ADAPTaTREE - IMPLEMENTING INNOVATIVE AGRONOMIC PRACTICES BY UNRAVELLING THE TREE'S ADAPTIVE RESPONSE TO CLIMATE EXTREMES

Lists of participants

1	CSIC, Spain (Research)	6	ARO, Israel (Research)	11	AREFLH, France (end-users)
2	UNIBO, Italy (Research)	7	CYBELETECH, France (SME)	12	HGU, Germany (Research)
3	UGENT, Belgium (Research)	8	BOSCH, Spain (Company)	13	BSC, Spain (Research)
4	INRA, France (Research)	9	WU, Netherlands (Research)	14	FRESHFEL, Belgium (Association)
5	RIH, Poland (Research)	10	DEX, Spain (SME)	15	BGU, Israel (Research)

1. Excellence

Fruit, wine and olive production are key sectors within the EU economy, society and environment account for about 13% of the total economic output (EUROSTAT) and provide nutritional benefits to citizens, including prevention of important diseases. Orchards and vineyards, if properly managed, can contribute to land preservation and stewardship, as well as to climate change (CC) mitigation through carbon sequestration and temperature regulation through evapotranspiration.

Fruit industry is facing both, economic and societal challenges imposed by fierce international global competition and citizenships demand for a more sustainable production. In addition, orchards and vineyards are highly vulnerable to CC, since fruit species face multiple stressors generated by abiotic constraints during their long life span (few decades), and due to the vulnerability of the sector to modification of agro-climatic conditions. Particularly CC will worsen the incidence of drought, salt and heat stresses, and induce shifts of an important economic agricultural area (such as oliviculture and citriculture in the Mediterranean basin, but also apple peach and grape production in central and southern European regions) thus compromising the typicality and future sustainability of these crops and products. Furthermore, fruit grape and olive consumption and market acceptance depends on specific quality standards (i.e. size, sweetness, taste, oil content) that are strongly related to genotype x environment interactions.

1.1. Objectives

The multidisciplinary ADAPTaTREE partnership, covering expertise in agronomy (UNIBO, HGU, RIH), physiology (UGENT, INRA, CSIC, ARO) modelling (CSIC, INRA, UGENT), genetics (INRA, ARO) epigenetics (INRA), metabolomics (BGU), climatology (BSC), socio-economy (WU) decision support systems (CYBELETECH), sensors (BOSCH) and communication (DEX, FRESHFEL and AREFL) will:

Unravel physiological, morphological and genetic traits driving **adaptation processes** (at cellular, organ and whole-tree level) of **woody crops** to conditions of **drought, salt stress and heat waves** and how these traits respond to changes in the environment (air temperature and CO_2 increase). Based on this knowledge, ADAPTaTREE will propose solutions to the farming sectors for breeding programs and plant management

This general goal will be achieved throughout the following **specific objectives**:

- **Identify** specific **physiological mechanisms and traits** determining both the **plant source capacity** and the **fruit sink strength** adaptations to drought, salt and high air temperature (i.e. heat waves)
- Identify **genes** and **gene regions** regulating plant adaptation to stress in relation to the traits previously identified
- Determine the **epi-genetic capability** of the selected crops for enhancing crop resilience to stress
- **Model** plant **physiological responses**, to predict plant adaptation to environmental changes. Research will start with existing stomatal conductance, photosynthesis, water and sugar transport models to be improved and combined in a single generic **whole-plant model**
- **Propose field strategies** linked to **plant sensors** use and Decision Support Systems (**DSS)** for crop adaptation to abiotic stresses and identify **markers/phenotyping tools** for future breeding programmes
- Enhance communication and final adoption of the project results through **specific technology transfer solutions** in collaboration with private companies and end-users' associations from all over Europe

1.2. Relation to the work programme

Specific challenges for the topic call "Looking behind plant adaptation" under the Agri-Aqua Labs topic (SFS-30-2019) and the contribution of ADAPTaTREE
Deciphering the dynamic responses of plants as they (pre)adapt to local conditions or adjust their growth and development to changes in the environment within their plasticity range
ADAPTaTREE will identify the traits and physiological processes underlying stress pre-adaptation (i.e. acclimation) quantifying the phenotypic plasticity as the result of the environment x genetic and epigenetic interactions.
Determining the different adaptation strategies for understanding how annual or perennial crops perform in a given environment or under changing conditions
The choice is to focus on fruit trees and other perennial crops in order to model their behaviour under different climatic conditions and provide recommendations for the genotypes to be employed and the adequate field practices in relation to tree carbon and water relations.
Proposals will look into the specific mechanisms (genetic, epigenetic, physiological, morphological, metabolic…) and dynamics that underlie adaptive processes of crops
Experiments will be set-up in controlled and field conditions across a gradient of environmental conditions where abiotic stress derived from CC will be applied to characterize plant physiological functioning, metabolomics and whole-plant responses with the use of specific sensors and model analyses. The physiological traits to characterize plant adaptation will be phenotyped on collections/populations to study intra-species variations and decipher their genetic control through Genome-wide association studies (GWAS) and/or Quantitative Trait Loci (QTL) analyses.
Proposals are expected to improve capacities for modelling plant adaptation responses to better predict changes in plant performance and inform crop improvement and crop management strategies.
ADAPTaTREE will start from the most advanced physiological models predicting fruit crop performances and will extend their range of application to other species. New process-based models (PBMs) for specific and key processes, like stomatal conductance regulation, will be incorporated. Research will be carried out under controlled conditions to identify the adaptation responses of some of the most economically important European fruit tree crops such as apple, peach, olive, citrus and grape. Partners will perform field trials under actual and forecasted agronomic conditions to test the suitability of model predictions for plant performance under stress-inducing conditions to improve crop management strategies and production. Findings coupled with the use of advanced digital technology (sensors) and the involvement of two industry partners (BOSCH and CYBELETECH) will help implement innovative agronomic practices in combination with DSS.
Proposals should foresee a task for joint activities with other projects financed under this topic.
ADAPTaTREE will liaise with other research projects funded under this topic to avoid duplication, search for potential synergies and build on previous research outcomes.

1.3. Concept and methodology

(a) Concept

The physiological and adaptive responses of plants to environmental changes are the result of complex interactions between genetic and epigenetic mechanisms that are translated into changes to specific functional traits. ADAPTaTREE intends to identify and quantify the role of the main physiological regulation mechanisms determining tree source capacity and carbon partitioning towards fruit in response to drought, salinity and heat waves, across a gradient in air temperature across Europe and including increased levels of atmospheric CO_2 increments. As a consequence, an **interdisciplinary approach** will be followed in ADAPTaTREE including genetic information in ecophysiological models via genotype-dependent parameters and studying the genes or region of genes and the epigenetic markers that influence or intervene in the plant adaptations. Since plant responses to abiotic stress might be mitigated under a concomitant

increase in atmospheric CO_2 concentration, model outputs will also be validated using trials conducted at the Free Air Carbon dioxide Enrichment (FACE) facility of HGU and under controlled greenhouse conditions at UGENT.

ADAPTaTREE will build off from existing models, which will be improved and coupled during the project, to identify **genes/gene regions**, **epigenetic and physiological mechanisms** that affect functional traits related to plant tolerance (acclimation)/adaptation to the abiotic stresses considered. ADAPTaTREE is unique because it will integrate the leading state-of-the-art models from the participating partners into a reliable unprecedented mechanistic whole-plant model. This research strategy will allow improved physiological response simulations, and therefore better forecasting and anticipating plant adaptation to different and changing environments. Eco-physiological PBMs can predict quantitative traits of a genotype in any environment and will enable identification of the epigenetic effects and their markers that could further improve PBMs and QTL models.

Specific **traits** will be identified by inter-species comparisons of different physiological processes both in field and greenhouse studies. The traits contributing most in explaining plant responses to the various stresses and being most suitable for phenotyping studies will be selected and used in intra-species (i.e. varieties) phenotyping studies on genotypes from available populations. These studies will aim at identifying the genes/gene regions involved in plant adaptation to abiotic stress derived from CC.

ADAPTaTREE will translate basic knowledge to **implement agronomic innovative practices** (e.g. precision and regulated deficit irrigation, pruning and crop load regulation, net shading and soil mulching) and **markers/phenotyping tools** for future breeding programmes that will facilitate crop adaptation to abiotic stresses. Specific plant sensors to assess the physiological traits related to the plant water and carbon relations under changing conditions will be used and improved by the industrial partner BOSCH and will be implemented in DSS by CYBELETECH in order to convey the physiological model outputs into recommendations for planning and scheduling field practices mainly related to tree water and carbon relations. The involvement of these industrial partners will allow for a practical outcome to the solutions proposed by ADAPTaTREE. During project execution, **socio-economic studies** coordinated by WR will be carried out to evaluate the benefits and the potential adoption of the proposed agronomic strategies.

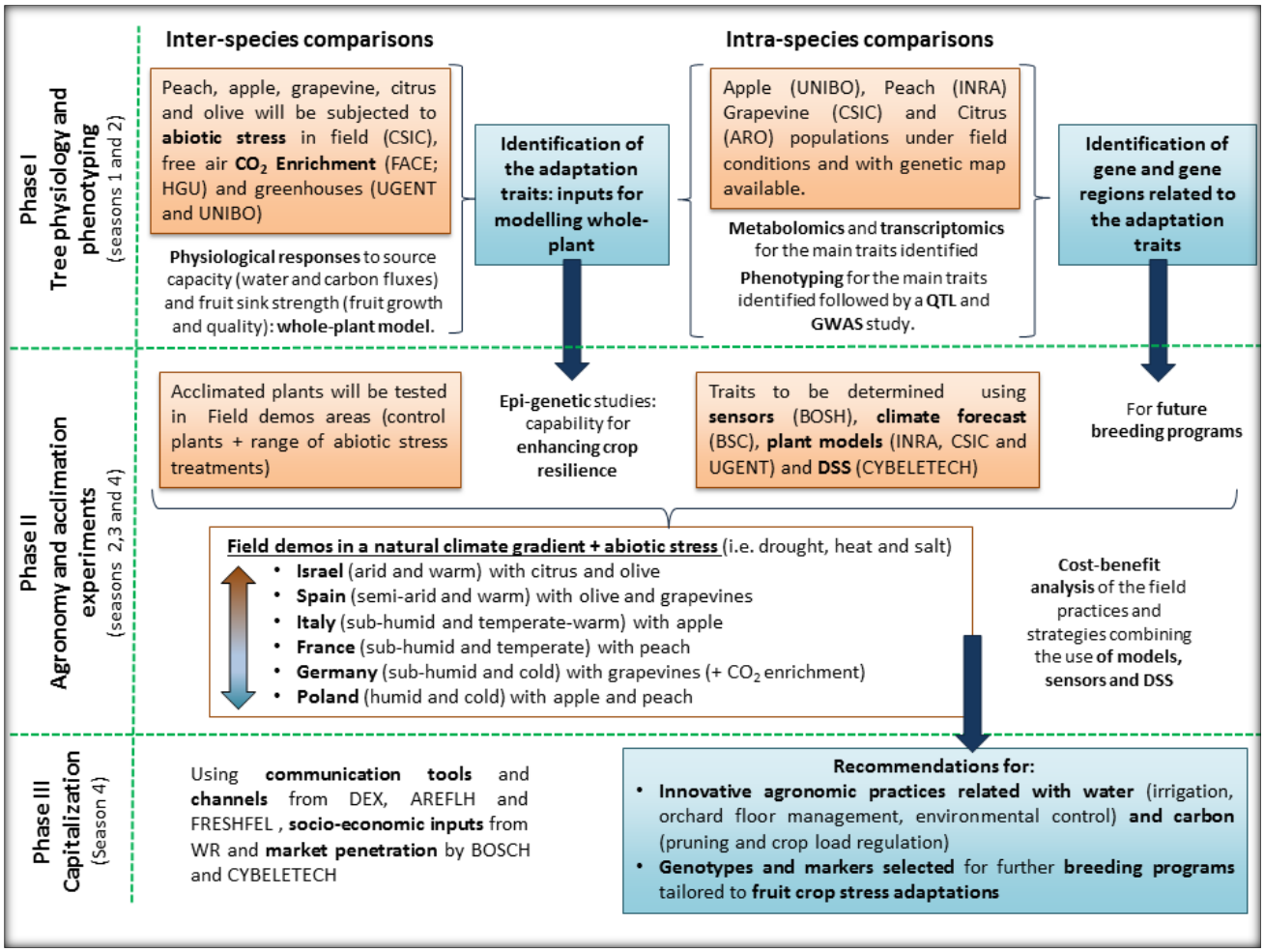
This research and development approach situates the project half-way between basic research and end-user application. The project has a basic science component aimed at exploring genetic and epigenetic changes affecting different functional traits and the resulting physiological responses in selected species under different environmental conditions. However, as the project will use experimental research and build on existing models and knowledge, it is expected that it will promote the development of agronomic strategies and DSS to help farmers face CC challenge. Therefore, the project will combine **TRL 3** research activities to more advanced **TRL 4-5.**

A number of FP7 and Horizon 2020 funded projects (TRADITOM, TOMRES and TOMGEM) have dealt with this issue but mainly in vegetable crops. Other projects developed novel methods and strategies aimed at yield maintenance under fluctuating water deficit (DROPS), but they were focused only on water relations and annual species. Research in woody perennial crops is limited to precision farming studies (FATIMA, VINEROBOT) to more specific aspects related to grape composition for wine production (INNOVINE and VISCA), to the improvement of quality and yields under non-stressing conditions (ISAFRUIT) or to the improvement of breeding strategies (FRUITBREEDOMICS). Also, biophysical models simulating vegetation responses to integrate climatic variability and extremes have been improved by the MODEXTREME and ADVICLIM. ADAPTaTREE will take advantage of the knowledge generated by these projects. For example, some phenotyping tools developed under FRUITBREEDOMICS will be used as a starting point to unravel the genetic control of the fruit crop adaptation and tolerance to the various stressors.

(b) **Methodology**

ADAPTaTREE will focus on the following woody perennial crops **peach, citrus, olive, apple and grapevine**, including both evergreen and deciduous species covering a wide range of soil and specific climatic conditions as well as increased CO_2 levels. Field and greenhouse studies will be conducted over a gradient range of air temperatures and annual reference evapotranspiration values from 1800 mm (Israel) to 650 mm (Poland) and precipitation regimes varying from less than 200 mm (Israel and Spain) to more than 1000 mm (France and Poland). Activities will be developed in three stages including:

1) **Tree physiology and phenotyping** experiments where interspecies and intraspecies comparisons will be carried out to identify the traits as well as the genes / gene regions that mostly affect the plant response to abiotic stress. The physiological traits identified will be used as input for improving the mechanistic integrated whole-plant model. The use of PBMs will allow avoiding the empiricism of plant models currently used in DSS.
2) **Agronomic and acclimation experiments** aimed to simultaneously determine: i) the epi-genetic capability of the selected species for enhancing crop resilience to stress and ii) crop responses and cost-benefit analysis of the field practices and strategies combining the use of crop models, sensors and DSS to be developed.
3) **A capitalization phase** which will take advantage of the socio-economic studies, the communication channels with the end-users and policy makers and the market penetration of the private companies involved in the proposal.



ADAPTaTREE proposes activities, over 4 years, arranged in 7 work packages (WPs), whereby WP1 coordinates and manages the project, WP2-WP6 related to R+D+i and WP7 will devise management strategies to disseminate innovations to stakeholders and communicate to society.

WP1. Coordination and management. Leader CSIC (Diego Intrigliolo) will include: i) clustering with other projects financed under the same related topic and ii) networking activities with EU researchers within the AREFLH/FRESHFEL/EUFRIN task forces.
WP2. Benchmarking and socio-economic governance. Leader WR (Marianne Groot) will embrace all project activities including: i) weather forecasts improvements for models and DSS, ii) a cost-benefit analysis of the proposed solutions and iii) to identify critical success factors, including institutional incentives and governance structures to encourage the adoption of sustainable adaptation practices.
WP3. Adaptation traits. Leader CSIC (Antonio Diaz-Espejo). The work will be focused on identifying the key physiological traits determining plant response to the changing environment by: i) comparing species and

cultivars to the stress conditions imposed, ii) single and specific PBMs, which will be fed directly with those physiological traits as parameters.
WP4. Acclimation and epi-genetics. Leader UGENT (Kathy Steppe). The work will consider: i) acclimation experiments to determine the extent of epigenome reprogramming (methylation, histone marks, Small RNA populations) generated by stresses in selected species of the project and the stability of epigenomic changes over time (one season and between seasons) and ii) field and greenhouse experiments under elevated CO_2 conditions and its interaction with other treatments derived from CC (i.e. heat waves, drought and salinity) in combination with PBMs to understand the plant adaptive responses.
WP5. Genetic x Environment model integration. Leader INRA (Michel Genard). The work will: i) improve existing PBMs in order to predict the effect of stressors on fruit tree crop species and ii) will integrate intra-species genotypic control within the models thanks to GWAS or QTL analysis results and iii) use the developed model to define Genotype x Practices combinations
WP6. Orchard & Vineyard level upscale. Leader UNIBO (Brunella Morandi). The knowledge generated by WP3, 4 and 5, will allow to better understand the mechanisms at the basis of plant adaptation and to translate this knowledge into practical solutions for growers. These solutions will be tested in field experiments foreseeing i) improved plant-based DSS; ii) optimized management practices (in terms of irrigation, crop load, soil and orchard light management) as well as iii) pre-acclimated planting materials.
WP7. Communication &Dissemination. Leader DEX (Fernando Méndez-Navia)**.** The work will include: i) feeding the main knowledge exchange platforms on agriculture research to disseminate the scientific outcomes, ii) develop targeted communication strategies to bring project findings closer to agricultural practices, producing technical notes and other dissemination materials, including brochure and short videos, and organizing a series of seminars and webinars.

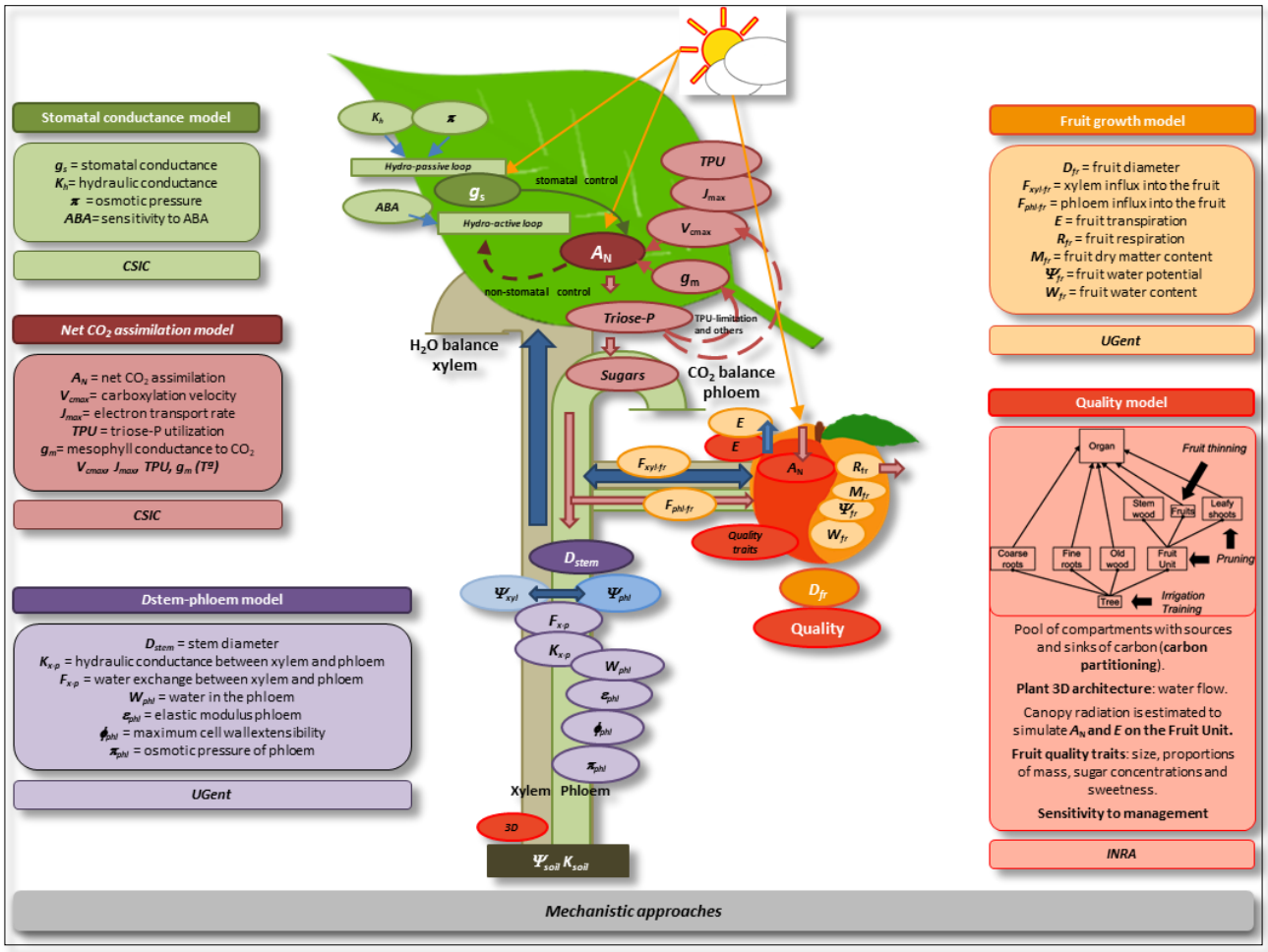
Gender aspects. ADAPTaTREE does not foresee any biological characteristics and social/cultural factors affecting the technical activities to be carried out. ADAPTaTREE will promote equality between sex/genders in terms of employment, work and pay. Within the project, women with successful professional careers are involved in leading positions in the scientific partnerships. More than half of the work package leaders are women, with a total representation of 42% of the technical staff involved.

1.4. Ambition

ADAPTaTREE will progress in 5 areas of research in order to integrate climatology, plant physiology, genetics and sensors/DSS advances into a package of practical solutions for fruit growers.

Climate and agriculture. ADAPTaTREE will integrate in the whole-plant model and DSS the recent advances in climate predictions with weather forecast and climate projections to provide atmospheric variables at different forecast windows known to affect agriculture management. The NMMB-MONARC model by BSC containing advanced physics, chemistry and aerosols modules will provide weather forecast (1-5 days). Regarding climate forecast, both sub-seasonal and seasonal climate predictions from the Copernicus Climate Change Service and the North American Multimodel Ensemble will be used.

Water relations, gas exchange and whole plant models. Our ambition is to move beyond the empirical approaches that currently dominate field management (e.g., crop coefficient method) by developing new mechanistic methods based on integrating experimental measurements of physiology into models of leaf gas exchange, dynamic water transport, carbon partitioning, fruit growth and quality development. Since these models are mechanistic, i.e. based on well-understood physiological processes, all their parameters have a physiological meaning. Moreover, mechanistic models have several advantages over empirical approaches. For example, only mechanistic models can help us to understand *why* response patterns differ across species. Furthermore, they will help us to interpret the output from the plant- based sensors used in horticulture. The comprehensive evaluation of the factors affecting plant responses and growth will help discerning whether fruit growth is source-limited or sink-limited. Moreover, the fundamental understanding of differences across species, regarding water and carbon partitioning during fruit development and its quality is important, not only to unravel the particular plant/tree behaviour and strategies but also to assess the main adaptive responses to climate changing conditions. The state-of-the-art sub-models to be implemented in the whole-plant/tree models are summarized below:



Arrangements of state-of-the-art sub-models into a single mechanistic whole-plant model. In the scheme, the balls written with white letters are the cores of sub-models, and are described in the boxes, and colours represents the parameters and characteristics that belong to each sub-model. Under each description box the ADAPTaTREE partners with expertise in modelling that will contribute to the whole-plant model are indicated

- Stomatal conductance model (BMF, Buckley et al. 2003[1]): based on turgor signals that triggers and regulate the osmotic pressure of guard cells simultaneously with abscisic acid signals. It is considered the best mechanistic approach to simulate stomatal conductance.
- Net CO_2 assimilation model (FvCB, Farquhar et al. 1980[2]): based on Rubisco kinetic constants and electron transport rates related to CO_2 fixation. A robust and widely accepted biochemical model
- D_{stem}-phloem model (water and sugar transport model, De Schepper et al. 2010[3]): this whole plant model couples water and sugar transport in the xylem and phloem. These transport pathways are hydraulically connected and the model enables simulating stem diameter variations and growth. This model is tightly coupled to the stomatal and photosynthesis models described above.
- QualiTree (Lescourret et al. 2011[4]) addresses a broad range of fruit quality traits. Fruit sugar content is described by differential equations that account for the processes involved in the development of soluble sugars within. QualiTree is parsimonious in terms of 3D representation of plant architecture because of its compartmental nature, and able to express a high degree of within-tree variability of fruit quality criteria.

Knowledge, tools and methods for efficient dissection and selection of relevant traits. Reference genomes have already been assembled for all species studied in ADAPTaTREE. In long-generation species

[1] Buckley et al. 2003. Modelling stomatal conductance in response to environmental factors. *Plant Cell Envi* 36:1691-1699
[2] Farquar et al. 1980. A biochemical model of photosynthetic CO2 assimilation in leaves of C3 species. *Planta* 149:78-90
[3] De Schepper et al. 2010. Development of a water and sugar transport model using measured stem diameter variations. *J Exp Bot* 61:2083-99
[4] Lescourret et al. 2011. QualiTree, a virtual fruit tree to study the management of fruit quality. I. Model development. *Trees* 25:519-530

such as fruit trees, the breeding cycle can be made significantly shorter by selecting young candidates based exclusively on genotypic information. The use of genome-wide markers and high-throughput genotyping methods has led to the development of new strategies for analysing complex quantitative traits, such as GWAS and genome-wide selection (GS). The molecular markers linked to QTL represent a useful resource for enhancing selection efficiency via marker-assisted selection (MAS) in fruit breeding programs. While MAS is suitable for mono-/oligogenic traits, GS, which uses the entire genomic information, enables to exploit loci with moderate to small effects. Initial studies demonstrated the validity of this approach in fruit trees where GS has been mostly used to predict fruit quality traits, e.g. in apple, peach, grape and citrus. However, until now, there is no systematic work using genome-wide approaches in genetic improvement for several traits simultaneously and for traits linked to adaptation to abiotic stresses in fruit trees. ADAPTaTREE will use GS to select future phenotypes or unobserved genetic/breeding values for such multi-trait objective. In parallel, ADAPTaTREE will explore epigenetic marks variations on few case-studies to decipher the role of epigenetics in the adaptation of young material to contrasted stress conditions and appraise the possibility of priming material before orchard plantation.

Epigenetics and acclimation of perennials to stresses. The difficulty that underlies adaptation of plants to changing environments relies on the interaction between genetics and environment as well as the epigenetic effects, proven to play roles in phenotypic expression. These mechanisms are not well understood and although they have been studied in ecology they have never been tested in the domain of plant modelling for its application in agriculture management. The study of plants response under changing environments relies on the magnitude of changes, and on how those changes affect phenotype expression through genetic-epigenetic interactions. Despite the fact that the epigenetic effects are currently studied with molecular markers in some commercial plants (Richards et al. 2017[5]), the effects of phenotypic plasticity and physiological responses under environmental conditions different from its origin, or under drastic/extreme changes in climate, are still poorly understood. In this sense, while epigenetics appears as a critical component of plant acclimation to stresses in annual species, there is no information available on their role in perennials Therefore, ADAPaTREE aims at studying relevant mechanisms by combining genome-wide selection and the whole-plant mechanistic model allowing its future application in the development of crop management and plant breeding strategies. ADAPTaTREE will perform experiments taking into account that the phenotypic plasticity could be due to the different physiological responses influenced by both epigenetic and CC conditions. For this purpose, experiments with different environmental conditions (e.g. latitudinal gradient) will be carried out with plants from the same origin (replicated genotypes). Understanding how rising CO_2 will influence productivity and leaf gas exchange will be critical for planning the adaptation of existing regions to changes in growing conditions under future projections.

Plant sensor and DSS. There is no consensus within the scientific community regarding the choice of the most valuable and reliable indicator of drought stress. Stem water potential is still the most widely-used reference for plant water status. However, there is sound empirical evidence on the direct effect of stomatal regulation on whole-tree transpiration in fruit trees, on its prime role limiting photosynthesis and also on its utility as a sensitive indicator of drought stress (Diaz-Espejo et al. 2018[6]). As a consequence of its pivotal role regulating the fluxes of H_2O and CO_2 in plants, ADAPTaTREE will incorporate the model prediction of stomatal conductance in DSS to estimate plant water requirements and as a drought stress indicator. Thanks to recent mathematical approaches, plant growth models, either at crop, plant or branch scales, can be used to analyse breeders trials data with better decorrelation between genotype and environmental effect than classical descriptive approaches. CYBELETECH will develop this type of solutions, enabling breeders to identify promising genetics with fewer trials (resistance to water stress, extreme temperatures and better yield quality). In addition, plant growth models associated to physiological sensors can help improving the accuracy of DSS for farmers, since they enable plot scale decision aid. Main targets will be anticipation of critical crop management stages for the growers (flowering, harvest) and fruit properties (yield, quality) for DSS to adapt crop implantation to specific climate and soil conditions.

2. Impact

[5] Richards et al. 2017. Ecological plant epigenetics: Evidence from model and non-model species, and the way forward. *Ecol Letter* 20:1576-1590
[6] Diaz-Espejo et al. 2018. The olive tree under water stress. *Water Scarcity and Sustainable Agriculture in Semiarid Environment*. 21pp

2.1. Expected impacts (as listed in the call text for SFS-30-2019 "Looking behind plant adaptation")

Results of funded activities will help to create knowledge hubs in their respective domains

The ADAPTaTREE project brings together most of the leading European research groups working on defining the physiological and agronomic impacts of abiotic stress on fruit and grape production. A good part of the ADAPTaTREE principal researchers were involved in the "Water & agriculture: adaptive strategies at farm level" EIP-Agri Focus Group, as well as in the EUFRIN[7] Working Group on "Water Relations & Irrigation". The ADAPTaTREE project will contribute to expand and consolidate this research network and the knowledge hub that is being generated on Water & Agriculture issues, open to partners in other projects and actions. The ADAPTaTREE research ambitions cover areas that were not addressed in the EIP-Agri Focus Group, which "was asked to focus on adaptive strategies at farm level", while "research strategies at molecular to plant level are not discussed". This knowledge hub is likely to succeed as it will start from existing relations and will count on many strengths and inputs that go far beyond the ADAPaTREE project and its partnership.

The ADAPTaTREE partners will also liaise with the EUFRUIT knowledge platform, the open access database of electronic documents related to productivity, sustainability and quality of fruit in the European fruit sector, which has been created by the H2020 CSA EUFRUIT Thematic Network, in collaboration with EUFRIN, AREFLH and FRESHFEL. This knowledge platform focuses on four thematic areas (Performance of new fruit varieties, Reduction in pesticide residues, Fruit quality; improvement of fruit handling/storage, secure sustainable fruit production). Maintaining yield and quality of fruit production under combined water and heat stresses is one of the topics within the last thematic area. ADAPTaTREE will feed with its results the EUFRUIT platform which will be maintained by the European Network EUFRIN after the end of the EUFRUIT project. The EUFRUIT knowledge platform and the EIP-Agri portal will be key reference points for the collection and dissemination of ADaPTATREE results, which will be presented in different forms: indications for improved management strategies will be translated into practice abstracts, while possible research gaps within the fruit sector and future developments can be brought to the attention of the EIP-Agri service point for the proposal of new focus groups.

Develop specific pathways to feed biological insight into agricultural practices.

ADAPTaTREE partners will develop the appropriate instruments to feed into agricultural practice (as close as possible to farming activities) the significant scientific advancements on the biological-physiological and genetic understanding of tree adaptation to drought salt and heat stresses expected.

- The knowledge on the most important **physiological traits** (i.e. stomatal conductance; xylem hydraulic conductivity, fruit features, -etc.) responsible for plant adaptation to stress will be identified and will be translated to improve the orchard management practice (e.g. irrigation and sink:source regulations) through plant-based DSS. In addition, the advanced data analysis will be employed to improve selection of stress-tolerant genotypes in breeding program. The industry partners BOSCH will improve and adapt existing sensors to monitor the physiological traits identified while CYBELETECH will take care to adapt the physiological models into algorithms within a DSS that can translate the sensors reading into indications for the growers. New sensors can be developed also to be used for high throughout phenotyping protocols.
- **Genes/gene regions and/or markers** related to the physiological traits determining the most efficient tree adaptive features can be useful for the screening of wide populations within breeding programs aiming at selecting the varieties with adapted features.
- **An integrated improved model** to forecast the adaptation strategies to CC will provide indication on the potential vocational features of the different crops anticipating which crops will be more adapted to the conditions foreseen for the different regions. In fact, agronomists and the scientific community agree with the importance of considering and incorporating the plant eco-physiological knowledge into the DSSs. Models used to manage irrigation, e.g. crop coefficient method, are empirical, and other solutions like the use of plant-based sensors are difficult to interpret and translate their outputs into agricultural practices.

[7] EUFRIN is an informal organization of research institutes that specialize in development, and extension on temperate fruit crops. http://kp.eufrin.eu/

Within the framework of ADAPTaTREE we suggest incorporating the key physiological knowledge of plant response to the environment into PBMs, which can be both valuable to understand the mechanisms that determine the contrasting behaviour of the different species and user-friendly for agronomists to implement their agricultural practices

- Knowledge on the **plasticity of the physiological traits** more involved in plant adaptation and on the **epigenetic mechanisms** determining their evolution under conditions of stress will be transferred too nurseries associations so that specific adaptation protocols can be developed and applied at the early stages of tree development and training.

ADAPTaTREE will develop a specific communication strategy to bring project findings closer to agricultural practice. In case of lower TRL results, a science communication strategy will be developed, approaching intermediate applied agricultural research and advisory services. On top of the publication and further dissemination of papers as appropriate, a series of seminars will be organised, also using ICT tools (webinars) to facilitate access to knowledge. As project progresses, partners will disseminate research outcomes and identify and share potential applied research avenues. As explained above, the project will liaise with the reference sites for knowledge dissemination in this area, making available a range of communication tools, such as technical notes, brochures and short videos showcasing the research results. The communication products will be targeted to meet specific stakeholders needs (i.e. knowledge on genes/markers will be translated to breeders; knowledge from acclimation studies will be transferred to nurseries associations etc.). The project partners AREFLH and FRESHFEL, which represent themselves the whole fruit production chain, will liaise with other relevant stakeholders to be addressed. Furthermore, dissemination of these findings through the EUFRUIT/EUFRIN knowledge platform as well as through the EIP-AGRI portal will reach the whole agricultural community.

Provide insight into the range of mechanisms that underpin plant responses (from single cell to whole plant) to specific and/or multiple environmental change

ADAPaTREE main strength resides on the integration of the most critical physiological knowledge into PBMs. Processes will be simulated by already-developed process-based models in ADAPaTREE and, since their parameters have full physiological meaning, we will be able to understand and quantify the role of each physiological trait on the performance of the plant for a given environment or combination of conditions. In the framework of ADAPaTREE the impact of using models is extended beyond the aim of simulation. In the case of the stomatal conductance we will be able to quantify the relative weight of hydraulic and chemical signals in the regulation of stomatal conductance.

Therefore, ADAPaTREE will produce knowledge, tools and methods to support the development and profiling of new fruit crops varieties/hybrids that are tolerant/resilient to abiotic stresses, productive in constraining climate conditions (especially water scarcity and increasing temperatures) and efficient in the use of limiting resources (water/soil fertility).

Deliver more accurate models for predicting crop adaptation in response to environmental stresses

ADAPaTREE will use existing PBMs for each of the key processes identified, covering the source capacity and the sink strength. The step forward in this project is the integration of all these models into a single one. This will be possible also considering that most of the developers and experts in the use of these models belong to the ADAPTaTREE consortium. Since the models are process-based and their parameters have physiological meaning, we are in a good position to apply all the physiological knowledge published on crop adaptation in response to environmental stresses in our new integrated model. During a given environmental stress we will identify how the physiological traits evolve and how their dynamics are driving acclimation and adaptation processes. Indeed these models employed in ADAPaTREE will provide information about the optimal distribution of fruit tree species according to the different climates and soil conditions, the key physiological traits that should be considered by breeders for improving genotypes and in genetic studies to locate and identify the related genes and their expression, and to be included in DSSs by companies providing advice or counselling in agricultural practices.

Translate knowledge on the adaptive plasticity of plants and complex genotype by phenotype interactions into crop improvement and management strategies

The dynamics of the physiological traits included in the models will be used in a first stage to evaluate and quantify the plasticity of each genotype to produce different phenotypes in response to the environment. When comparing the differences in these physiological traits among species adapted to contrasting environments or genotypes acclimating to environmental stresses, we will identify the mechanism and limitations for the adaptive plasticity of plants and complex phenotype by genotype x environment interactions. This knowledge will be used by breeders in crop improvement and by agronomists in selecting the most suitable species and genotypes for their growing conditions and management strategies

The acclimation experiment will allow understanding how stress conditions during the young stages of tree growth can change the physiological performance of adult trees under stressors, thus adapting them to better cope with CC. This trial will provide guidelines on how to pre-adapt trees, thus improving the starting plant material to be used for future orchards. Using the AREFLH and FRESHFEL dissemination channels, this knowledge will be spread to EU nurseries.

Activities will allow making assertions on how crops will respond and better adapt to the effects of CC.

By integrating sub-routines from several models into a complete and mechanistic whole-plant model, it will be possible to perform several simulations under the different CC scenarios as predicted by IPCC with the advantage of combining the different expected changes in the environmental conditions. Because the models to be refined and integrated are mechanistic, it is expected to obtain robust outputs. In any case, some model outputs will be validated under experimental conditions where changes in air temperature and CO_2 will occur and crop productivity will be experimentally measured. ADAPaTREE models will also be used to determine the possible effects of physiological adaptation changes on crop modelling. This will allow determining how the revealed adaptation mechanisms determined will influence the crop responses to CC, quantifying the final contribution to the whole-plant behaviour and afterwards for implementation innovative agronomic practices

General impacts using key performance indicators for quantifying ADPTaTREE outcomes

Plant performance. The foreseen decrease in yields due to CC could be alleviated thanks to new knowledge generated on the potential adaptation of these crops, thus allowing them to maintain their typical productions and quality standards. At the same time, ADPTaTREE partners experience with the model routines to be employed, suggests that CO_2 fixation can be increased by 12% in fruit trees, 8% in olives and 6% in grapevines if orchard designs and the genetic material is employed according to the ADAPTaTREE integrated model and DSS recommendations. An improved plant performance, can also positively affect fruit secondary metabolites composition often determining fruit and product quality. This should result in improved grape and olive composition, an aspect of importance for the wine (EU production 168 million hectolitres) and the olive oil industries with Europe accounting for two/thirds of the world olive oil production (2.2 million tons).

Environmental impacts. Several field trials have demonstrated how water use by irrigation can be reduced by 15 to 30% in continental environments by applying tools such online expert systems for irrigation scheduling, shading nets, and canopy and soil management practices. These reductions in water application also have positive consequences on leaching of pollutants and nutrients, to the water table. Results from ADAPTaTREE will work on the adaptation plasticity of the plant material and will lead to the planting of more tolerant orchards, whose management will be adapted accordingly. These approached can lead to significant increase in tree water and nitrogen use efficiency (+20-30% for water) and (10-20% for nitrogen).

Innovation and creation of market opportunities. The involvement of industry in the consortium (BOSCH, CYBELTECH), the implementation dedicated to on-farm experiments and advanced dissemination through the end-users and value association (AREFLH, FRESHFEL) will enable translation of the project results into marketable products. Participating companies will scale-up selected ADAPTaTREE solutions, thus increasing their own commercial competitiveness as well as that of growers and breeders through the implementation of more adapted and more qualitative cultivars. The industry partners will also be vigilant in the development of modelling approaches focussing on the criteria relevant for the agricultural sector end-users. On the other hand, the identification of genes, gene regions, and potential genitors could be employed in at least 12 fruit trees and vines existing breeding programs both from public and private sectors (Source FRUITBREEDOMIC project).