria* spp., *Alternaria alternata*, *Botrytis cinerea*, *Botryosphaeria* spp.), bacterial infections (Erwinia spp., *Pseudomonas savastanoi*), and insect pests (Aproaerema albipunctella, Bactrocera oleae, *Acyrthosiphon pisum*). A dedicated water regime experiment in olive orchards will help distinguish drought effects from biotic stress responses. Alfalfa and potato will serve as reference crops for spectral scaling, while recent 2025 campaign data, in available crops, will support multi-season validation across crop types and stress conditions. These experiments will also enable the evaluation of reduced spectral bandsets by integrating multiple spectral and spatial resolutions through radiative transfer models and hybrid ML approaches.

To bridge the gap between high-resolution airborne data and spaceborne EO, HYDRA-EO establishes a spectral-temporal scaling framework. Intermediate resolution platforms (e.g., Sentinel-2, Landsat, ECOSTRESS) will Connect UAV and aircraft observations with current hyperspectral and thermal satellite missions (PRISMA, EnMAP) and extend this linkage to upcoming missions (CHIME, Copernicus LSTM) through simulated datasets, ensuring continuity and scalability across spatial and spectral domains even where operational satellite data are not yet available. This scaling framework will evaluate the effect of spectral degradation and spatial coarsening on the retrieval of key plant traits and stress signals, contributing to exploring possibilities and scientific challenges in the application of the modelling techniques in the upcoming satellite missions.

The project’s integrated and interdisciplinary design is fully aligned with ESA’s vision for operational, field-to-space EO solutions that address agricultural threats under dynamic climatic and environmental conditions.

Radiative transfer models (e.g., PROSAIL and SCOPE) are central to the methodological framework, providing physically-based simulations that:

* Link plant physiological traits with observed spectral/thermal signals;
* Quantify the impact of sensor spectral and spatial configurations on stress trait retrieval;
* Generate synthetic reflectance spectra across stress gradients and sensor platforms;
* Support the design of optimized vegetation indices tailored to specific stressors.

These RTM outputs will feed into a hybrid ML framework, trained and validated using field-measured plant traits. This approach improves model interpretability, generalizability, and robustness, enabling the extrapolation of stress detection algorithms across regions, sensors, and crop types. It also facilitates the discrimination between overlapping stressors, such as drought and disease, a key challenge for precision agriculture and EO-driven monitoring systems.

Additionally, the project will focus on the optimization of spectral band selection across sensors, providing insights for efficient spectral use, improved trait retrieval, and cross-platform interoperability—especially for integration between UAV, Sentinel-2, satellite missions (PRISMA, EnMAP), and simulated datasets as, CHIME, and LSTM. Fluorescence data (e.g., from SIF measurements) will be incorporated to capture subtle physiological changes linked to stress onset.

Ultimately, HYDRA-EO will deliver a comprehensive EO-based methodology to monitor crop stress with improved accuracy, flexibility, and scalability. By combining high-resolution airborne and UAV datasets with satellite observations across multiple spectral and spatial domains, the project lays the foundation for operational monitoring systems that can be tailored to both local precision agriculture and broader regional needs. Importantly, the project will explore the feasibility of extending key findings to coarser-resolution missions, including TROPOMI (Sentinel-5P), Sentinel-3 OLCI, and the upcoming FLEX satellite. By evaluating the potential of these platforms to detect large-scale stress signals—such as changes in fluorescence dynamics and atmospheric interactions—HYDRA-EO contributes to the development of global plant health surveillance systems. The outcomes will directly support future EO mission design, enhance early-warning capabilities, and promote more resilient agricultural systems in the face of escalating biotic and abiotic threats under changing climatic conditions.

* 1. *First Iteration of all Tasks (emphasis on task 2-6)*

The **HYDRA-EO** project proposes a comprehensive framework for integrating hyperspectral, thermal, and multispectral EO data to assess plant health, detect stressors, and retrieve key plant traits. This first iteration outlines the major tasks, aligned with the project's Work Packages (WPs), and introduces preferred methodological concepts supported by technical validation. The approach emphasizes integration of field data, radiative transfer modelling, hybrid machine learning, and multi-sensor EO fusion to ensure both scientific rigor and operational scalability.

This section outlines the first iteration of all project tasks, with emphasis on Tasks 2 to 6, and links each task to the appropriate WP as defined in the technical Statement of Work.

**Table 1**. Overview of Work Packages and Corresponding Tasks

|  |  |  |
| --- | --- | --- |
| No. WPs | Work Packages | No. WPs |
| WP1 | Scientific Requirement Consolidation | Task 1: Consolidation of scientific requirements, use cases, models, algorithms |
| WP2 | Dataset Collection | Task 2: Collection, documentation, and description of datasets |
| WP3 | Development and Validation | Task 3: Development and validation of models, algorithms, and EO products |
| WP4 | Experimental Dataset Generation | Task 4: Generation of experimental datasets and EO products |
| WP5 | Advancing Earth System Science | Task 5: Earth system science exploitation and analysis |
| WP6 | Transferring Science Results into Societal Solutions | Task 6: Demonstration of societal relevance and transfer to stakeholders |
| WP7 | Scientific Roadmap | Scientific roadmap and gaps for future research and EO missions |
| WP8 | Scientific Collaboration | Collaboration with ESA and relevant Horizon EU activities |
| WP9 | Promotion and Coordination | Promotion, dissemination, and stakeholder engagement |
| WP10 | Management | Project coordination, reporting, and risk management |

The HYDRA-EO project follows the structure outlined in the ESA Statement of Work, which defines ten key tasks mapped to ten corresponding Work Packages (WPs). This section outlines the first iteration of all tasks, with detailed emphasis on Tasks 2 to 6, which encompass data acquisition, modelling, analysis, and operational transfer. Each task is aligned with the relevant ESA requirements (REQs) to ensure full compliance with the call objectives.

**Task 1**: Scientific Requirement Consolidation (WP1)

**Related REQs: REQ-1, REQ-2, REQ-3, REQ-4, REQ-10, REQ-13, REQ-17, REQ-23, REQ-24, REQ-25, REQ-26, REQ-27, REQ-28, REQ-29**

Task 1 establishes the scientific foundation of the HYDRA-EO project by consolidating the requirements for detecting crop stress and retrieving plant traits across multiple spectral, spatial, and temporal scales. In line with REQ-1 and REQ-2, this task defines the key use cases and user needs for EO-based plant health monitoring. These needs are translated into technical specifications that guide the design of the models, traits, and EO indicators to be used in subsequent tasks.

A multi-sensor integration strategy will be developed, encompassing hyperspectral (e.g., PRISMA, EnMAP, CHIME), multispectral (e.g., Sentinel-2, Landsat, Sentinel-3), thermal (e.g., ECOSTRESS, LSTM), and fluorescence (e.g., FLEX, TROPOMI) satellite data. This framework ensures REQ-3 and REQ-17 are met by promoting cross-sensor harmonization and data fusion capabilities. A core output of Task 1 is the development of a trait–stressor matrix, linking biophysical and biochemical traits—such as chlorophyll content, nitrogen status, canopy temperature, and LAI—to key biotic and abiotic stressors, including drought, pests, pathogens, and heat.

To address REQ-4 and REQ-10, Task 1 includes an in-depth analysis of how these plant traits evolve in response to different stressors. It will establish mechanistic links between EO observables and stress responses using both physiological understanding and existing literature, thereby enabling more accurate interpretation of sensor data. Special attention will be given to solar-induced fluorescence (SIF) and its use for early stress detection, including evaluation of FLEX data and synthetic FLEX-like products in heterogeneous orchard environments (e.g., olive and pistachio), supporting REQ-17.

As required by REQ-13, this task will support the development of a trait-based modelling framework that enables attribution of stressor impacts and improves generalization across crops, sensors, and sites. These outputs will be systematically documented to serve as inputs for radiative transfer modelling (Task 4), hybrid ML development (Task 5), and EO product scaling (Task 6), ensuring consistency across the entire workflow.

By consolidating prior expertise in remote sensing, trait retrieval, and EO-based stress diagnostics, Task 1 provides the conceptual and methodological blueprint for HYDRA-EO. It ensures scientific rigor, operational coherence, and relevance to user needs—laying the groundwork for robust trait-to-stressor modelling and the development of transferable EO-based monitoring tool.

Finally, this task directly contributes to Open Science principles and the EarthCode EO Open Science Catalogue, ensuring that all project outputs—including datasets, algorithms, and reports—are openly accessible, reproducible, and discoverable (REQ-23, REQ-24, REQ-25). Additionally, it supports the scientific requirement consolidation process (REQ-26 to REQ-29), ensuring alignment with major European initiatives like BEXYL, STELLA and CERBERUS. This includes reviewing relevant methodologies, assessing risks, identifying knowledge gaps, and specifying technical requirements and validation protocols essential for advancing EO-based plant health monitoring.

**Task 2**: Collection, documentation, and description of datasets (WP2)

**Related REQs: REQ-3, REQ-4, REQ-5, REQ-6, REQ-7, REQ-8, REQ-9, REQ-10, REQ-12, REQ-13, REQ-17, REQ-18, REQ-23, REQ-25, REQ-30 to REQ-34, REQ-4 to REQ-51**

Task 2 ensures systematic collection, documentation, and preparation of datasets required for model training, calibration, and validation. The activity addresses the SoW mandate for reliable and consistent reference data (as outlined in REQ-3 through REQ-7), by organizing a series of coordinated aerial campaigns in 2026, complemented by harmonized legacy data from 2025. These campaigns, conducted across four experimental sites in Spain, the Netherlands, and Italy, will capture a wide range of crop types, environmental conditions, and stressor combinations.

Flights will employ UAV-mounted and aircraft-based sensors, including Headwall Photonics VNIR and SWIR hyperspectral imagers (covering 400–2500 nm) and thermal infrared cameras such as the FLIR SC655. These sensor configurations will ensure the acquisition of high-resolution spectral and temperature data across key physiological windows. The campaigns will target five crop systems: alfalfa and potato—used as structurally homogeneous baselines—and more heterogenous landscapes of woody crops such as olive, pistachio, and grapevine.

These systems have been chosen to cover a diverse gradient of crop architectures and stress conditions, allowing robust testing of retrieval strategies and model transferability. Stressors include regulated quarantine pests such as *Flavescence Dorée* in grapevine and Potato Virus Y (PVY), which represent high-priority risks for European agriculture. In addition, fungal and bacterial pathogens will be monitored, including *Septoria* spp., Alternaria alternata, *Botryosphaeria* spp., and *Botrytis cinerea* in pistachio and olive trees, and *Erwinia* spp. (bacterial soft rot) in potato. Olive orchards will also be assessed for *Pseudomonas savastanoi pv. Savastanoi,* and *Spilocaea oleagina*, alongside *Bactrocera oleae* under several water stress regimes. In alfalfa, infestations of different insects will be tracked, with special interest in *Acyrthosiphon pisum*.

Abiotic stress, especially water limitation, will be addressed through experimental management of irrigation regimes. In olive systems, trials will include both rainfed and irrigated plots to allow the separation of water and pathogen-driven physiological changes. This supports REQ-5, REQ-6,and REQ-7 enabling attribution of physiological responses to water or pathogen-driven stress.

Field data will include physiological (SIF, leaf temperature, Cab, NBI), structural (LAI, pigment content), and genomic (SNPs, qPCR) traits, supported by expert visual scoring and ground truthing. Data documentation will follow ESA protocols for metadata, calibration, and traceability in accordance with REQ-48, REQ-49, and REQ-50. All datasets will be prepared for open access and integration into ESA’s Open Science Catalogue as requested in REQ-25.

Field datasets will cover:

* Physiological plant traits: solar-induced chlorophyll fluorescence, leaf temperature, pigments, stomatal conductance, and nitrogen balance index. In the selected site of alfalfa, a FLOX tower system will be deployed in a representative place to provide continuous ground-based measurements of SIF and red/far-red reflectance. The availability of a pure FLEX pixel in the homogenous field will enable a robust integration between in situ measurements and satellite-derived data, thereby supporting the interpretation of spaceborne SIF observations (REQ-8, REQ-9, REQ-12).
* Biochemical and structural traits: Chlorophyll and carotenoid content, dry matter, relative water content, LAI, and macro/micronutrient profiles (e.g., nitrogen, potassium). These leaf measurements will be obtained through biochemical analyses and calibrated against hyperspectral signatures and thermal data to ensure accurate trait retrieval (REQ-3, REQ-4, REQ-5, REQ-12).
* Genomic and transcriptomic traits: Quantitative PCR (qPCR) assays targeting stress-response genes, and SNP-based genotyping for selected trials (e.g., pistachio and olive). These genetic indicators will be linked to phenotypic and spectral responses (REQ-4, REQ-10, REQ-13).
* Visual disease inspection: Expert visual scoring of disease severity and pest damage by experienced phytopathologists from the University of Florence, Wageningen University, and CIAG-IRIAF. This provides a critical ground-truth reference for biotic stress models and EO validation (REQ-3, REQ-7, REQ-18).
* Environmental data: To monitor site-specific meteorological variability and support biotic/abiotic stress interpretation, dedicated weather stations will be deployed at field trial locations (REQ-6). These stations will collect continuous measurements of temperature, relative humidity, solar radiation, wind speed, and precipitation. These datasets will help identify environmental triggers for disease outbreaks or water stress (REQ-5, REQ-6, REQ-12).

In addition, existing datasets from the 2025 aerial campaigns (e.g., in potato, pistachio, and olive orchards under controlled and natural stress conditions) will be harmonized with the 2026 acquisitions (REQ-49). This continuity will enable temporal analysis of crop responses, improve phenological interpretation, and increase the robustness of trait retrieval validation across growing season.

All campaign activities will follow ESA best practices for calibration, documentation, and traceability (REQ-48, REQ-49). This includes the use of radiometric and thermal calibration targets, RTK-GNSS positioning, metadata protocols, and quality control procedures harmonized across partners. Documentation will include stressor metadata, site management logs, and full sensor specifications (REQ-50).

The feasibility of this task is supported by the extensive field and airborne experience of the consortium. Technical risk (e.g., weather delays, hardware failure) will be managed through sensor redundancy, staggered planning windows, and coordination with ongoing satellite acquisitions (linked to Task 3). These datasets will serve as the empirical foundation for trait validation, spectral simulation (Task 4), ML development (Task 5), and EO product scaling across temporal and spatial domain (Task 6, REQ-49, REQ-51).

In alignment with REQ-30 to REQ-34, Task 2 will establish and maintain a centralized project database (D2.1) containing harmonized satellite, airborne, in-situ, and campaign datasets, ensuring consistent data usage across project partners and activities. This database will be continuously updated, with any data usage restrictions communicated to ESA, and documented via the Dataset Description (D2.2). Furthermore, Task 2 contributes to Open Science principles (REQ-23 to REQ-25) by ensuring that all datasets, metadata, and associated algorithms are openly accessible and discoverable via ESA's EO Open Science Catalogue and EarthCode platform. This fosters transparency, reproducibility, and broad scientific engagement beyond the project lifecycle.

**Task 3**: Development and validation of models, algorithms, and EO products (WP3)

**Related REQ-3, REQ-4, REQ-5, REQ-6, REQ-8 to REQ-25, REQ 35 to REQ-47**

This task addresses the requirements of the ESA Statement of Work concerning the design, development, and validation of algorithms for stress detection and plant trait retrieval based on EO data (REQ-3, REQ-9, REQ-13). The HYDRA-EO approach integrates hyperspectral data from PRISMA, EnMAP, and simulated CHIME; multispectral imagery from Sentinel-2 and Landsat; thermal observations from ECOSTRESS and simulated Copernicus LSTM; and fluorescence measurements from FLEX and TROPOMI (REQ-8, REQ-9, REQ-16). Leaf-level measurements, UAV and airborne datasets serve as high-resolution references for calibration and validation (REQ-17).

To support REQ-11, the methodology explicitly addresses the cascading effects of multiple stressors (e.g., drought, heat, pathogens) by analyzing non-linear and synergistic responses in key plant traits such as LAI, canopy temperature, and chlorophyll content. This allows better understanding of stress interactions and their compounded impacts on crop health.

In line with REQ-12, EO data will constrain radiative transfer models (PROSAIL, SCOPE) by minimizing reliance on unconstrained or poorly correlated parameters. Observations including SIF, canopy temperature, and pigment-related indices will enable more realistic simulations and improve hybrid inversion approaches, reducing error propagation in scaled applications.

REQ-4, REQ-5, and REQ-6 will be addressed through the integration of soil moisture, weather, and irrigation data to monitor abiotic stressors and disentangling their interaction with disease emergence. These environmental drivers will be used to explain vegetation status evolution and improve attribution of stress responses.

A major technical challenge addressed in this task is the spatial and spectral scaling gap between UAV/airborne datasets and coarse-resolution satellite data (e.g. Landsat, Sentinel-2 PRISMA ENMAP, REQ-9). This gap will be addressed through RTM-based simulations tailored to specific sensors for easy transferability our method to the remote sensing community through R packages (REQ-22, REQ-23). This includes evaluating FLEX and TROPOMI’s potential to detect stress in structurally complex canopies (e.g., olive trees) compared to homogeneous crops like alfalfa (REQ-8, REQ-16).

Thermal observations will complement optical data by providing water stress indicators, including canopy temperature and stomatal regulation metrics derived from UAV thermal imaging and ECOSTRESS data (REQ-9). These will aid in separating abiotic stress effects from biotic responses.

Hybrid ML models will be developed to fuse RTM-based simulations with EO datasets for the classification of stressor types and retrieval of traits such as LAI, pigment content, and nitrogen indices (REQ-19). These models will be trained and validated across the multiple crops and stress conditions, with performance metrics derived through robust, site-based validation protocols (REQ-20, REQ-21).

A critical outcome of this task will be the generation of sensor-optimized band configurations and the design of new vegetation indices and modelling frameworks for downscaled implementations and future EO missions (REQ-22). These reduced feature sets will be integrated in Tasks 4 and 5 for scaling and operational readiness. To ensure temporal consistency, the timing of satellite and airborne acquisitions will be aligned, supporting the generation of harmonized time series and phenology-informed stress maps (REQ-3, REQ-16).

In response to REQ-22, a validation and impact assessment strategy will be conducted, involving expert stakeholders and the scientific community. This will include the development of a roadmap for model refinement, operational product delivery, and long-term monitoring capabilities.

Finally, as required by REQ-23, the project will fully adopt the principles of Open Science. All datasets, algorithms, and EO products will be openly accessible, reproducible, and well-documented. Project outputs—including calibration protocols, trait retrieval scripts, and training data—will be released through open repositories (e.g., GitLab), and a dedicated Open Science workshop and seminar at Wageningen University will be organized to engage the community, foster transparency, and accelerate uptake of results. This open approach ensures rapid scientific turnaround and the translation of methods into actionable crop monitoring solutions.

Task 3 addresses REQ-35 to REQ-47 by developing and validating EO-based methods using hybrid multi-mission approaches (e.g., Copernicus Sentinels, FLEX). Models will be tested on olive, potato, and vineyard systems, integrating datasets from CERBERUS and STELLA (REQ-39 to REQ-40). Validation targets 2025–2026 (REQ-41), with final methods detailed in the ATBD (D3.1) and validation in the PVR (D3.2) (REQ-43 to REQ-46). Results will be published (D9.3, REQ-47) and datasets shared via ESA platforms under coordinator oversight, supporting Open Science (REQ-23 to REQ-25).

**Task 4**: Generation of experimental datasets and EO products (WP4)

**Related REQs: REQ-12, REQ-14, REQ-22, REQ-23, REQ-48 to REQ-55**

This task focuses on generating synthetic datasets and trait retrieval products to support model development and the optimization of satellite band configuration (REQ-12, REQ-14). The preferred concept is the use of RTMs(e.g. PROSAIL and SCOPE) to simulate plant reflectance, fluorescence, and thermal responses across gradients of biotic (e.g., pathogens, pests) and abiotic (e.g., drought) stress.

The simulations will be tailored to match the spectral configurations and spatial resolutions of current (e.g., Sentinel-2, PRISMA, EnMAP) and upcoming satellite platforms CHIME, LSTM), thus enabling direct transfer of airborne-derived insights to spaceborne applications. Trait responses modelled will include chlorophyll fluorescence, pigment dynamics, water content, and LAI.

A major deliverable of this task is the reduction of hyperspectral signals into optimized bandsets that preserve information critical for stress detection (REQ-22, REQ-23). These reduced configurations will guide feature selection for ML models (Task 3) and support the design of new vegetation indices sensitive to disease or water stress signals under degraded spatial and spectral resolutions.

To ensure scientific validity and cross-platform relevance, these simulations will be iteratively calibrated with in-situ and airborne observations gathered in Task 2. The resulting experimental EO products will serve as baselines for sensitivity analyses, performance benchmarking, and inter-sensor harmonization (REQ-26). The task will also contribute to the scientific roadmap (Task 7) by identifying key gaps in stress signal simulation across sensor types and configurations.

In alignment with Open Science principles (REQ-23), all synthetic datasets, simulation scripts, and derived products will be openly accessible and fully documented. This transparency ensures reproducibility and facilitates the transfer of scientific results into actionable solutions.

The Experimental Dataset will integrate all developed products, EO data, in-situ measurements, and model outputs, ensuring reproducibility and enabling testing of alternative algorithms (REQ-48). Methods will scale from test areas to broader spatial and temporal coverage, targeting 2020–2026, with earlier periods (2020–2024) supported by Sentinel-2 and other relevant missions (REQ-49, REQ-50). Dedicated campaigns will cover 2025–2026, ensuring comprehensive datasets for scientific analyses (REQ-51). Validation will include cross-comparisons with existing products, reanalysis data, and climatologies to assess accuracy and advantages (REQ-51). All datasets will be described in the publicly available Experimental Dataset Description (EDD, D4.2) (REQ-52) and shared via online platforms with DOIs assigned (REQ-53, REQ-54). All datasets will be shared with the scientific community via GitLab and, if required, through ESA-supported platforms (e.g., EarthCode, Euro Data Cube) (REQ-55), ensuring broad accessibility and alignment with Open Science principles.

**Task 5**: Earth system science exploitation and analysis (WP5)

**Related REQs: REQ-17, REQ-19, REQ-21, REQ-23, REQ-24, REQ-26, REQ-56 to REQ-61**

The preferred concept is a hybrid ML framework that fuses radiative transfer model outputs (from Task 4) with empirical EO and field data (from Task 2) to retrieve plant traits and classify stressors (REQ-17, REQ-19). Models will focus on functional traits such as chlorophyll content (Cab), nitrogen status, LAI, and canopy temperature, while enabling the differentiation of overlapping stressors like drought and disease through the integration of spectral, thermal, and temporal features (REQ-26).

The framework will employ both supervised and unsupervised learning algorithms, trained on multi-source datasets and validated across sensor types, spatial scales, and crop systems to ensure robustness and generalizability (REQ-24). Reduced bandsets and trait-specific indices derived in Task 4 will support model efficiency and transferability (REQ-23).

To enable seasonal monitoring and phenological analysis, multi-temporal satellite acquisitions will be temporally aligned with aerial campaigns (REQ-21). Outputs from this task will feed directly into Task 6 to generate user-ready EO products and tools for decision support.

The HYDRA-EO team brings significant experience in machine learning, radiative modelling, and operational EO applications through prior ESA and Horizon EU projects (e.g., BEXYl, CORBERUS, SYLVA). Development risks are minimized by modular design, tested pipelines, and access to extensive annotated datasets.

Task 5 will deliver novel Earth science results through at least two science cases focused on crop pests and diseases, addressing key knowledge gaps (REQ-56, REQ-57). Interdisciplinary research, combining EO, AI, and data analytics, will enhance scientific return (REQ-58). A thorough assessment of dataset utility will support conclusions on the effectiveness of EO for stress detection (REQ-59), with findings submitted to peer-reviewed journals and promoted at international conferences. Results will be recorded in the Impact Assessment Report – Science Chapter (D5.1, REQ-60) and disseminated through peer-reviewed publications (D8.3, REQ-61) to maximize scientific impact.

**Task 6**: Demonstration of societal relevance and transfer to stakeholders (WP6)

**Related REQs: REQ-20, REQ-21, REQ-24, REQ-26, REQ-28, REQ-30, REQ-62 to REQ-71**

This task demonstrates how the scientific outcomes of HYDRA-EO will be operationalized into tools and services that are directly relevant to users, policymakers, and the broader EO community (REQ-20, REQ-30). The preferred concept focuses on translating multi-source EO data—from UAV, airborne, and satellite platforms—into harmonized, cross-scale information products. These include plant trait maps, biotic and abiotic stress indicators, and hybrid retrieval algorithms (REQ-21, REQ-24).

A central deliverable of this task is the development of a public GitLab repository where all modelling, simulation, and retrieval tools produced in the project will be hosted (REQ-65, REQ-70). This includes the ongoing evolution of the ToolsRTM and SCOPEinR packages, developed by Wageningen University, which will be expanded to support a broader range of EO sensors and crop types. New functionalities will include:

* Spectral resampling functions to convolve high-resolution hyperspectral inputs to the spectral configurations of satellite platforms such as Landsat, Sentinel-2, PRISMA, EnMAP, and CHIME. These functions ensure interoperability and allow for consistent trait retrieval across platforms (REQ-21).
* RTM–ML integration modules for coupling outputs from physically-based radiative transfer models, such as PROSAIL and SCOPE, which simulate top-of-canopy reflectance and fluorescence emissions, with empirical datasets. This integration improves the prediction of key biochemical and structural plant traits such as chlorophyll content, water status, and LAI. Additionally, these methods enhance model explainability and scalability across varying spatial and spectral resolutions(REQ-24, REQ-26).
* Stressor classification routines using optimized spectral band combinations to differentiate between overlapping stressors such as drought, nutrient deficiency, and pathogen infection. These will be adaptable to each satellite platform’s constraints, increasing their operational relevance (REQ-28).
* Thermal–spectral fusion tools to integrate canopy temperature with hyperspectral data. This will allow deeper exploration of stress physiology, especially under water-limited or disease-affected conditions—critical for olive and pistachio systems (REQ-24).
* A spectral library generated from RTM simulations and field observations across diverse crop and stress scenarios. This will serve as a benchmark to quantify how spectral signal integrity is impacted by spatial and spectral coarsening, aiding future mission planning and trait retrieval design (REQ-23).

To enhance accessibility and stakeholder engagement, a web-based Shiny application will be developed. The app will provide an interactive environment for ESA stakeholders, researchers, and users to visualize spectral degradation, explore retrieval workflows, and assess trait uncertainties across spatial and spectral scales (REQ-71). Modules will support trait inversion, simulation-based testing, and comparison across sensor platforms, fully aligned with ESA’s open science and data democratization goals (REQ-70).

This application and its underlying tools will be hosted on WU-DES or ESA cloud services, complete with training materials, documentation, and demonstration pipelines. This will ensure long-term accessibility and replicability while fostering collaboration with other ESA and Horizon EU projects via shared codebases, technical contributions, and outreach activities (REQ-65, REQ-71).

Feasibility is supported by the HYDRA-EO team’s established experience in open-source software development, EO product generation, and stakeholder engagement. Risks related to user adoption or platform integration will be mitigated through iterative user feedback, stakeholder co-design workshops, and demonstration pilots tailored to regional agencies and research institutions.

Task 6 will demonstrate the societal relevance of HYDRA-EO by implementing four prototype demonstration cases with Early Adopters (e.g., public agencies, NGOs), showcasing the operational potential of the developed products (REQ-62 to REQ-65). These cases will leverage EO data, modelling, AI, and digital technologies (e.g., HPC, cloud computing) to support decision-making in agriculture and food security (REQ-66, REQ-67). Collaboration with relevant EC or national initiatives will ensure broader integration (REQ-68). Results will be documented in the Impact Assessment Report – Societal Impact Chapter (D6.1) and disseminated through peer-reviewed publications (D8.3) (REQ-69).

**Task 7**: Scientific roadmap and gaps for future research and EO missions (WP7)

**Related REQs: REQ-66, REQ-67**

This task will deliver a Scientific Roadmap (D7.1) to guide future research on EO-based plant trait monitoring and stress detection, ensuring that HYDRA-EO outcomes contribute to ESA’s mission planning and the Digital Twin Earth initiative. The roadmap will define priority scientific questions, observational requirements, and community coordination mechanisms to advance the state of the art.

Key components include:

* Critical analysis of HYDRA-EO’s results against scientific objectives and societal challenges (e.g., crop pest, disease, and multi-stressor monitoring).
* Identification of knowledge gaps and observational gaps—both satellite-based (e.g., CHIME, FLEX, LSTM, Copernicus Land services) and in-situ—to address in the 2026–2029 timeframe (REQ-66).
* Recommendations for spectral/spatial resolutions and EO payload designs, including solutions for gaps like SIF retrieval in mixed canopies, spectral redundancy, and spectral degradation impacts (REQ-67).
* A development and evolution plan, coordinating with relevant EU and international projects to ensure alignment with broader scientific initiatives.
* A strategy for transitioning research outputs into operational systems, including integration into Digital Twin Earth.

Consultation with the scientific community and operational stakeholders will ensure actionable, coordinated outcomes that shape next-generation EO capabilities.

Feasibility is high due to the HYDRA-EO consortium’s multidisciplinary expertise and strong involvement in ESA and Horizon Europe strategic planning. This task ensures that the project's scientific outcomes inform broader programmatic goals and next-generation EO capabilities.

**Task 8**: Collaboration with ESA and relevant Horizon EU activities (WP8)

**Related REQs: REQ-65, REQ-68, REQ-70, REQ 71, REQ 72, REQ 73, REQ 74, REQ 75, REQ 76, REQ 77, REQ 78, REQ 79, REQ 80**

This task ensures integration of HYDRA-EO with ongoing ESA scientific activities and Horizon Europe projects (BEXYl, CORBERUS, SYLVA). In alignment with REQ-65 and REQ-68, the task focuses on knowledge sharing through model, dataset, and tool exchange with external scientific initiatives. The consortium has already secured formal support letters from the CERBERUS and BEXYL projects and from a TROPOMI expert. expressing commitment to collaborate on these initiatives. The preferred approach includes participation in EO networks (e.g., ESA Network of Resources), collaborative development via open repositories, and alignment with community-defined standards for data and code interoperability (REQ-70).

The following activities will be implemented throughout the project duration:

1. Activity database management: Partners will maintain an inventory of relevant activities across all connected projects (REQ-71), documenting collaboration arrangements and points of contacts.
2. Cross-project coordination meetings: Regular meetings will ensure dialogue and alignment of actions (REQ-72), with special focus on collaborating with BEXYL, CERBERUS, STELLA and SYLVA (REQ-77, REQ-78).
3. Data and resource exchange platform: Linked to task 2, a collaborative research database will facilitate two-way sharing of data, tools and results (REQ-73, REQ-79), including development of enhanced EO components supporting partner projects (REQ-80).
4. Joint scientific output development: These coordination efforts will foster joint scientific outputs (REQ-74), publications and outreach (REQ-75), emphasizing community synthesis papers integrating findings across projects (REQ-76).

Partners will actively contribute to ESA science clusters in agriculture and climate, and foster synergies with biodiversity, disease surveillance, and sustainability programs. Collaboration will also extend to education and early-career scientist engagement via open-access resources and workshops. Feasibility is high given the consortium’s active roles in ESA and Horizon EU platforms. Risks of misalignment or duplication will be mitigated through regular coordination meetings and mutual feedback with ESA and partner institutions.

A Collaborative Research Actions Report will be updated quarterly, documenting all integration activities, partnership developments, and joint outputs achieved during the reporting period, ensuring transparent tracking of progress across all four action streams.

**Task 9**: Promotion, dissemination, and stakeholder engagement (WP9)

**Related REQs: REQ-69, REQ-71, REQ-72, REQ-74, REQ-75, REQ 81**

This task focuses on ensuring effective communication, dissemination, and public engagement of HYDRA-EO results. The following activities related to REQ=81 will be executed during the project:

* Scientific community engagement and networking: Coordinate cross-project (REQ-72), with relevant scientific networks (as mentioned in the Statement of Work), investigate and pursue integration opportunities with international scientific initiatives (an ESA contribution), organize g targeted outreach to regional agricultural services, farmer cooperatives, EO companies, and ecosystem managers.
* Scientific workshop organization: A workshop will be organised at the Wageningen Campus to gather EO, agriculture, and food system scientists, identify main research issues and a roadmap, and produce a workshop report (D9.4).
* Scientific publication and dissemination: Linked to task 8, this activity includes publishing peer-reviewed articles (D.9.3) in open-access journals (REQ-69, REQ-75), participation in international scientific congresses (REQ-74), and the development of science-policy briefs for agricultural and environmental agencies.
* Digital presence and visual communication: Create and maintain a project website (D9.2), generate high-quality graphical materials, maps, infographics, and animations, develop and maintain presentation materials (1,3, and 10-slide PowerPoint presentations), Multilingual materials and visual explainer tools will be created to ensure broad accessibility. Coordination with ESA dissemination platforms will reinforce visibility and adoption across sectors. Assets will be regularly updated throughout the project and remain available for 2 years post-completion of the project.
* Coordination documentation and reporting: Track coordination activities (REQ-71), maintain an archive of all promotion materials and event participation, prepare quarterly updates on coordination and promotion activities.

Feasibility is supported by the consortium’s prior experience in EO outreach and by leveraging communication staff and networks from each partner institution.

**Task 10**: Project coordination, reporting, and risk management (WP10)

**Related REQs: REQ-31 to REQ-81**

This task ensures that HYDRA-EO is delivered in full compliance with ESA’s administrative, technical, and financial requirements. It includes project coordination, partner communication, reporting, risk monitoring, and milestone tracking, as specified in REQs 31–81.

A dedicated coordination team will oversee daily operations, supported by work package leaders who will manage technical execution and deliverable submission. A risk register and management plan will guide mitigation actions, and regular consortium meetings and ESA check-ins will ensure transparency and accountability.

Feasibility is guaranteed through the consortium’s extensive experience in leading ESA-funded EO projects, with clear governance, communication structures, and resource planning in place.

* 1. *Technical Reservations – Technical Compliance*

*2.3.1 Reservations*

No technical reservations are foreseen. The HYDRA-EO consortium confirms full compliance with the technical requirements outlined in the Statement of Work (SoW). All deliverables, methods, and objectives have been carefully aligned with the expectations and mandatory elements of the ESA ITT. Any minor adjustments required during implementation (e.g., timing of satellite tasking) will be handled via coordination with ESA technical officers, ensuring flexibility without compromising scientific or operational quality.

*2.3.2 Technical Compliance Matrix (Statement of Work/Technical Requirements)*

|  |  |  |
| --- | --- | --- |
| REQUIREMENT (\*) | COMPLIANT (Y/N/P) (\*\*) | REMARKS (\*\*\*) |
| REQ-1 | Y |  |
| REQ-2 | Y | . |
| REQ-3 | Y |  |
| REQ-4 | Y |  |
| REQ-5 | Y |  |
| REQ-6 | Y |  |
| REQ-7 | Y |  |
| REQ-8 | Y |  |
| REQ-9 | Y |  |
| REQ-10 | Y |  |
| REQ-11 | Y |  |
| REQ-12 | Y | . |
| REQ-13 | Y |  |
| REQ-14 | Y |  |
| REQ-15 | Y |  |
| REQ-16 | Y |  |
| REQ-17 | Y |  |
| REQ-18 | Y |  |
| REQ-19 | Y |  |
| REQ-20 | Y |  |
| REQ-21 | Y |  |
| REQ-22 | Y |  |
| REQ-23 | Y |  |
| REQ-24 | Y |  |
| REQ-25 | Y |  |
| REQ-26 | Y |  |
| REQ-27 | Y |  |
| REQ-28 | Y |  |
| REQ-29 | Y |  |
| REQ-30 | Y |  |
| REQ-31–38 | Y |  |
| REQ-39 | Y | Test sites will compromise several environments and crops, adding also data from main EU projects. |
| REQ-40 | Y | Test sites will include olive, potato and vineyard. |
| REQ-41 | Y | Target period will be 2025 and 2026. |
| REQ-42-47 | Y |  |
| REQ-48 | Y |  |
| REQ-49 | P | Scaling is limited to aerial campaigns (2025–2026) and Sentinel-2/Landsat (2020–2026); full multi-sensor scaling beyond these platforms is not feasible. |
| REQ-50 | Y |  |
| REQ-51 | Y |  |
| REQ-52-64 | Y |  |
| REQ-65 | Y |  |
| REQ-66 | Y |  |
| REQ-67 | Y |  |
| REQ-68 | Y |  |
| REQ-69 | Y |  |
| REQ-70 | Y |  |
| REQ-71 | Y |  |
| REQ 72-81 | Y |  |

* 1. Existing own concepts/products to be used (Prime and Subcontractors)

**Use of internal datasets (Dutch potato trial – WU-DES)**

A dataset generated from Wageningen University’s potato field trial (NL) will be used to support the development and validation of EO-based stress detection models. The trial is conducted in collaboration with private sector partners involved in commercial breeding programs and is subject to confidentiality agreements. As such, any dissemination of raw data or derived outputs will require prior written approval from the stakeholders.

**Data Use and Confidentiality Clause**

The dataset generated from the Dutch potato site will be used exclusively for scientific analysis of EO-based stress detection under the HYDRA-EO project. The trial is conducted in collaboration with private sector partners involved in commercial breeding programs. The project guarantees that no commercially sensitive information will be disclosed without prior consent. All outputs relevant to ESA—such as trait retrieval algorithms, processing pipelines, and aggregated, non-sensitive validation results—will remain open and accessible, fully aligned with ESA contractual terms. The project will also make use of open-access datasets from complementary trial sites (e.g., CNR-IBE, CIAG-IRIAF) to ensure transparency, reproducibility, and deliverable quality.

* 1. Third Party’s concepts/products (outside of the consortium which is composed by the Prime Contractor and Subcontractor/s) intended to be used

While no proprietary third-party products will be embedded in project deliverables, the HYDRA-EO project collaborates with private agricultural companies in the Netherlands that manage the field trials used for data collection. These partners provide agronomic oversight and facilitate access to experimental sites under established agreements. Similar confidentiality and data governance arrangements apply across all such collaborations. However, no third-party intellectual property or commercial datasets will be integrated, licensed, or disclosed within the ESA deliverables.

Any use of third-party data will remain observational and subject to Non-Disclosure Agreements (NDAs) that restrict the release of sensitive information. All public outputs related to the ESA contract—such as trait retrieval methods, algorithms, and aggregated validation results—will be developed independently of proprietary content and made openly available in full alignment with ESA requirements.

* 1. Potential Problem Areas
     1. Identification of the main problem(s) or problem area(s) likely to be encountered in performing the activity

The HYDRA-EO project is built around a multiscale, multi-sensor framework that spans high-resolution UAV platforms, airborne sensors, and satellite missions. This setup enables a comprehensive assessment of crop stress dynamics, but it also introduces several technical challenges that must be anticipated and addressed:

1. **Scaling across spatial, spectral, and thermal resolutions**

A central challenge in HYDRA-EO lies in scaling accurate plant trait retrievals from high-resolution data sources—such as UAV-mounted VNIR/SWIR hyperspectral sensors and thermal cameras—to medium and coarse-resolution satellite platforms (e.g., Sentinel-2, PRISMA, EnMAP, and simulated CHIME for hyperspectral, simulated Copernicus LSTM for thermal). This scaling complexity is further amplified when integrating coarse-resolution systems like FLEX and TROPOMI, whose pixel footprints range from ~300 m (FLEX) to 7–10 km (TROPOMI), severely limiting the ability to isolate vegetation-specific signals. As a result, localized or early-stage plant stress signals become diluted, especially in heterogeneous agricultural landscapes.

This problem is particularly pronounced in crops with fragmented or row-based architectures, such as olive, pistachio, and vineyards. In these systems, canopy gaps, soil background, and shadowing introduce mixed signals that undermine the spectral coherence of downscaled data. Consequently, trait retrieval models suffer from increased uncertainty, and the reliability of derived vegetation indices decreases.

The integration of thermal data introduces additional complexity. Leaf temperature, a key indicator of stomatal conductance and evapotranspiration, is sensitive to canopy structure and observation geometry. While UAV-based thermal imaging provides high spatial fidelity for detecting localized physiological stress, transferring these insights to coarser-resolution thermal platforms (e.g., ECOSTRESS, MODIS) is challenging. Coarse thermal pixels often span heterogeneous surfaces, making it difficult to disentangle plant-related temperature signals from soil, infrastructure, or understory contributions.

Understanding how thermal and spectral traits degrade across spatial resolutions is essential for scaling physiological indicators such as evapotranspiration, water use efficiency, and canopy cooling. HYDRA-EO addresses this by leveraging radiative transfer modelling (e.g., SCOPE) to simulate temperature-sensitive variables under various stress and canopy configurations, supporting robust cross-scale integration of thermal indicators.

1. **Loss of Trait-Specific Spectral Sensitivity Under Band Reduction**

Key physiological and biochemical plant traits—such as chlorophyll fluorescence, nitrogen-related absorption features, and leaf water content—are characterized by narrow spectral signatures, which can only be reliably captured using high-resolution hyperspectral sensors. When these detailed spectra are resampled or aggregated to match the broader bands of multispectral satellites (e.g., Sentinel-2, PRISMA, CHIME), there is a substantial risk of trait-specific signal dilution and loss of diagnostic wavelengths.

This limitation is especially critical for stress-related trait retrievals, where early detection of drought, nutrient deficiencies, or pathogen infection relies on subtle variations in reflectance around narrow bands (e.g., 705 nm for red-edge chlorophyll absorption, 970 nm for water content, 1240–1510 nm for protein and nitrogen features). Additionally, important stress indicators such as brown pigments, carotenoids (Car), and anthocyanins (Anth)—which are involved in oxidative stress responses and senescence—display distinct absorption features in the visible and shortwave infrared regions. Their retrieval becomes increasingly difficult as spectral resolution decreases.

In structurally heterogeneous crops such as olive, pistachio, and grapevine, canopy architecture introduces further complexity. Discontinuous canopies, variable leaf angles, and mixed background signals from soil or understory vegetation reduce spectral coherence and mask weak trait signals, especially under coarse spectral and spatial configurations. These effects severely constrain the accuracy of inversion models and limit the sensitivity of commonly used vegetation indices (e.g., NDRE, MCARI, PRI, CRI).

To safeguard the operational viability of spaceborne plant trait retrieval, HYDRA-EO will deploy a combination of radiative transfer model simulations, trait-specific spectral index design, and hybrid ML algorithms to identify robust band combinations and mitigate the effects of spectral degradation. These methods will ensure that critical biochemical and physiological traits remain detectable even after downsampling, enabling the use of EO data across platforms and scales.

1. **SIF retrieval limitations from coarse-resolution platforms**

While TROPOMI and FLEX provide valuable insight into photosynthetic function through SIF emission, their coarse spatial resolution presents significant constraints. The coarse pixel aggregation in FLEX (~300 m) and TROPOMI (~7 km) results in mixed spectral signals that mask crop-specific SIF variations—especially in fragmented or mixed-use landscapes. This reduces the diagnostic power of SIF-based indices for capturing crop stress at the management scale.

1. **Disentangling overlapping stressors (biotic and abiotic)**

The co-occurrence of biotic stressors—such as fungal infections (e.g., *Septoria* spp., *Pseudomonas savastanoi*), viral diseases (e.g., Potato Virus Y), or insect pests (Aproaerema *albipunctella*)—with abiotic stressors like drought, poses a significant diagnostic challenge for EO-based monitoring systems. These stressors often induce similar spectral and thermal signatures, such as reduced chlorophyll absorption, lower fluorescence yield, and elevated leaf temperatures due to impaired stomatal conductance. As a result, trait inversion models may misattribute the physiological origin of stress signals, especially when using multispectral data or low-resolution satellite imagery.

This confounding effect varies across host plants: for example, olive and pistachio trees, which have complex canopies and deeper rooting systems, may exhibit delayed drought responses compared to potato or alfalfa, which are shallow-rooted and structurally homogeneous. Furthermore, pathogen-specific responses—such as altered pigmentation (e.g., increased anthocyanins during viral infection) or necrosis—can be spatially localized, making them difficult to detect at coarse scales.

1. **Transferability and generalization of hybrid machine learning models**

Hybrid methodologies that integrate Radiative Transfer Models with ML have shown strong potential for plant trait retrieval, particularly under controlled conditions using high-resolution datasets from UAV and airborne platforms. However, a key challenge arises when these models are transferred to coarser-resolution satellite data: their performance often degrades due to differences in spatial scale, sensor characteristics, and observation geometry.

This issue is amplified in structurally complex crop systems—such as olive, pistachio, and grapevine—where variability in canopy structure, row orientation, and background signals (e.g., soil, understory) introduces additional spectral noise and confounding effects. As a result, model predictions trained on homogeneous, well-resolved datasets may not generalize well across sensor types, crop types, or ecological regions.

Ensuring robust cross-scale applicability of RTM–ML frameworks is therefore a core methodological challenge within HYDRA-EO. It requires adaptive training strategies, data augmentation from simulated spectra, and cross-validation across multiple platforms and field conditions to maintain prediction accuracy and reliability in diverse agroecosystems.

* + 1. Proposed solutions to the problems identified

To address the multiscale, multi-sensor challenges inherent to the HYDRA-EO framework, we propose the following integrated solutions, tailored to each of the key technical problems:

1. **Scaling across spatial and spectral resolutions**

One of the core technical challenges in remote sensing of crop stress lies in maintaining prediction accuracy and signal reliability when transitioning from high-resolution UAV or airborne observations to coarse-resolution satellite data. As spatial resolution degrades—particularly for missions like FLEX (~300 m) or TROPOMI (~7 km)—plant trait signals such as chlorophyll content, canopy temperature, and water status become increasingly confounded by background elements such as soil, canopy gaps, and non-vegetated surfaces. This presents a significant limitation in structurally complex or heterogeneous agroecosystems such as olive orchards, where sub-pixel variability, discontinuous canopies, and mixed spectral signatures severely affect retrieval reliability.

To address this, HYDRA-EO proposes a spectral-temporal scaling framework grounded in advanced 1D RTMs, as PROSAIL and SCOPE models. These models will simulate canopy reflectance, SIF, and thermal emission across a continuum of spatial and spectral resolutions—from UAV-based sensors (cm scale) to satellite missions such as Sentinel-2 (10 m), PRISMA and CHIME (30 m), and FLEX and TROPOMI (300 m and ~7 km, respectively). Simulated outputs will be resampled to match the exact characteristics of these platforms, allowing the team to quantify the impact of spectral degradation and pixel coarsening on the detectability of key plant traits.

The project will generate transfer functions, uncertainty maps, and band reduction strategies to preserve trait-sensitive spectral regions and correct for scale-induced signal loss. However, it must be emphasized that retrieval performance at coarse satellite resolutions (e.g., FLEX, TROPOMI) is inherently constrained. In such cases, methods proposed here do not guarantee high predictive accuracy, particularly in landscapes where vegetation cover is fragmented or where trait heterogeneity occurs within the pixel. These limitations will be explicitly addressed through validation analyses, sensitivity testing, and documented thresholds of reliability.

Structurally homogeneous crops such as alfalfa and potato will be used as empirical calibration sites to support robust scaling analyses. Their dense, uniform canopies minimize background interference and serve as reference benchmarks to test downscaling and upscaling approaches. This will enable a clearer understanding of the scale transferability of trait indicators and guide the design of spatially-aware retrieval models.

The thermal domain will be similarly integrated using field-based thermography (e.g., FLIR SC655), satellite data (Landsat, ECOSTRESS), and physically-based radiative transfer models such as SCOPE, which simulate canopy temperature, energy balance components, and evapotranspiration These data streams will inform the estimation of transpiration, canopy conductance, and water-use efficiency, supporting cross-platform physiological stress mapping. RTM-ML hybrid algorithms will link these thermal features to physiological processes while accounting for resolution-induced uncertainty.

Through this comprehensive, model-driven scaling strategy, HYDRA-EO will define the feasibility limits and performance boundaries of cross-scale plant trait monitoring. It enables operational insights while transparently addressing where and why performance degrades, ensuring scientific integrity and practical usability across Earth Observation missions.

1. **Loss of Trait-Specific Spectral Sensitivity Under Band Reduction**

To safeguard the retrieval of plant traits from spectrally degraded datasets, HYDRA-EO will implement a targeted strategy centred on physically-based radiative transfer modelling. Specifically, the project will employ the PROSAIL model for simulating directional canopy reflectance in the optical domain, and the SCOPE model for integrating photosynthetic activity, leaf energy balance, and solar-induced fluorescence (SIF) emission. These RTMs will be employed to generate synthetic datasets under controlled biophysical conditions, enabling systematic evaluation of signal degradation across sensor resolutions. This will guide the development of robust inversion and scaling algorithms for plant trait retrieval and provide a controlled basis to assess how spectral aggregation—such as that from Sentinel-2, PRISMA, or CHIME configurations—affects the detectability of key biochemical and physiological traits.

Reduced, trait-specific bandsets will be identified through systematic sensitivity analyses applied to both RTM outputs and empirical spectral datasets. These optimized band combinations will ensure retention of critical information for traits such as chlorophyll content, water status, nitrogen balance, dry matter, and pigment composition. Particular attention will be given to secondary pigments—including carotenoids, anthocyanins, and brown pigments—which are vital indicators of oxidative stress, senescence, and plant resilience mechanisms, yet highly susceptible to loss during spectral downsampling.

To enhance retrieval robustness in structurally heterogeneous crops (e.g., olive, pistachio, grapevine), HYDRA-EO will co-design novel vegetation indices aligned with the specific bandsets of target sensors. These indices will be optimized for resilience to spectral convolution and background contamination, which are common in mixed-pixel environments. Building on existing indices such as NDRE, CRI, and PRI, the approach will incorporate continuum removal techniques in the red-edge and shortwave infrared (SWIR) regions. Additionally, the indices will be extended through the application of soil-adjusted transformations, angular normalization routines, and spectral unmixing algorithms—ensuring improved sensitivity to crop-specific biochemical and physiological traits under complex canopy structures.

All tools developed will be integrated into the ToolsRTM and SCOPEinR R packages, and further deployed via an interactive Shiny app to support trait simulation, signal degradation visualization, and platform-specific adaptation. This software suite will allow researchers and stakeholders to explore trait detectability under various sensor resolutions, ensuring HYDRA-EO’s methodology remains operationally applicable across spatial scales and satellite missions

**3. SIF retrieval limitations from coarse-resolution platforms**

Retrieving Solar-Induced Chlorophyll Fluorescence from coarse spatial resolution platforms such as TROPOMI (~7 km), Sentinel-3 OLCI (~1 km), and even the upcoming FLEX mission (~300 m) presents a major scientific and operational limitation, particularly in fragmented or heterogeneous agroecosystems. The large footprint of these sensors results in significant land cover mixing, making it extremely challenging to isolate crop-specific SIF signals. In orchard systems like olive, pistachio, or vineyard plots, where discontinuous canopies, bare soil, and inter-row vegetation dominate, the measured SIF is often an aggregate of multiple sources—only part of which originates from the target crop. This dilution effect leads to ambiguous signals and loss of physiological specificity, which undermines the core objective of using SIF as an early stress indicator at these spatial scales.

Moreover, at FLEX, Sentinel-3 OLCI and TROPOMI resolutions, background effects from soil reflectance, topography, and non-photosynthetic vegetation can exceed the physiological SIF signal itself, especially under stress conditions when photosynthetic activity is already suppressed. This places a hard constraint on the interpretability, attribution, and quantitative use of SIF for stress monitoring or plant trait retrieval in mixed systems.

To address these constraints, HYDRA-EO will implement a multi-scale SIF scaling and validation framework, combining empirical and model-based approaches. High-resolution UAV hyperspectral imagery and airborne SIF measurements using FluorSpec will provide benchmark reference data at the plot scale. These will be cross-compared with synthetic FLEX-equivalent SIF outputs generated through the radiative transfer models, which simulates canopy fluorescence emissions under varying structural and physiological conditions.

The large-scale alfalfa fields, due to their structurally homogeneous and fully closed canopies, will serve as calibration testbeds for spatial scaling experiments. In these settings, SIF signal contamination from soil and canopy gaps is minimized, allowing for more accurate quantification of how fluorescence signals degrade when aggregated to FLEX, Sentinel-3 OLCI, and TROPOMI scales. These use cases will guide the development of scaling factors, spatial correction routines, and spectral disaggregation strategies. To accomplish a more robust comparison with spaceborne derived SIF, in addition to UAV-SIF measurements, the alfalfa site was chosen for placing a FloX system that delivers continuous and high-frequency measurements of SIF at ground level.

Nevertheless, the project acknowledges that in highly heterogeneous or open-canopy environments, retrieval of SIF from coarse satellite sensors will not provide reliable trait-level or stress-specific insights. Instead, HYDRA-EO will clearly delineate the limits of SIF usability, establishing uncertainty thresholds and feasibility domains for FLEX, Sentinel-3 OLCI, and TROPOMI-based fluorescence products. The aim is not to force the use of SIF where it cannot work, but to scientifically define when and where it does, ensuring methodological transparency and operational realism.

In summary, while HYDRA-EO will pursue best practices in SIF scaling and validation, the team explicitly recognizes that coarse-resolution SIF retrieval is not universally applicable. The derived models and empirical findings will inform sensor-specific guidance for SIF use cases, enabling better alignment between satellite capabilities and field-level decision-making.

**4. Disentangling overlapping biotic and abiotic stressors**

To overcome the spectral and physiological overlap between biotic (e.g., *Pseudomonas savastanoi, Septoria spp*.) and abiotic (e.g., drought) stressors, HYDRA-EO will implement targeted field experiments in olive and pistachio orchards, where irrigation regimes are carefully manipulated in parallel with monitored pathogen presence. This experimental design enables the isolation and interaction analysis of multiple stress conditions under real-world agronomic settings.

A multi-modal trait dataset will be collected, including leaf-level fluorescence (SIF), leaf temperature, chlorophyll content, water indices, and pathogen severity scores provided by expert phytopathologists. These physiological and visual assessments will be complemented by biochemical (e.g., pigment profiling), genomic (qPCR), and structural traits to construct a robust ground truth.

To separate overlapping EO signals, HYDRA-EO will deploy hybrid ML models incorporating radiative transfer simulations (e.g., SCOPE, PROSAIL) and empirical data. These models will be designed to disentangle compound stress responses, exploiting decision-tree feature selection, ensemble classification, and spectral unmixing techniques. Particular focus will be placed on identifying spectral–thermal combinations (e.g., chlorophyll red-edge shifts + canopy temperature anomalies) that are differentially sensitive to biotic vs. abiotic processes.

Moreover, structurally homogeneous reference crops (e.g., alfalfa, potato) will serve as baseline controls, enabling validation of stressor disentanglement strategies under minimal background interference. These references will guide the optimization of band combinations and trait indices for structurally heterogeneous systems.

Feasibility is reinforced by the HYDRA-EO consortium’s experience in integrating physiological, thermal, and genomic data into EO workflows and by the inclusion of proven sensor platforms and field infrastructure. Risks will be mitigated through replicated experimental designs, cross-seasonal comparisons, and multi-sensor cross-validation.

**5. Transferability and generalization of hybrid ML models**

Hybrid frameworks that combine Radiative Transfer Models with ML represent a powerful approach for plant trait retrieval, particularly when leveraging high-resolution UAV and airborne data under controlled conditions. However, the generalization of these models to coarser-resolution satellite platforms poses a major technical hurdle, largely due to mismatches in spatial resolution, viewing geometry, and signal-to-noise ratios between platforms.

This issue becomes particularly pronounced in structurally heterogeneous crops such as olive, pistachio, and grapevine, where discontinuous canopies, row planting configurations, and variable background signals (e.g., soil, understory vegetation) introduce spectral mixing and spatial variability. These factors undermine the transferability of ML models trained on uniform, high-fidelity data, leading to reduced accuracy and robustness in broader-scale applications.

To address these challenges, HYDRA-EO will implement modular hybrid ML pipelines that are explicitly designed for cross-scale and cross-sensor adaptability. These pipelines will be trained on a combination of RTM-simulated spectra (e.g. PROSAIL, SCOPE) and multi-source empirical datasets, including UAV-derived reflectance, airborne thermal imagery, and temporally synchronized satellite data from Sentinel-2, PRISMA, EnMAP, CHIME, and ECOSTRESS.

Key strategies will include:

* Spatial upscaling of training data to simulate sensor footprints and resolution effects.
* Domain adaptation techniques, such as adversarial training and transfer learning, to account for sensor variability and crop structural differences.
* Regularization methods to prevent overfitting and maintain model generality.
* Uncertainty quantification modules, providing confidence intervals for trait retrieval under diverse observation conditions.

Validation will follow a multi-tiered approach, using independent test datasets from structurally divergent crops—ranging from homogeneous (alfalfa, potato) to complex (olive, pistachio, grapevine) systems. Performance metrics will include trait-specific accuracy, model robustness across spatial resolutions, and cross-crop consistency.

The resulting models will feed into Task 6, where harmonized, uncertainty-aware EO products will be generated for end-users. These products will support the operational monitoring of crop stress across different agro-ecological contexts, reinforcing the scalability and societal relevance of the HYDRA-EO framework.

To ensure reproducibility, transparency, and long-term usability of the hybrid ML pipelines, HYDRA-EO will further invest in the development and open dissemination of analytical tools, expanding the existing ToolsRTM and SCOPEinR packages. These R-based packages, originally developed by the Wageningen University team, will be enhanced with new modules specifically designed to:

* Simulate multi-scale spectral signatures for diverse crops and canopy structures.
* Support custom spectral resampling for all major EO satellite missions (Sentinel-2, Landsat, PRISMA, CHIME, FLEX).
* Integrate thermal and fluorescence channels for complete energy balance and photosynthetic trait retrieval.
* Link RTM-simulated data directly to ML pipelines for trait prediction and stress classification.

Additionally, a user-friendly Shiny application will be built to allow stakeholders — from researchers to policy users — to:

* Visually explore trait retrieval outputs across sensors and resolutions.
* Understand uncertainty propagation from model simulation to real-world application.
* Experiment with spectral scaling, band harmonization, and retrieval performance across stress scenarios.

This platform will serve as a training, collaboration, and demonstration space—highlighting how RTM-ML frameworks can be transferred across contexts and embedded into operational workflows. It also provides a bridge to ESA's open science and Digital Twin Earth objectives, supporting standardization, transparency, and code sharing across Horizon EU and ESA-funded missions.

* + 1. Proposed trade-off analyses and identification of possible limitations or non-compliances

The HYDRA-EO framework involves several trade-offs and potential limitations, which are inherent to multiscale EO-based trait retrieval and stress detection. These are acknowledged below with corresponding strategies to ensure technical compliance and scientific validity:

* 1. **Spectral Fidelity vs. Platform Coverage**

**Trade-off**: The use of high-resolution hyperspectral UAV and airborne data enables accurate plant trait retrieval but limits spatial and temporal coverage. In contrast, multispectral satellites offer broader coverage but with reduced spectral granularity.

**Mitigation**: We address this trade-off by designing reduced bandsets and trait-specific indices informed by RTM simulations and validated against field campaigns. This approach ensures information continuity across spatial scales while retaining trait sensitivity.

**Limitation**: Despite harmonization efforts, some trait signals (e.g., subtle pigment changes, early pathogen onset) may remain undetectable at satellite resolutions, particularly in heterogeneous canopies (e.g., olive, pistachio). This may limit trait retrieval reliability in specific use cases.

* 1. **Trait Disentanglement Under Mixed Stressors**

**Trade-off**: Separating biotic and abiotic stress signals is complex due to overlapping physiological effects (e.g., reduced chlorophyll, increased canopy temperature). This is exacerbated in multispectral and coarse-resolution imagery.

**Mitigation**: Controlled experiments (e.g., irrigated vs. rainfed olive plots) and hybrid RTM–ML models will be used to derive disentanglement algorithms. Biochemical, genomic, and visual assessments will support model training and stressor attribution.

**Limitation**: In operational settings lacking ground truth or co-located measurements, classification ambiguity may persist. This could result in partially resolved stress maps or reduced model confidence in mixed-stress zones.

* 1. **SIF Retrieval from Coarse-Resolution Sensors**

Trade-off: While TROPOMI, Sentinel-3 OLCI, and FLEX provide valuable SIF data, their large pixel sizes (~7 km, ~1 km and ~300 m, respectively) reduce crop specificity and introduce signal mixing.

**Mitigation**: We simulate FLEX, Sentinel-3 OLCI, and TROPOMI footprints using RTMs over structurally uniform fields (e.g., alfalfa) to calibrate degradation patterns and design scaling correction functions.

**Limitation**: SIF-based retrievals over fragmented or row-structured crops (e.g., vineyards) will have limited precision, especially under mixed land use. These datasets may require flagging or confidence masking in final products.

* 1. **Generalizability of ML Models Across Sensors and Crops**

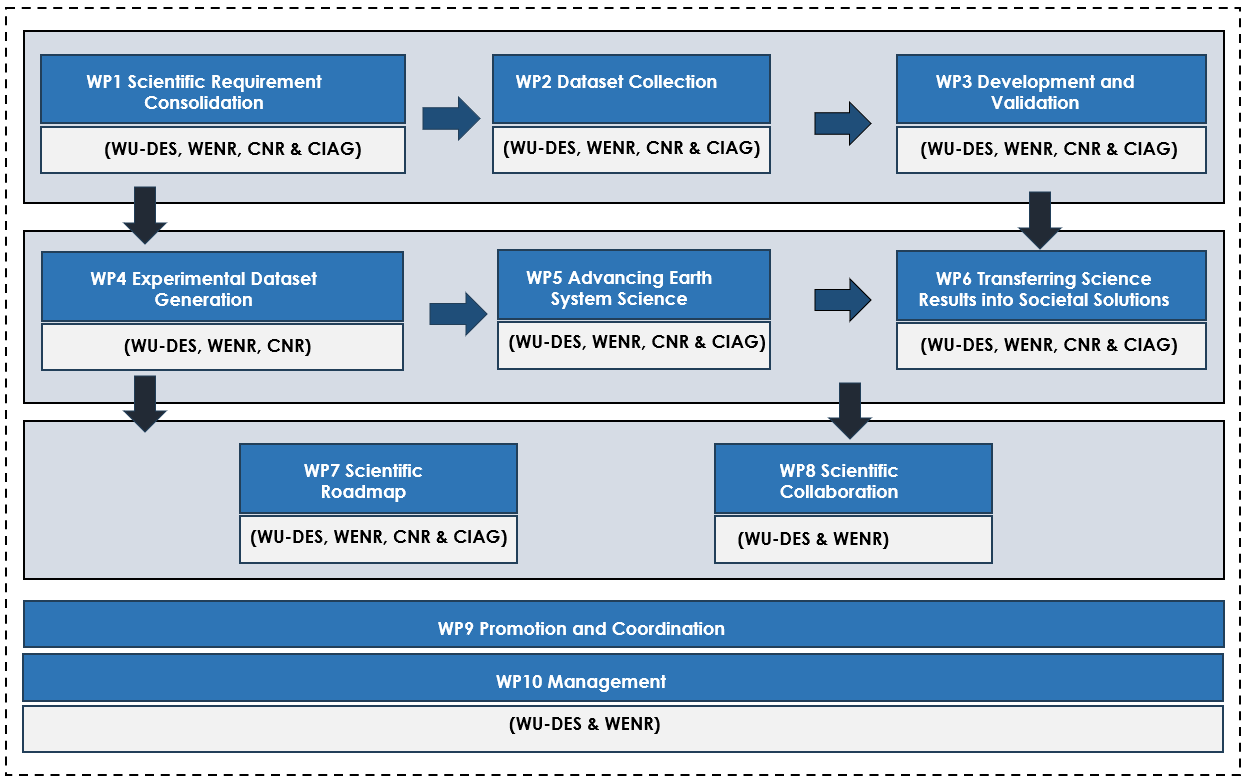
**Trade-off**: Machine learning models trained on high-resolution, site-specific data may fail to generalize across sensors or agro-ecological contexts without adjustment.

**Mitigation**: We employ domain adaptation, cross-validation across crop types, and RTM-augmented training to increase model robustness. Structural field controls (e.g., alfalfa) will benchmark generalization capacity.

**Limitation**: Full compliance across all sensor platforms may not be guaranteed. Some algorithms may require sensor-specific tuning, and performance may degrade when applied to unseen crop structures or climatic regions.

* 1. Technical Implementation/Programme Of Work
     1. Proposed Work Logic

The HYDRA-EO project is structured across ten Work Packages (WPs), which are logically sequenced and interconnected to ensure smooth execution from scientific requirement definition to societal impact and stakeholder engagement. The figure below illustrates the proposed work logic, outlining the interdependencies and flow of information between WPs.



**Figure** **1**. Work Logic Diagram of the HYDRA-EO Project

* + 1. Contents of the proposed work
       1. *Work Breakdown Structure (“WBS”)*

The Work Breakdown Structure (WBS) of the HYDRA-EO project includes ten Work Packages (WPs), organized in alignment with the ESA Statement of Work. Each WP includes clearly defined responsibilities, lead institutions, and key personnel. The table below summarizes the WBS:

|  |  |  |  |
| --- | --- | --- | --- |
| **WP** | **Work Package Title** | **Responsible Institute(s)** | **WP Leader** |
| WP1 | Scientific Requirement Consolidation | Dr. Carlos Camino & Dr. Lammert Kooistra | WU-DES |
| WP2 | Dataset Collection | Dr. Carlos Camino (WU-DES) & Dra. Rosa Merida | WU-DES & CIAG-IRIAF |
| WP3 | Development and Validation | Dr. Lorenzo Genesio & Dr. JL. Pancorbo | CNR-IBE |
| WP4 | Experimental Dataset Generation | Dr. Lorenzo Genesio & Dr. JL. Pancorbo | CNR-IBE |
| WP5 | Advancing Earth System Science | Dr. Carlos Camino & Dr. Lammert Kooistra | WU-DES |
| WP6 | Transferring Science Results into Societal Solutions | Dr. Carlos Camino & Dr. Lammert Kooistra | WU-DES |
| WP7 | Scientific Roadmap | Dr. Lorenzo Genesio & Dr. JL. Pancorbo | CNR-IBE |
| WP8 | Scientific Collaboration | Annemarie Klaasse | WENR |
| WP9 | Promotion and Coordination | Annemarie Klaasse | WENR |
| WP10 | Management | Dr. Carlos Camino & Dr. Lammert Kooistra | WU-DES |

* + - 1. *Work Package Description (“WPD”)*

**WP1 – Scientific Requirement Consolidation**

**Lead Partner**: WU-DES

**Participating Partners**: WENR, CNR-IBE, CIAG-IRIAF

**WP Manager**: Dr. Carlos Camino & Lammert Kooistra

This work package lays the scientific foundation for HYDRA-EO by establishing the core requirements for retrieving plant traits across spatial and spectral scales, under both biotic and abiotic stress conditions. Informed by the ESA Statement of Work, previous ESA and Horizon Europe projects (e.g., BEXYL, CORBERUS, SYLVA), and stakeholder consultations, it synthesizes scientific priorities with user needs. The outputs include a harmonized baseline framework defining key trait–stressor combinations, sensor requirements, and scaling constraints. This framework will directly guide the experimental designs in WP2, model structures in WP3, simulation protocols in WP4, and ML strategies in WP5.

WP1 begins by identifying and ranking critical plant traits—such as chlorophyll content, leaf area index, water status, SIF, and canopy temperature—across the five focus crops: alfalfa, potato, grapevine, pistachio, and olive. The team then defines the stressor scenarios to be addressed (e.g., drought, Potato Virus Y, Flavescence Dorée, Septoria spp.), linking them with measurable EO signals like red-edge reflectance shifts or thermal anomalies. Requirements are harmonized across EO platforms, spanning UAV-mounted Headwall hyperspectral sensors, airborne fluorescence (FluorSpec) and thermal imagers (NEC ThermoTracer), and satellite systems including Sentinel-2, PRISMA, FLEX, and simulated CHIME hyperspectral and Copernicus LSTM thermal. A final set of specifications—covering acquisition protocols, sensor resolution thresholds, and validation constraints—is delivered to support downstream implementation of data acquisition, algorithm development, and simulation tasks.

**WP2 – Dataset Collection**

**Lead Partner:** WU-DES & CIAG-IRIAF

**Participating Partners:** WENR, CNR-IBE

**WP Manager:** Dr. Carlos Camino & Dra. Rosa Merida

WP2 operationalizes the scientific specifications developed in WP1 by planning and executing four coordinated aerial and field campaigns across the Netherlands, Italy, and Spain in 2026. These campaigns will generate a unique multi-modal dataset integrating UAV, airborne, satellite, and in-situ measurements across five crop systems—alfalfa, potato, grapevine, pistachio, and olive—capturing a variety of stress conditions, including drought and plant pathogens. Legacy datasets from 2025 will be incorporated to enhance temporal continuity. Data will be collected using VNIR/SWIR hyperspectral sensors (e.g., Headwall), thermal cameras (e.g., FLIR, NEC), and field instrumentation for SIF, chlorophyll, nitrogen indices, pigment composition, and canopy temperature.

This work package encompasses multiple coordinated tasks. Campaign planning and sensor deployment are handled under Task 2.1, while Task 2.2 manages in-situ measurements, including molecular diagnostics (e.g., qPCR, SNPs) in pistachio and olive trials managed under controlled irrigation. Task 2.3 ensures methodological consistency by harmonizing field protocols across sites and stressor types. In Task 2.4, datasets are co-registered and integrated into a centralized HYDRA-EO repository with metadata that aligns with FAIR data principles. Special attention is given to temporal alignment with satellite overpasses from Sentinel-2, PRISMA, CHIME, FLEX, and ECOSTRESS. The resulting high-resolution, multi-

sensor database forms the foundation for modelling and analysis activities in WP3–WP5.

**WP3 – Development and Validation**

**Lead Partner:** CNR-IBE

**Participating Partners:** WENR, WU-DES

**WP Manager:** Dr. Lorenzo Genesio / Dr. Jose Luis Pancorbo

This work package focuses on the development, calibration, and validation of algorithms for plant trait retrieval and stressor classification across spatial and spectral scales. Using the multi-modal datasets produced in WP2, WP3 will generate sensor-specific and harmonized models that account for differences in spectral resolution, observation geometry, and canopy structure. Special attention is given to temporal alignment with satellite overpasses from Sentinel-2, Landsat, PRISMA, and ECOSTRESS, along with simulated datasets for upcoming missions including CHIME hyperspectral and Copernicus LSTM thermal.

WP3 begins by synchronizing satellite acquisitions with the aerial campaigns conducted in WP2, ensuring temporal and spatial consistency across datasets. These datasets will be used to train and validate inversion models for key physiological and biochemical traits—such as chlorophyll content, nitrogen balance, water status, SIF, and leaf temperature—under various stress scenarios. Radiative transfer models (e.g., PROSAIL and SCOPE) will be used to simulate how these traits manifest across different sensors, enabling sensitivity analyses and the design of band-reduction strategies for each satellite platform.

A key innovation in this WP is the coupling of RTM simulations with empirical datasets to produce hybrid ML models capable of handling spectral degradation and scaling effects. These models will be tested across structurally diverse crop systems—including uniform crops like alfalfa and potato, and heterogeneous canopies such as olive, pistachio, and grapevine. The robustness of the models will be assessed using cross-validation techniques and uncertainty estimation, ensuring reliability in operational settings. Outputs from WP3, including calibrated algorithms and trait maps, will be transferred to WP6 for integration into decision-support systems and stakeholder-ready products.

**WP4 – Experimental Dataset Generation**

**Lead Partner:** CNR-IBE

**Participating Partners:** WU-DES, WENR, CIAG-IRIAF

**WP Manager:** Dr. Lorenzo Genesio / Dr. Jose Luis Pancorbo

This Work Package is driven by the outputs of WP1 (scientific requirements) and WP2 (empirical data collection), and provides critical inputs to WP5 (ML model development) and WP6 (operational transfer). It focuses on the simulation of spectral, fluorescence, and thermal responses of crops under biotic and abiotic stress conditions using state-of-the-art Radiative Transfer Models. These simulations will be tailored to the spectral configurations of existing and upcoming EO missions such as Sentinel-2, PRISMA, EnMAP, upcoming FLEX fluorescence, along with simulated datasets for upcoming missions including CHIME hyperspectral and Copernicus LSTM thermal. The core objective is to generate synthetic datasets that reflect trait variability and stressor influence under different spatial and spectral resolutions. These datasets will inform the development of optimized band combinations, trait-sensitive indices, and scaling strategies. The WP will also deliver sensitivity analyses, reduced bandsets for satellite-scale retrieval, and calibration datasets for training hybrid ML models. The output will be integrated into WP5 for trait inversion and stress classification, and into WP6 for dissemination and tool deployment.

**WP5 – Advancing Earth System Science**

**Lead Partner:** WU-DES

**Participating Partners:** WENR, CNR-IBE, CIAG-IRIAF

**WP Manager:** Dr. Carlos Camino

Building on the outputs from WP2 (empirical datasets) and WP4 (simulations), WP5 is dedicated to developing robust, scalable algorithms for plant trait retrieval and stressor classification. It will implement a hybrid modelling framework that couples RTM simulations with ML techniques to retrieve key traits such as chlorophyll content, LAI, nitrogen indices, and leaf temperature. The focus will be on the generalization of these models across sensor types, spatial resolutions, crop types, and agro-ecological zones. A core challenge addressed here is the disentanglement of overlapping stressor signals (e.g., drought and disease) under spectral degradation. The WP will validate ML models using cross-platform and cross-crop data and integrate temporal consistency by using aligned satellite and airborne acquisitions. The final deliverables will include validated trait retrieval models, stressor classification pipelines, and confidence metrics for integration into the operational tools developed under WP6.

WP6 – Transferring Science Results into Societal Solutions

**Lead Partner:** WU-DES

**Participating Partners:** WENR, CNR-IBE, CIAG-IRIAF

**WP Manager:** Dr. Carlos Camino

This WP translates scientific outcomes into practical, user-oriented solutions. It will integrate data products and algorithms developed in WP2 through WP5 into harmonized, operational-ready EO tools for plant trait mapping and stress detection. A major output is the deployment of an open-access GitLab repository that hosts the RTM and ML modules, spectral libraries, and band reduction tools. These will be added to the ToolsRTM and SCOPEinR R packages maintained by WU-DES. Additionally, a web-based Shiny app will be developed for interactive exploration of trait retrieval pipelines, scaling effects, and spectral index performance. Outputs will be validated with stakeholders through early pilot testing and feedback sessions. This WP ensures the long-term usability, reproducibility, and societal relevance of HYDRA-EO outcomes and supports synergy with other ESA and HorizonEU initiatives through code sharing, co-development, and alignment with the EO Network of Resources.

**WP7 – Scientific Roadmap**

**Lead Partner:** CNR

**Participating Partners:** WENR, WU-DES, CIAG-IRIAF

**WP Manager:** Dr. Lorenzo Genesio / Dr. Jose Luis Pancorbo

WP7 builds on the technical and scientific findings of WP4–WP6 to produce a strategic roadmap that guides future EO-based plant trait retrieval research. The roadmap will synthesize sensor requirements, experimental protocols, spectral band recommendations, and trait-stressor relationships critical for improving crop monitoring and Digital Twin Earth applications. Particular attention will be paid to limitations in current EO capabilities (e.g., scaling of SIF, spectral degradation impacts) and recommendations for future missions such as LSTM, CHIME, or FLEX. The output will include a peer-reviewed white paper and a roadmap presentation aligned with ESA science planning activities.

**WP8 – Scientific Collaboration**

**Lead Partner:** WENR

**Participating Partners:** WU-DES, CNR-IBE, CIAG-IRIAF

**WP Manager:** Annemarie Klaasse

WP8 ensures alignment and collaboration with ESA, HorizonEU projects, and the wider scientific community. It facilitates exchange of models, datasets, processing workflows, and results with projects and initiatives in related domains, including agriculture, biodiversity, and climate change. This WP will coordinate participation in joint working groups and integration of HYDRA-EO outputs with shared platforms such as the EO Network of Resources. It also supports standardization of data formats and practices in line with ESA and EC guidelines. The WP contributes to scientific impact, visibility, and reusability of HYDRA-EO outcomes.

**WP9 – Promotion and Coordination**

**Lead Partner:** WENR

**Participating Partners:** WU-DES

**WP Manager:** Annemarie Klaasse

This WP focuses on the dissemination and promotion of HYDRA-EO outcomes through a coordinated outreach strategy. Activities will include the development of a project website, open-access scientific publications, presentations at international conferences (e.g., ESA Living Planet, AGU, EGU), and the preparation of policy briefs and technical factsheets for stakeholders. Special attention will be given to visual communication and multilingual content targeting agricultural users and regional environmental agencies. WP9 ensures the HYDRA-EO results reach their intended audiences and support informed decision-making.

**WP10 – Management**

**Lead Partner:** WU-DES

**Participating Partners:** WENR

**WP Manager:** Dr. Carlos Camino & Lammert Kooistra

WP10 provides project coordination and administrative oversight, ensuring all contractual, financial, and reporting obligations to ESA are met. It manages risk through regular assessment, mitigation planning, and partner coordination. A central coordination team will oversee progress across WPs, monitor milestones and deliverables, and maintain transparent communication with ESA and consortium partners. The WP will produce periodic reports, financial statements, and the Final Review Report. It ensures that HYDRA-EO operates efficiently, meets its objectives, and delivers high-impact results within scope and timeline.

* 1. Deliverable Items – Specification of any Non-Conformance
     1. Deliverable Items

The HYDRA-EO consortium fully accepts and commits to the delivery of all items specified in the Statement of Work (SoW) and in the Draft Contract (Article 2), as outlined in Appendices 1 and 2 of the Invitation to Tender (ITT). We acknowledge that no separate Deliverable Item List (DIL) is required at this stage, and we confirm that all documents, datasets, software components, and other project items listed in the SoW will be delivered in accordance with ESA's technical, administrative, and quality standards.

All deliverables have been mapped to specific outputs within the corresponding Work Packages (WPs), as detailed in Section 2.7.2 of this proposal. These deliverables will encompass scientific documentation, model outputs, datasets, software tools, training materials, dissemination products, and management reports.

Each item will be delivered according to the project timeline and milestones, ensuring interoperability, traceability, and compliance with FAIR data principles. Software deliverables and source code will be versioned and made available in open-access repositories (e.g., GitLab), and documents will follow ESA formatting and submission protocols.

In summary, the consortium is committed to delivering the full scope of required items without limitations, as outlined in the SoW and contractual appendices. Any proposed additions or optional enhancements are listed in Section 2.8.2.

* + 1. Non-conformances/limitations/additions regarding deliverable items

The HYDRA-EO consortium does not anticipate any non-conformances, limitations, or deletions with respect to the deliverable items outlined in the Statement of Work (SoW) and Draft Contract. All documentation, datasets, software components, outreach materials, and related items will be delivered in full and in accordance with the project’s Work Breakdown Structure and Work Package responsibilities described in Section 2.7.2.

In addition to meeting the required deliverables, the consortium proposes several value-adding outputs designed to strengthen the long-term scientific, technical, and societal impact of the project. First, an open-access GitLab repository will be established to host the project’s source code, including radiative transfer functions, spectral simulation tools, band reduction modules, and ML learning pipelines. This repository will house the expanded versions of the ToolsRTM and SCOPEinR packages developed by WU-DES, as well as scripts for spectral resampling, thermal-spectral fusion, and trait-based stress classification. The repository will support version control, documentation, and community contributions, ensuring transparency, reproducibility, and integration with ESA's open science and digital twin initiatives.

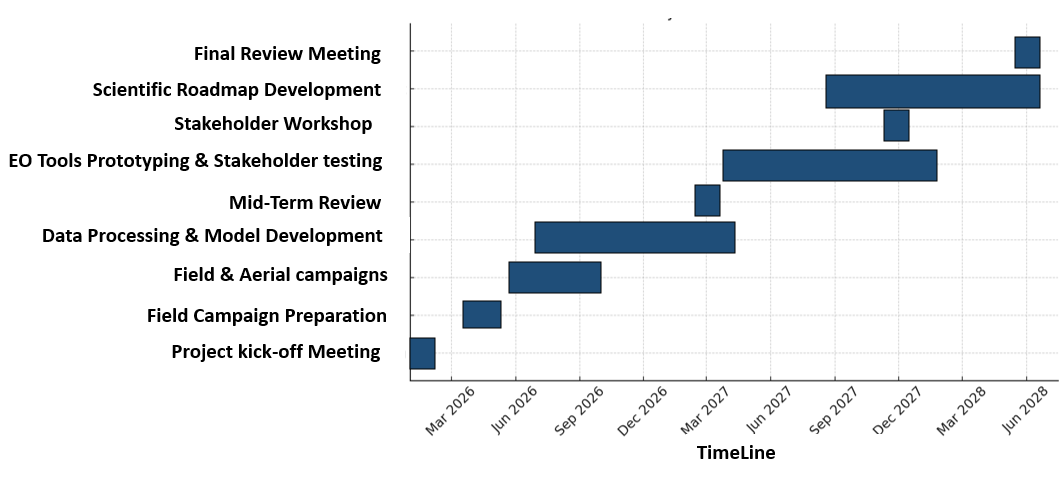
Second, the consortium will develop a user-friendly, web-based Shiny application for visualizing the trait retrieval pipeline, simulating spectral degradation effects, and testing EO-based indicators across spatial scales and crop–stressor scenarios. This application will be designed to serve both scientific and operational users, providing a practical interface to interact with spectral libraries, trait maps, and diagnostic indices. It will also support demonstration pilots and stakeholder engagement sessions conducted in WP6 and WP9.

A third key addition is the delivery of a comprehensive spectral library focused on trait–stressor interactions under spectral degradation. This library will integrate field-based measurements with simulated reflectance and fluorescence datasets generated via PROSAIL and SCOPE. It will span multiple crop types—olive, pistachio, grapevine, potato, and alfalfa—and multiple stressor scenarios, including drought, and biotic infections (e.g., PVY, *Septoria* spp., *Flavescence Dorée*). The library will document how specific plant traits degrade when transitioning from hyperspectral to multispectral or coarse-resolution satellite data, and will include sensitivity profiles, reference spectra, and optimal band subsets for each satellite platform. This output will be central to guiding band selection, trait inversion strategies, and future EO mission planning.

Finally, to support widespread adoption, the consortium will provide detailed user documentation, technical manuals, and capacity-building materials, including multilingual tutorials and training videos. These materials will help researchers, agricultural advisors, and policy stakeholders interpret EO data outputs and integrate them into monitoring and decision-support workflows. All value-added deliverables will be traceable to WP5 (scientific modelling), WP6 (operational transfer), WP8 (collaboration), and WP9 (outreach), ensuring that they are fully resourced, peer-reviewed, and aligned with project objectives.

* 1. Planning
     1. Proposed schedule and milestones

The HYDRA-EO project is scheduled to run for 30 months, with an anticipated start date of January 2026 and an expected completion date in June 2028 (Figure 2). The timeline assumes consortium-wide readiness at contract signature and accounts for academic calendars and national holidays in the Netherlands, Italy, and Spain. Activities are organized into ten work packages (WP1–WP10), each aligned with the project’s technical objectives and ESA’s Statement of Work. Interdependencies between work packages are reflected in the logical sequence of phases, ensuring continuity from scientific groundwork to operational output delivery.



**Figure 2**. HYDRA-EO Project Schedule and Milestones.

The initial phase (Months 1–6) emphasizes scientific consolidation (WP1), campaign design and logistics (WP2), and the early development of model architectures (WP3). This foundational period culminates in Milestone 1 – Project Kick-Off in January 2026, aligning all partners and ESA on the technical and operational strategy.

The second phase (Months 6–15) focuses on data acquisition, with four coordinated field and aerial campaigns conducted across Spain, Italy, and the Netherlands. These activities are supported by harmonized in-situ measurements and sensor deployments, aligned with EO satellite overpasses. Milestone 2 – Campaign Preparation Review (Month 5) confirms site readiness and protocol calibration, while Milestone 3 – Mid-Term Review (Month 15) evaluates the performance of retrieval models and simulation tools developed in WP3–WP5.

The third phase (Months 15–30) is centred on integration, validation, and transfer. EO products, spectral libraries, and trait retrieval tools are packaged into operational tools via WP6, including a web-based Shiny interface and an open GitLab repository. A stakeholder-facing event—Milestone 4 – Demonstration & Stakeholder Workshop (Month 24)—will enable practical engagement, testing, and feedback collection.

The project culminates in Milestone 5 – Final Review Meeting (Month 30, June 2028), where all deliverables, tools, documentation, and roadmap recommendations will be submitted to ESA. Throughout the project, monthly virtual coordination meetings and biannual consortium assemblies will ensure timely progress and cross-WP integration.

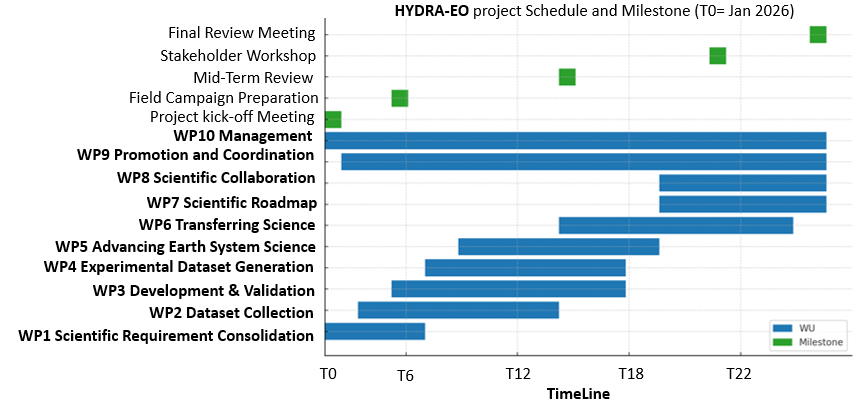
* + 1. Bar chart

The HYDRA-EO project is structured across a 30-month implementation timeline beginning in January 2026 (T0), with coordinated technical, scientific, and operational activities distributed across ten interlinked Work Packages (WP1–WP10). The Figure 3 the detailed execution schedule of the project, showing when each of the ten Work Packages (WP1–WP10) will be active, along with the placement of key milestones and coordination events throughout the project’s duration. The schedule is designed to reflect the logical dependencies between technical activities, ensuring that upstream tasks (e.g., requirement consolidation, data collection) are completed in time to inform model development, simulation, and stakeholder tool deployment.

The first six months of the project focus on consolidating scientific requirements (WP1), designing field campaigns (WP2), and initiating preliminary model frameworks (WP3). From Month 6 onward, empirical data collection begins and continues through Month 15, supported by aerial and field campaigns in Spain, Italy, and the Netherlands. This feeds directly into the development and validation of trait retrieval algorithms (WP3), spectral simulations (WP4), and ML pipelines (WP5), which span the mid-phase of the project.

Starting around Month 18, efforts shift toward operational integration and societal transfer (WP6), where EO tools are consolidated into user-facing platforms. Scientific roadmap development (WP7), community engagement (WP8), and dissemination activities (WP9) ramp up toward the latter part of the timeline. Project coordination and reporting (WP10) are maintained continuously throughout all phases.

Key project milestones are interspersed throughout the timeline, including the Kick-Off (T0), Mid-Term Review (T0+15), Demonstration and Stakeholder Workshop (T0+24), and Final Review Meeting (T0+30). These checkpoints are designed to evaluate progress, align on outputs, and ensure successful delivery of all project components.



**Figure 3.** HYDRA-EO Project Schedule and Milestones.

* 1. Personal Data Processing

The HYDRA-EO project does not involve the systematic processing of personal data as a primary activity. However, limited personal data may be processed in the context of project coordination, communication, stakeholder engagement, and dissemination activities (e.g. registration lists for stakeholder workshops, mailing lists for newsletters, and contact information for project participants).

In such cases, the consortium ensures full compliance with the European Union General Data Protection Regulation (EU GDPR) and the European Space Agency’s Personal Data Protection Framework. Below, we outline our approach to data processing and protection:

**Data Processing Tools, Location, Retention, and Deletion**

Personal data will be processed exclusively within the European Economic Area (EEA), primarily in the Netherlands, Italy, and Spain, where partner institutions are located. Data will be stored securely on institutional servers protected by university-level IT infrastructure. The tools used may include Microsoft 365 (WU-DES), institutional servers (CNR-IBE, CIAG-IRIAF, WENR), and secure platforms for surveys (e.g., Qualtrics or LimeSurvey). Personal data will be retained only for the duration of the project and deleted securely upon contract completion, following certified deletion protocols. Subcontractors, if engaged, will be required to comply fully with GDPR and will be included in the Data Processing Agreements as applicable.

**Consent and Transparency for Data Subjects**

Where applicable, informed consent will be obtained explicitly from Data Subjects prior to any data collection, using digital or physical consent forms. These forms will describe the purpose of data processing, retention period, data subject rights, and contact information for data protection officers. Participants will be informed via privacy notices during registration for any surveys, workshops, or mailing list subscriptions. The right to withdraw consent at any time will be clearly stated and respected.

**Data Transfer to ESA**

Any personal data transferred to the Agency will be limited, pseudonymised where applicable, and conducted via encrypted, secure channels. Transfers will be accompanied by relevant documentation including consent forms and data protection declarations.

**Organisational and Security Measures**

All personnel involved in data processing have received GDPR compliance training. Access to personal data will be restricted to designated staff members via role-based access controls. All partner institutions apply robust cybersecurity measures, including two-factor authentication (2FA), firewalls, regular security audits, and encrypted backups. Regular checks will be performed to ensure data access is limited and traceable.

**Incident Management Procedures**

Each consortium member has an internal data breach response protocol in place. Any incident involving potential unauthorised disclosure of personal data will be immediately reported to the project coordinator and relevant Data Protection Officers. Notification to the Agency and Data Protection Authorities will be carried out within 72 hours of identifying a breach, as per GDPR Article 33.

In summary, while personal data processing within HYDRA-EO is minimal and limited to operational and communication activities, all measures are in place to ensure its full protection and compliance with ESA and EU regulations. A Data Protection Impact Assessment (DPIA) will be conducted should any new processing activities emerge during the course of the project.

1. **MANAGEMENT PART**
   1. Team Organisation: Reporting lines within the team and communication lines with ESA

The HYDRA-EO project is coordinated by Wageningen University, Department of Environmental Sciences (WU-DES) as the Prime Contractor. Project leadership is provided by Dr. Carlos Camino (Project Coordinator) and Prof. Lammert Kooistra (Scientific Advisor), both from the Geo-Information Science and Remote Sensing (GRS) group at WU-DES. The overall management structure follows a WP-oriented logic, supported by institutional leads and cross-WP integration mechanisms.

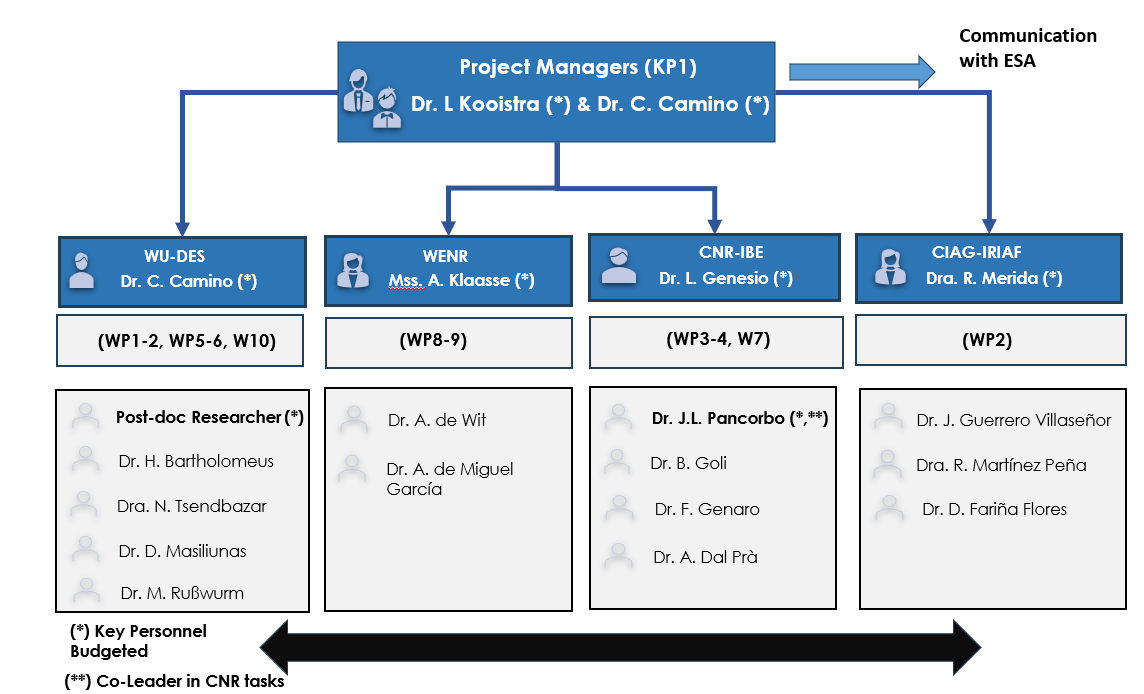
A dedicated Project Management Team at WU-DES oversees the full implementation of the contract and maintains direct and regular communication with the ESA Technical Officer. WP Leaders are distributed across the consortium partners according to technical expertise and institutional leadership. Each WP has at least one Key Personnel designated to ensure quality control, task execution, and timely delivery of milestones. Communication across the project is supported by monthly virtual coordination meetings, quarterly WP progress reviews, and two plenary assemblies annually (either hybrid or in-person), ensuring alignment across scientific, technical, and operational tasks.

In addition to the project coordination role of WU-DES, the following partner roles and WP leadership responsibilities are defined:

* **Wageningen University, Department of Environmental Sciences**: Leads overall coordination, as well as WP1 (Scientific Requirement Consolidation), WP2 (Dataset Collection) in collaboration with CIAG-IRIAF, WP5 (Advancing Earth System Science), WP6 (Transferring Science Results into Societal Solutions), and WP10 (Management). WU-DES also co-leads dissemination and modelling strategy across WPs. Key contributors include Dr. Carlos Camino (WP1, WP2, WP5, WP6, WP10), Prof. Dr. Lammert Kooistra (WP1, WP5, WP6), Dr. Nandika Tsendbazar, Dr. Dainius Masiliunas, Dr. Harm Bartholomeus, and Dr. Marc Rußwurm.
* **Stichting Wageningen Environmental Research**: Leads WP8 (Scientific Collaboration) and WP9 (Promotion and Coordination), and co-leads WP6 (Operational Integration). The institutional lead is Annemarie Klaasse, who is also WP Leader for WP8 and WP9.
* **Chaparrillo Agro-Environmental Research Center**: Co-leads WP2 (Dataset Collection) and is responsible for executing WP4 (Experimental Dataset Generation) focused on pistachio and olive trials. Coordination is led by Rosa Mérida García, with contributions from Raquel Martínez Peña, Julián Guerrero Villaseñor, and David Fariña Flores.
* **Consiglio Nazionale delle Ricerche – Institute of BioEconomy (CNR-IBE)**: Leads WP3 (Development and Validation), WP4 (Experimental Dataset Generation), and WP7 (Scientific Roadmap). CNR-IBE also contributes significantly to hyperspectral validation, sensor scaling, and site-specific fieldwork in vineyards and alfalfa. WP responsibilities are led by Lorenzo Genesio with support from José Luis Pancorbo, Aldo Dal Prà and Salvatore Filippo Di Gennaro.

Each institution maintains a structured internal team under its respective WP lead, contributing their scientific, technical, or field expertise as needed. All WP leaders report to the Project Coordinator, ensuring centralized communication with ESA. The ESA Technical Officer is integrated into the reporting structure via direct reporting from the WU-DES Project Management Team, ensuring smooth coordination and responsiveness to ESA’s feedback and technical reviews

The Figure 4 below illustrates the HYDRA-EO organizational structure, showing the central coordination by WU-DES, WP leadership distributed across partner institutions, and the direct communication line to ESA.



**Figure 4**. HYDRA-EO Team Structure, WP Assignments and Reporting Lines to ESA.

* 1. Time dedication of the Key Personnel

The HYDRA-EO project brings together a team of senior scientists and experienced professionals who contribute both operationally and strategically to the achievement of project goals. Within this framework, the proposal distinguishes between two types of Key Personnel:

Key Personnel with dedicated budget allocation, whose time and effort are explicitly covered under the financial forms (PSS A2), and Senior advisory staff, who are actively involved in guiding the scientific direction of the project but are not budgeted in this proposal.

**Advisory Key Personnel without Direct Budget Allocation**

Several senior experts from Wageningen University, Department of Environmental Sciences (WU-DES), WENR, and CNR-IBE are involved in the project in an advisory capacity, contributing through internal institutional support or in-kind time contributions. The following senior experts from Wageningen University, Department of Environmental Sciences (WU-DES), Sichting Wageningen Environmental Research (WENR), CIAG-IRIAF, and CNR-IBE contribute as non-budgeted Key Personnel:

**Wageningen University, Department of Environmental Sciences (WU-DES)**

* Dr. **Nandika Tsendbazar**: Specialist in EO validation and spatial upscaling across heterogeneous landscapes; advises WP3 and WP7.
* Dr. **Dainius Masiliunas**: Expert in time series and phenology-based modelling; contributes to the methodological design of WP2 and WP6.
* Dr. **Harm Bartholomeus**: UAV LiDAR and thermal sensing specialist; provides coordination guidance for aerial data acquisition in WP2.
* Dr. **Marc Rußwurm**: Leading expert in deep learning and domain adaptation; supports the hybrid ML design in WP5.

**Stichting Wageningen Research, Wageningen Environmental Research (WENR)**

**Consiglio Nazionale delle Ricerche – Institute of BioEconomy (CNR-IBE)**

* Dr. **Salvatore** **Filippo Di Gennaro**: Hyperspectral data analyst with strong experience in UAV remote sensing campaigns; supports sensor calibration and quality assurance.
* Dr. **Aldo Dal Prà**: Agronomic modelling and field operations coordinator; supports crop–sensor configuration assessments in WP4 and WP5.

**Chaparrillo Agro-Environmental Research Center (CIAG- IRIAF)**

* Dr. **Julián Guerrero Villaseñor**: Expert in pistachio and olive agronomy; provides technical advice on genotype trials and WP4 stressor detection.
* Dr. **Raquel Martínez Peña**: Plant physiology and remote phenotyping advisor; supports field calibration strategies and trait validation workflows.
* Dr. **David Fariña Flores**: Agronomic trials and disease monitoring specialist; supports the integration of pathogen diagnostics with EO indicators.

These advisors do not draw budget from the Contract, but their scientific contributions are essential. Their roles include providing strategic input to WP1-WP7; reviewing milestone outputs; advising on modelling consistency; and contributing to ESA-aligned dissemination strategies. Their involvement ensures continuity with other European EO projects and reinforces the methodological rigor of HYDRA-EO.

**Budgeted Key Personnel and Operational Capacity**

The core team leading implementation is composed of the following budgeted Key Personnel, whose efforts are fully included in the PSS A2 financial forms:

* Dr. **Carlos Camino** (WU-DES): Project Coordinator and WP1, WP2, WP5, WP6, and WP10 Lead; oversees overall coordination, scientific integration, and methodological development for EO-based trait retrieval and stress detection.
* Prof. **Lammert Kooistra** (WU-DES): Scientific Advisor and co-lead for WP1, WP5, WP6, and WP10; provides strategic guidance on trait definition, radiative transfer modeling, sensor harmonization, and scientific roadmap development.
* Ms. **Annemarie Klaasse** (WENR): WP8 and WP9 Lead; responsible for stakeholder engagement, communication, and promotion activities, ensuring the uptake and dissemination of project results.
* Dr. Allard de Wit (WENR) supports WP5 and WP7
* Dr. Ángel de Miguel García (WENR) supports WP2 and WP6
* Dr. **Rosa Mérida García** (CIAG-IRIAF): Co-lead for WP2; manages field trials in pistachio and olive orchards, coordinating in-situ data acquisition and multi-stressor validation.
* Dr. **Lorenzo Genesio** (CNR-IBE): Co-lead for WP3, WP4, and WP7; expert in EO–flux integration, long-term environmental monitoring, and ecosystem functioning; supports validation strategies using flux tower and hyperspectral data.
* Dr. **José Luis Pancorbo** (CNR-IBE): Co-lead for WP3, WP4, and WP7; leads the development and calibration of hyperspectral retrieval algorithms, supporting model transferability across sensors including PRISMA and upcoming CHIME.
* **One Postdoctoral Researcher** (WU-DES): Full-time technical researcher (12 months); supports implementation of WP2 through WP6 by managing dataset harmonization, spectral simulation, trait modeling, and EO product validation.

The postdoctoral researcher will be recruited for one year to provide focused technical capacity for dataset harmonization, model development, simulation processing, and EO product validation. This ensures continuity of implementation while senior experts provide oversight.

|  |  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Key personnel** | **Role in the activity** | **WP1** | **WP2** | **WP3** | **WP4** | **WP5** | **WP6** | **WP7** | **WP8** | **WP9** | **WP10** | **TOTAL** | **Percentage time dedication (Time of activity/Total working time)** |
| Dr. Carlos Camino | Project Coordinator, WP1/WP5-6 & WP10 Lead | 40 | 50 | 80 | 70 | 60 | 40 | 40 | 30 | 30 | 60 | 500 | 20% |
| Prof. Lammert Kooistra | Scientific Advisor; Supports WP1-WP9, Management | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 100 | 10% |
| Dr. Rosa Mérida García | WP2 Co-Lead; Coordinates Field Trials in Pistachio/Olive | 40 | 230 | 60 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 400 | 30% |
| Dr. Lorenzo Genesio | WP3-4 and WP7 Lead; Responsible for PRISMA-based validation and spectral scaling (WP3–WP7) | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 100 | 10% |
| Dr. José L. Pancorbo | WP3-4 and WP7 Lead; Responsible for PRISMA-based validation and spectral scaling (WP3–WP7) | 180 | 300 | 500 | 500 | 400 | 200 | 400 | 150 | 10 | 10 | 2650 | 75% |
| Ms. Annemarie Klaasse | WP8-9 Lead; Coordinates Stakeholder Engagement & Integration (WP6–WP9) | 20 | 0 | 50 | 50 | 0 | 0 | 0 | 200 | 100 | 90 | 510 | 20% |
| Dr. Allard de Wit | Supports WP5 and WP7 | 0 | 0 | 0 | 0 | 40 | 0 | 50 | 0 | 0 | 0 | 90 | 3% |
| Dr. Ángel de Miguel García | Supports WP2 and WP6 | 0 | 20 | 0 | 0 | 0 | 40 | 0 | 0 | 0 | 0 | 60 | 2% |
| Non-Key Personnel | |  |  |  |  |  |  |  |  |  |  |  |  |
| Post-doc | Research & technical staff | 0 | 0 | 300 | 500 | 300 | 400 | 65 | 0 | 0 | 0 | 1565 | 100% |
| … |  |  |  |  |  |  |  |  |  |  |  |  |  |
| … |  |  |  |  |  |  |  |  |  |  |  |  |  |
| **TOTAL** |  | **300** | **620** | **1010** | **1150** | **830** | **710** | **585** | **410** | **170** | **190** | **5975** |  |

1. **FINANCIAL PART**
   1. Price Quotation for the Contemplated Contract

The HYDRA-EO consortium proposes a Firm Fixed Price (FFP) of 699,983 € for the implementation of the activities described in this proposal. This amount has been calculated based on detailed institutional cost estimates and is quoted in Euro, delivery duty paid (DDP), excluding VAT and import duties, in full compliance with the pricing conditions set out in the Draft Contract (Appendix 2) and the Statement of Work.

The breakdown per partner is as follows:

* Wageningen University, Departement of Environmental Sciences (WU-DES): 325,305.00 €
* CIAG-IRIAF: 95,000.00 €
* Consiglio Nazionale delle Ricerche – Institute of BioEconomy (CNR-IBE): 174,078 €
* Sichting Wageningen Research, Wageningen Environmental Research (WENR): € 105,600.00 €

These figures reflect all direct and indirect costs, including personnel, travel, data processing, and software development activities necessary for the successful delivery of all contractual items. Unlike other partners, who can cover part of their staff time through existing research budgets and therefore do not allocate costs for internal personnel and management support, WENR includes these costs in its contribution.

No royalties, license fees, or external commercial software dependencies are included. All deliverables, including software tools (e.g**., ToolsRTM, SCOPEinR** modules), datasets, and documentation, will be made available as open-access products unless otherwise noted and are developed within the project’s internal IP framework. Furthermore no budget for the High Performance Computing Cluster (WUR HPC) is reserved.

All consortium members are located within ESA Member States and operate under frameworks that ensure exemption from VAT and customs duties in accordance with Article 3 of the Draft Contract. As such, no additional taxation is anticipated or applied in this quotation.

No currency conversion has been applied, as all partners are located in the Eurozone.

* 1. Detailed Price Breakdown
     1. PSS costing forms

In accordance with ESA procurement requirements, the HYDRA-EO consortium has prepared a full financial proposal using the PSS A2 forms (Issue 5), including a complete breakdown of the total price per participating company or institute, as well as Exhibit A and Exhibit B forms where applicable.

All forms have been compiled, character-recognisable, and integrated into a single financial proposal document. Each partner institution has submitted its own signed PSS A2 form detailing internal costs, labour rates, overheads, and, where applicable, profit margins. The coordinating institution, Wageningen University, Department of Environmental Sciences, has also submitted the aggregated PSS A2 form for the total project budget.

The breakdown of the proposed Firm Fixed Price (FFP) of 699,983 € is as follows:

* Wageningen University, Depart. of Environmental Sciences (WU-DES): 325,605.00 €
* Consiglio Nazionale delle Ricerche –Institute of BioEconomy (CNR-IBE): 174,078 €
* CIAG-IRIAF: 95,000.00 €
* Sichting Wageningen Research, Wageningen Environmental Research (WENR): 105,600.00 €

Each institution confirms that:

* No royalties or license fees are included.
* No taxes or import duties are foreseen, as all partners operate within ESA Member States.
* All costs are quoted in Euros and calculated without currency conversions.

The profit (fee), where applicable, remains within the 8% limit as per ESA guidelines and is transparently stated in the financial annex.

All relevant documentation—including signed PSS A2 forms for WU-DES, WENR, CNR-IBE, and CIAG-IRIAF—is submitted as part of the Financial Proposal Attachment. These documents provide detailed insights into labour distribution, internal cost structure, and cost justification per Work Package (WP).

This breakdown ensures financial transparency, traceability, and full compliance with the ESA PSS Costing Regulations.

* + - 1. PSS A2 (Breakdown of total price per participating company or institute), including Exhibit A and Exhibit B form, if applicable

In compliance with ESA’s requirements and following the guidelines of the Draft Contract and PSS Issue 5 documentation, each consortium partner has completed an individual PSS A2 form reflecting its financial commitment, internal labour and overhead structure, and applicable fees (profit). All forms are signed by authorised representatives and have been compiled into the financial annex of this proposal submission.

The total Firm Fixed Price (FFP) for the HYDRA-EO project is 699,983 €, fully inclusive of all costs, and broken down per partner as follows:

|  |  |  |  |
| --- | --- | --- | --- |
| **Partner Institutions** | **Total Quoted Price (€)** | **Profit Applied** | **Role / Contribution Summary** |
| WU-DES | 325,305.0 | NO | Prime contractor; leads overall coordination and contributes to scientific development across WPs 1–6. |
| CIAG-IRIAF | 95,000.0 | YES | Leads field trials for pistachio and olive under biotic and abiotic stress scenarios |
| CNR-IBE | 174,078.0 | YES | Leads PRISMA hyperspectral data acquisition and validation; coordinates field campaigns in vineyards and alfalfa; supports RTM simulation and sensor benchmarking. |
| WENR | 105,600.00 | NO | Contributes to WP coordination and technical implementation; leads thermal data processing and EO integration. |

All PSS A2 forms strictly adhere to the following conditions:

* Profit (Fee): Where declared, the profit applied (line 9 of PSS A2) remains within the ESA-mandated limit of 8% of the Total Company Cost (line 8).
* Subcontractor Costs: Each partner is considered a direct participant rather than a subcontractor. Therefore, no subcontractor markup has been applied (line 13).
* Currency & VAT: All costs are quoted in Euros, exclusive of VAT and import duties. No foreign exchange rates or hedging mechanisms are applied, as all partners operate within Eurozone Member States.
* Licences/Royalties: No royalties, licences, or third-party proprietary software have been included in any PSS form.

Each partner’s Exhibit A (labour hours by WP and category) and Exhibit B (equipment and other cost justification) are also attached in the financial annex, providing full transparency and traceability of cost allocation by Work Package.

This pricing structure ensures budget clarity, accountability, and alignment with ESA’s cost eligibility framework. The aggregated PSS A2 Total Summary consolidates all individual institutional contributions and defines the contractual value agreed upon with the Agency.

* + 1. Milestone Payment Plan

The HYDRA-EO project will be implemented over a 30-month period, with a total Firm Fixed Price (FFP) of 699,983 €. The project is structured around a series of interdependent Work Packages (WPs), each contributing to clearly defined deliverables. In line with Article 4 of the Draft Contract, all payments—except any agreed Advance Payment—are linked to the achievement of verifiable technical milestones. These milestones are designed to reflect critical phases of progress across data collection, model development, tool deployment, and stakeholder engagement. Payments will be requested upon ESA’s formal acceptance of the deliverables associated with each milestone. The schedule and breakdown of these payments are summarized in the table below.

|  |  |  |
| --- | --- | --- |
| **Milestone (MS) Description** | **Schedule Date** | **Payments from ESA to (Prime) Contractor**  **(in Euro)** |
|
| Progress (MS 1):  Upon successful completion of WP1 and WP2, including delivery of EO requirements, stressor definitions, and field campaign protocols. | T0 + 6 months | 175,000.00 |
| Progress (MS 2):  Upon successful completion of WP3 and WP4, including validated retrieval models, RTM simulations, and trait-specific sensitivity datasets. | T0 + 15 months | 200,000.00 |
| Progress (MS 3):  Upon successful completion of WP5 and WP6, including release of operational tools (GitLab, Shiny App) and stakeholder integration reports. | T0 + 24 months | 250,000.00 |
| Final Settlement (MS 4):  Upon the Agency’s acceptance of all deliverable items due under the Contract and the Contractor’s fulfilment of all other contractual obligations. | T0 + 30 months | 74,988.0 |
| **TOTAL** | | **699,983 €** |

In accordance with applicable ESA guidelines, the HYDRA-EO consortium includes CIAG-IRIAF and CNR-IBE, both of which qualify as SMEs under the European Commission Recommendation 2003/361/EC. These institutions are therefore eligible for a 35% advance payment of their respective budget shares.

As the Prime Contractor, Wageningen University, Department of Environmental Sciences (WU-DES) requests an advance payment to cover upfront costs associated with the early stages of the project, including field logistics, sensor deployment, and preparatory data acquisition tasks led by SME subcontractors. Although WU does not require advance funds for its own activities, it will coordinate the redistribution of the advance to CIAG-IRIAF and CNR-IBE to ensure uninterrupted progress during the first 9 months of implementation (T0+0 to T0+9).

The advance will be offset across the final two milestones (i.e., 10% at Milestone 2 and 25% at Milestone 3), as per ESA’s SME financial recovery framework. Official self-certification letters confirming SME status for CIAG-IRIAF and CNR-IBE will be retained on file and made available to ESA upon request.

The table below summarizes the advance payment arrangement applicable to the Prime Contractor:

|  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- |
| **Prime**  **(P)** | **Company**  **Name** | **ESA Entity Code** | **Country**  **(ISO code)** | **Advance Payment**  **(in Euro)** | **Offset against[[1]](#footnote-2)** | **Offset by Euro** | **Condition for release of the Advance Payment** |
| P | Wageningen University, Department of Environmental Sciences  (WU-DES) |  | NL | 100,000 | MS-1 | 100,000 | Upon signature of the Contract by both Parties |

1. **CONTRACTUAL PART**
   1. Background Intellectual Property Rights

The HYDRA-EO consortium fully commits to the open and transparent management of all Background Intellectual Property Rights (BIPR) used or developed during the execution of this project. All tools, models, datasets, and software workflows are designed to be interoperable, reproducible, and accessible to ESA and authorized stakeholders.

Our project will adhere to FAIR (Findable, Accessible, Interoperable, Reusable) Open Science practices. All project resources will be maintained in GitLab repositories structured to facilitate long-term preservation and reuse. Data outputs will be delivered in cloud-native formats (Cloud Optimized GeoTIFF (COG), GeoJSON) with accompanying STAC metadata, while algorithms will be packaged as reproducible workflows (Rmarkdown, Jupyter Notebooks). Upon project completion, these resources will be packaged according to EarthCode specifications and migrated to ESA's EarthCode Open Science Data Catalogue with DOI assignments.

Core software components, such as the ToolsRTM and SCOPEinR R packages, are central to the project’s capacity for plant trait retrieval, radiative transfer simulation, and spectral-spatial harmonization. ToolsRTM incorporates novel modules developed by WU-DES to support scaling functions between high-resolution UAV/airborne imagery and satellite-based hyperspectral platforms such as PRISMA, EnMAP, and upcoming CHIME. These include sensor-specific Full Width at Half Maximum (FWHM) convolution routines, band-reduction simulators, and trait-preserving spatial upscaling algorithms that enable robust spectral degradation analysis across EO scales.

In parallel, SCOPEinR provides a direct interface for simulating photosynthesis-related traits (e.g., SIF, APAR) under varying stressor conditions, serving WP3–WP5 through high-fidelity RTM-based training datasets.

A dedicated GitLab repository will host all project-developed processing pipelines, spectral libraries, RTM–ML integration scripts, and a Shiny-based visualization app. These tools will be released under permissive open-source licenses (e.g., MIT), ensuring long-term accessibility and compliance with ESA’s FAIR data principles.

Field-based biological markers (e.g., qPCR and SNP-based stressor indicators in pistachio and olive), contributed by CIAG-IRIAF, will also be incorporated into the data integration pipeline. These will be anonymized and aggregated in compliance with GDPR, without introducing licensing restrictions.

Thermal evapotranspiration (ET) processing routines developed by WENR will also be incorporated into ToolsRTM, further enabling thermal–spectral integration for water stress quantification.

The table below lists the BIPR items relevant to HYDRA-EO, including licensing, versioning, ownership, and their role within project deliverables.

|  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **Exact name of BIPR Item** | **Owner** | **Description** | **Patent # or Ref./**  **Issue/**  **Revision/**  **Version # (\*)** | **Contract/**  **Funding Details under which the IPR was created (\*\*)** | **Date of creation of the version of the BIPR listed here** | **Type of Licence (Third Party IP) (\*\*\*)** | **Affected deliverable with comments (\*\*\*\*)** | **Protected Format (Y/N) (\*\*\*\*\*)** |
| ToolsRTM R package | WU-DES | R-based package for radiative transfer modelling, spectral band reduction, scaling, and retrieval of plant traits from satellite, UAV, and field data | V 0.62 | Internal development by WU – Open repository | 2023-06 | MIT Open source | Used in WP4–WP6. Deliverables include trait retrieval workflows, scaling tools, and spectral band simulations (e.g., SW3, SW4). | N |
| SCOPEinR | WU-DES | Interface for SCOPE RTM simulations in R, tailored for SIF modelling and reflectance, fluorescence, and thermal using a model that integrated the balance energy. | v0.3 | Internal development by WU – Open repository | 2023-12 | MIT Open source | Used in WP3–WP5 for SIF and thermal simulation generation. Results integrated into GitLab repository and Shiny application. | N |
| GitLab Repository Codebase | WU-DES / HYDRA-EO Consortium | Central version-controlled repository containing EO pipelines, ML-RTM code, scaling functions, and Shiny tools | v1.0 (to be initiated at project start) | Funded under this ESA contract | Planned for 2026 | ESA | Includes full trait inversion, spectral degradation, and platform harmonization pipelines (e.g., SW3, SW4, SW5). ESA will retain full access rights. | N |
| Shiny App for plant Trait Retrieval | WU-DES / HYDRA-EO Consortium | Visualization and interaction interface for plant trait monitoring, ML inference, and sensor harmonization workflows | v1.0 | Developed within WP6 of HYDRA-EO | Planned for 2027 | ESA | Tool to explore scaling effects, simulate EO retrieval pipelines, and demonstrate algorithm outputs to users (e.g., SW5, SW6). | N |
| qPCR and SNP Stressor Markers | CIAG-IRIAF | Genomic markers for drought and pathogen stress in pistachio and olive | Internal references | Regional agrigenomic research project, co-funded (non-ESA) | 2021–2025 | N/A | Supports WP2–WP4 field validation, stressor disaggregation, and correlation with EO indices (e.g., SW1, SW4). Data processed in compliance with GDPR and anonymized. | N |
| Thermal Evapotranspiration Routines | WU-DES /WENR | R-based thermal integration routines for estimating ET from UAV and satellite imagery | Integrate in ToolsRTM package | WENR institutional activities | 2022–2024 | MIT Open source | Used in WP5 to derive ET-based plant stress indicators and integrate thermal features into trait retrieval models. Documented in GitLab under SW3.. | N |

**ATTACHMENTS**:

ANNEX 1: FILLED IN DRAFT CONTRACT

The Draft Contract has been fully completed and signed by the authorized representative of the Prime Contractor, Wageningen University, Department of Environmental Sciences (WU-DES), on behalf of the HYDRA-EO consortium. All contract fields have been filled according to the ITT instructions.

The Tenderer confirms full and unconditional compliance with the terms and conditions of the Draft Contract as provided in the ITT documentation. No modifications, additions, or deletions have been requested.

The HYDRA-EO consortium acknowledges that any remarks concerning the Draft Contract must be strictly limited to objectively manifest (e.g., typographic) errors or inconsistencies in the contractual text. No deviations from the ESA standard contractual terms are proposed, ensuring that this submission remains fully eligible for evaluation.

The completed Draft Contract is attached to this proposal as Annex 1.

1. An SME has the right to request offset of the 35% advance at the end of the Contract, i.e. the last two milestones (ideally 25% at the last milestone and 10% at the preceding milestone), if this can be justified in view of the economic progress in the Contract. [↑](#footnote-ref-2)