1 Final publishable summary report

1.1 Executive summary

Increasing water scarcity and environmental concerns have urged the search for solutions for better water management in irrigated agriculture. Precision irrigation is one of these solutions.

Technologies have developed potential systems, although effective partnerships have to be fostered between private industry and scientific community to shape up some common and complementary solutions.

The project proposes the development of an expert system, based on the exploitation of results from three previous projects in order to acquire data from sensors, match it against a data base, produce decisions on water and energy savings.

The innovative solution of the project recalls on the following pillars:

- On his historical database built upon real cases studies,
- Is shared on the web which guarantees cheaper access to this technology and,
- Helps changing the current culture and behaviour and into getting agricultural exploitation into the use of ICTs.

The **direct benefits** of the project are:

- Saving water, especially where annual traditional amount of irrigation water is beyond average crop water requirements.
- Saving energy and manpower required to pump and distribute excess water.

As **indirect benefits** of the project:

- Reducing leaching of fertilizers out of the plant root zone.
- Improving water and fertilizers availability for the plant.
- Reducing deep water percolation and contamination to underground aquifer by agricultural chemicals.
- Providing information about the local soil hydrodynamic characteristics, the advance of wetting front during irrigation events and the depth and daily pattern of root water uptake.
- Providing information on the hydraulic performance of the irrigation system in use.
- Providing information on the current crop development and growing stages.
- Creating a closer relationship between the farmer and his production system. It offers him a better real understanding of water and nutrient balance within water-soil-plant-system.
- Creating consistency in yields between years.

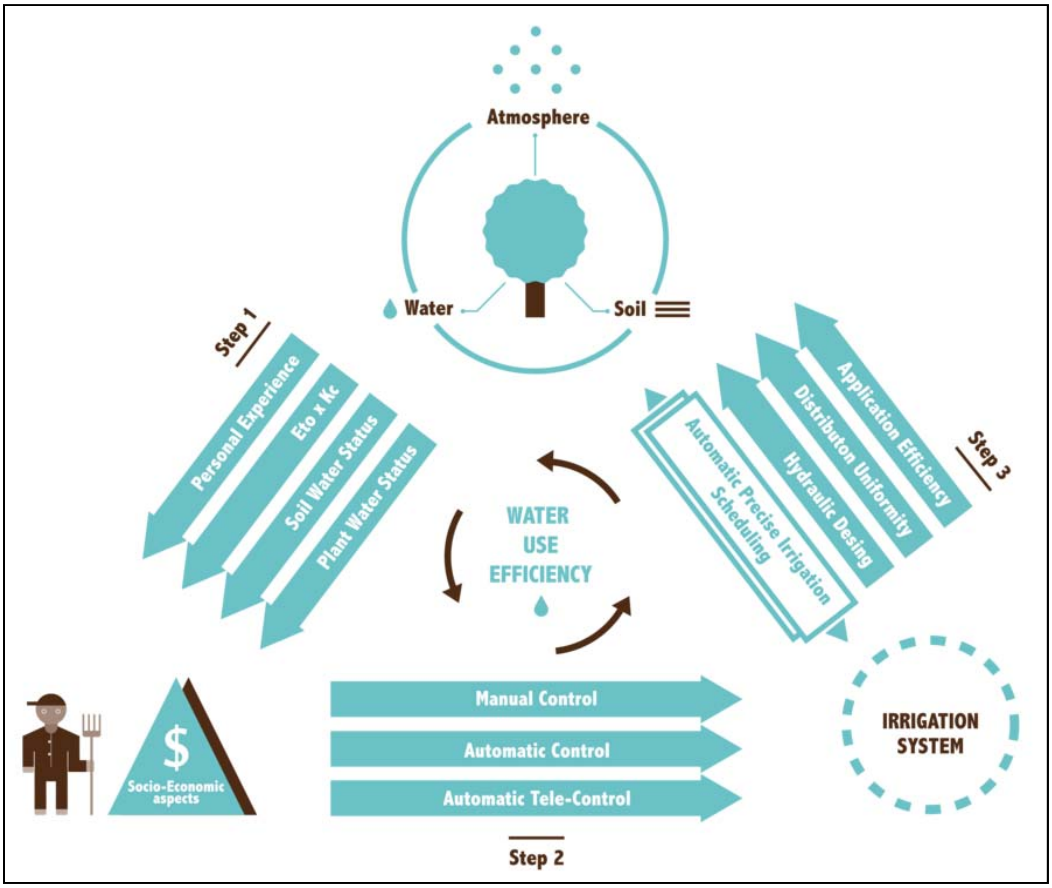
1.2 Project context and objectives

In the 21st century, water shortage, water quality degradation, underground water depletion, population growth and demographic unbalances between rural and urban areas as well as crop water requirements and prolonged periods of drought (Pereira et al., 2007) have become evident challenges in the arid and semiarid areas. In Europe, awareness of the need for sound water quantity management has slowly acquired relevance in recent years due to the increase in drought and long-term imbalances of water supply (EU-COM (0672), 2012). Currently, large areas of Europe, particularly in Southern and South-Eastern Europe, are vulnerable to water scarcity and drought events and this area is likely to increase in size in the future (Florke et al., 2011). Projected climate change indicates a longer growing season (Sabaté et al., 2002), higher water demand and less available water in the future (Lavalle et al., 2009). Consequently, concerns about water conservation and saving are becoming as much a priority as health concerns. The human community has begun to understand the urgent need to enhance the productivity of water use and to reduce the amount of pollutants in the used water they are discharging to the environment.
Given the aim of the call in which this project has been selected for funding (FP7-KBBE-2013-7-single-stage) for boosting the translation of FP projects' results into innovative applications in the field of agriculture, **our overall objective was to build a knowledge-based system for online precise irrigation scheduling (OpIRIS) using advanced results from 3 previous FP projects CLOSYS (FP5-LIFE QUALITY-QLK-CT-2000-01301), IRRIQUAL (FP6-FOOD-CT-2006-023120) and SIRRIMED project (FP7-KBBE-2009-3-245159), for optimize water and fertilizers productivity in fruit trees orchards and hydroponic productions in greenhouses.**

The OPIRIS expert system is based on the basic irrigation-control approach, which consists of three main steps summarised below:

1) **Assessment and decision making on when to irrigate:** This depends on the farmer's ability to observe, understand and interpret the interconnected relationships within the water-soilplant- atmosphere continuum.
2) **Determination of how much water to apply:** This depends on the availability and quality of water resources and on the hydraulic characteristics of soil and water delivery system.
3) **Delivery of irrigation water to the crop or frequency of application:** This depends on the hydraulic and agronomic design of the irrigation system.

The precision of matching the applied water to the real water requirements for optimum crop production depends on the time required and the level of disturbance (climatic demand, soil water dynamics, plant physiological response, etc.) accumulated on the way from step one through step three.



OpIRIS aimed at developing an expert system based on an irrigation scheduling algorithm based on a combined interpretation of real-time readings from soil and plant water status indicators and/or weather information. The implementation of this algorithm has facilitated the closer relationship between the farmer and his production system. It offers him a better factual understanding of water and nutrient balance within water-soil-plant system. OpIRIS user now has historical records of his irrigation practices and can compare them with similar cases available on OpIRIS-Database. This system is able to help saving water by 15 to 30 % and to improve fertilizers productivity by 5 to 10 %. Furthermore, it helps highlighting and quantifying potential cost opportunities. The OPIRIS overall goal has been achieved through 5 specific stages:

- **Stage 1:** To generate a database on water and fertilizers productivity in fruit tree orchards and hydroponic productions in greenhouses. Data has been gathered from real-case studies developed during the above mentioned FP projects. It has provided practical information on crop water and fertilizers requirements under different climatic conditions and for different irrigation scheduling methods and technology.

- **Stage 2:** To develop an online precise irrigation-scheduling algorithm based on a combined interpretation of soil and plant-based or weather sensors. Plant-based or weather readings helped identifying when to irrigate and soil-based reading has been used to compute how much water to apply. The algorithm can read, analyse and interpret real-time data coming up from physical sensors installed in the field or greenhouse and connected to the OpIRIS through a device-to-web datalogger. This option enables the user to experience the use of precise irrigation technology through an affordable economic investment with a direct professional support from the OpIRIS distributors.

- **Stage 3:** To develop a web-based friendly graphic user interface that enables the user to easily identify potential benefits associated to each irrigation-scheduling option.

- **Stage 4:** To design, test, validate and disseminate the results of online irrigation scheduling on water and fertilizers productivity and related opportunity cost.

- **Stage 5:** To market the OpIRIS expert system in the different identified European markets. The graphic user interface and system manuals will be published in at least three European languages (English, French and Spanish).

The overall strategy of OpIRIS' work plan consisted of three complementary activities structured into specific work packages and tasks:

1) **OpIRIS development:** it has been achieved after building up a historical database, editing a series of mathematical modules and designing a friendly graphic-user-interface (in work packages 1 and 2). This has required continuous collaboration among OpIRIS's researchers, operators and producers to progressively integrate scientific-knowledge with client-tailored features into one attractive, feasible and professional product:
    - **WP1- Validation of results from previous FP projects.**
    - **WP2- Development of OpIRIS methodology and Algorithms.**

2) **OpIRIS validation and demonstration:** the system resulting from activity-1has been installed in 6 agricultural exploitations (3 fruit trees orchards and 3 hydroponic productions) for validation through periodic feedbacks on system versatility and performance in fruit trees (WP3) and hydroponic crops (WP4). The same agricultural exploitations will be used as demonstration plots for local dissemination and training activities.
    - **WP3-OpIRIS system testing on fruit tree exploitations.**
    - **WP4-OpIRIS system testing on hydroponic exploitations.**

3) **OpIRIS dissemination and commercialization:** the results obtained during the projects lifespan has been periodically disseminated toward potential end-users, e.g. farmers, relevant public institutions, water management bodies, extension services. For larger commercialization of the product, special efforts have been made to highlight OpIRIS innovative features, reasonable cost and potential benefits, maintenance and after-sale services.
    - **WP5-Results and OpIRIS system dissemination and exploitation.**

1.3 OPIRIS results

1.3.1 Work-package 1: Validation of results from previous FP projects

This work package aimed to validate on a real scale results obtained from previous FP7 projects: CLOSYS (FP5-LIFE-QUALITY-QLK.CT-2000-01301), IRRIQUAL (FP6-FOOD-CT-2006-023120) and SIRRIMED (FP7-KBBE-2009-3-245159). In addition, it included compilation of information for creating a database to provide irrigation decision-makers at farm level with practical information on water and fertilizers productivities as affected by irrigation-related technologies and scheduling methods.

Task 1.1: Data selection on fruit trees and hydroponic production: OPIRIS_Researchers from CSIC and CERTH collected a wide range of results describing the impact of different irrigation scheduling methods on water productivity at farm level. There results were gathered from previous FP7 projects as well as from our end users all available scientific papers.

Task 1.2: Database generation and Server setup and configuration: Afterwards, the information was organized into a well-structured database called DB1-Ref by CSIC and CERTH. It holds all the technical and scientific information of the corresponding experiment or case study to be used as reference when needed.
DB1-Ref has been integrated into section one of a standard database composed of 5 compartments. The sections 2 and 3 host “DB2-F” and “DB2-H” which refers to “Fruit trees” and “hydroponic crops” respectively. Both derive from DB1-Ref and hold only the information of applied character which could interest OPIRIS_Visitors when presented for public access on OPIRIS_GUI. The forth section hosts the “DB3” which holds all kind of information and reports that can be exchanged with potential clients willing to test an OPIRIS_demo before buying OPIRIS services. The last section hosts “DB4” that is reserved to hold all the technical details related to OPIRIS_Clients.
For more details, please refer to **D1.1 - Database on fruit trees and hydroponic crops.**

Task 1.3: Algorithm and system validation (Scale up): OPIRIS_Users provided all technical information about their agricultural-exploitation forming part of OPIRIS_Trials. OPIRIS_Researchers (CSIC and CERTH) evaluated all the agronomic (water, soil, plant, atmosphere), physical (sensors installation and maintenance) and technical (specifications of telecom devices) aspects and recommended the number of monitoring sites and the parameters to be monitored at each sites. A special guide was developed describing the operational concept of each sensor, the main criteria to be considered for selecting the appropriate site for installing in field or in greenhouse and all the steps needed to install it properly. The reasons for potential failures have also been exposed together with the recommend solutions to maintain the sensor’s performance at acceptable level. OPIRIS_Reserachers and OPIRIS_Operators defined the structure of OPIRIS server, its main components and their minimum technical requirements.

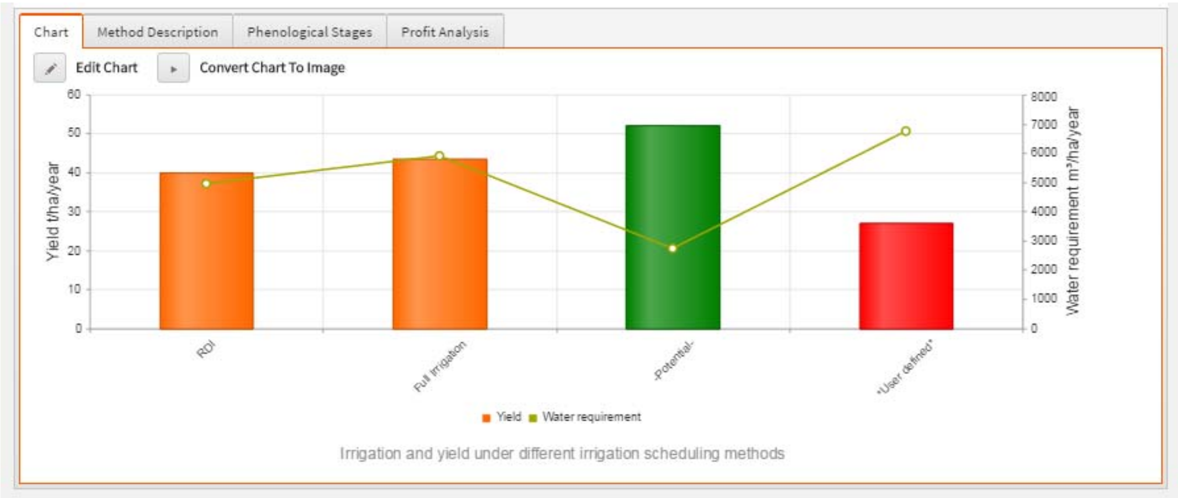
A special guide was developed describing the operational concept of each sensor, the main criteria to be considered for selecting the appropriate site for installing in field or in greenhouse and all the steps needed to install it properly (**D1.2 - Technical Guide for Sensors Installation and Maintenance**).

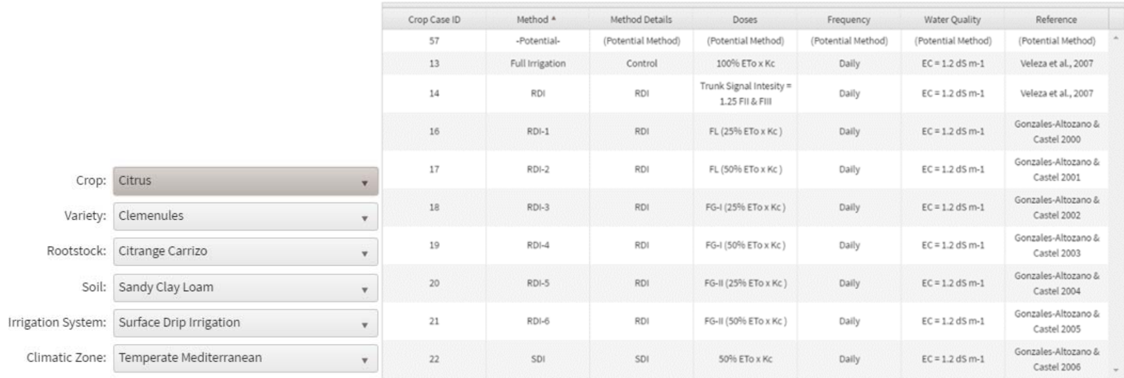
OPIRIS_Reserachers and OPIRIS_Operators defined the structure of OPIRIS server, its main components and their minimum technical requirements are described in **D1.3 - First report on Server Setup and Configuration**.

WP1 Significant results:

Several important sets of data were identified by the OPIRIS_Researchers and included in the DB. The DB was enriched with about 70 entries related to fruits trees and 75 entries related to greenhouse crops. From those data, significant outputs can be produced for the OPIRIS_Visitors.

Concerning the fruit trees, a visitor can find several data for Citrus, Grapes, Olives and Stone fruit related to fruit-yield and water consumption under different irrigation regimes. Figure 1 shows the data presented for a specific variety of Citrus under different irrigation treatments where different amounts of irrigation water were applied to the crop. It can be seen that increasing the given irrigation water would results in fruit yield increase but this relation is not linear. A “Regulated deficit irrigation” strategy used 20% less water and produce almost the same crop (an insignificant loss of 5%). But the most important observation comes up when comparing the farmer’s results with those of OPIRIS_DB which highlight the need for a full revision of the farmer’s actual irrigation scheduling method.





Crop Case ID	Method	Method Details	Doses	Frequency	Water Quality	Reference
57	-Potential-	(Potential Method)	(Potential Method)	(Potential Method)	(Potential Method)	(Potential Method)
13	Full Irrigation	Control	100% ETo x Kc	Daily	EC = 1.2 dS m-1	Veleza et al., 2007
14	RDI	RDI	Trunk Signal Intesity = 1.25 FII & FIII	Daily	EC = 1.2 dS m-1	Veleza et al., 2007
16	RDI-1	RDI	FL (25% ETo x Kc)	Daily	EC = 1.2 dS m-1	Gonzales-Altozano & Castel 2000
17	RDI-2	RDI	FL (50% ETo x Kc)	Daily	EC = 1.2 dS m-1	Gonzales-Altozano & Castel 2001
18	RDI-3	RDI	FG-I (25% ETo x Kc)	Daily	EC = 1.2 dS m-1	Gonzales-Altozano & Castel 2002
19	RDI-4	RDI	FG-I (50% ETo x Kc)	Daily	EC = 1.2 dS m-1	Gonzales-Altozano & Castel 2003
20	RDI-5	RDI	FG-II (25% ETo x Kc)	Daily	EC = 1.2 dS m-1	Gonzales-Altozano & Castel 2004
21	RDI-6	RDI	FG-II (50% ETo x Kc)	Daily	EC = 1.2 dS m-1	Gonzales-Altozano & Castel 2005
22	SDI	SDI	50% ETo x Kc	Daily	EC = 1.2 dS m-1	Gonzales-Altozano & Castel 2006

Figure 1: Fruit yield and water requirements of citrus fruit trees under different irrigation regimes that can be visualized on a graphic chart or in table format.

Concerning the greenhouse crops, a visitor can explore the water needs and the respective yield observed for different greenhouse crops cultivated in the soil or soilless in different hydroponic systems. A representative graph output shows the correlation between the fruit yield obtained and the water consumed from the crop under different conditions (Fig. 2). It is very interesting to see that fruit yield is almost linearly increased as water consumption is increased, with some exceptions depending on the conditions under which the study was carried out.

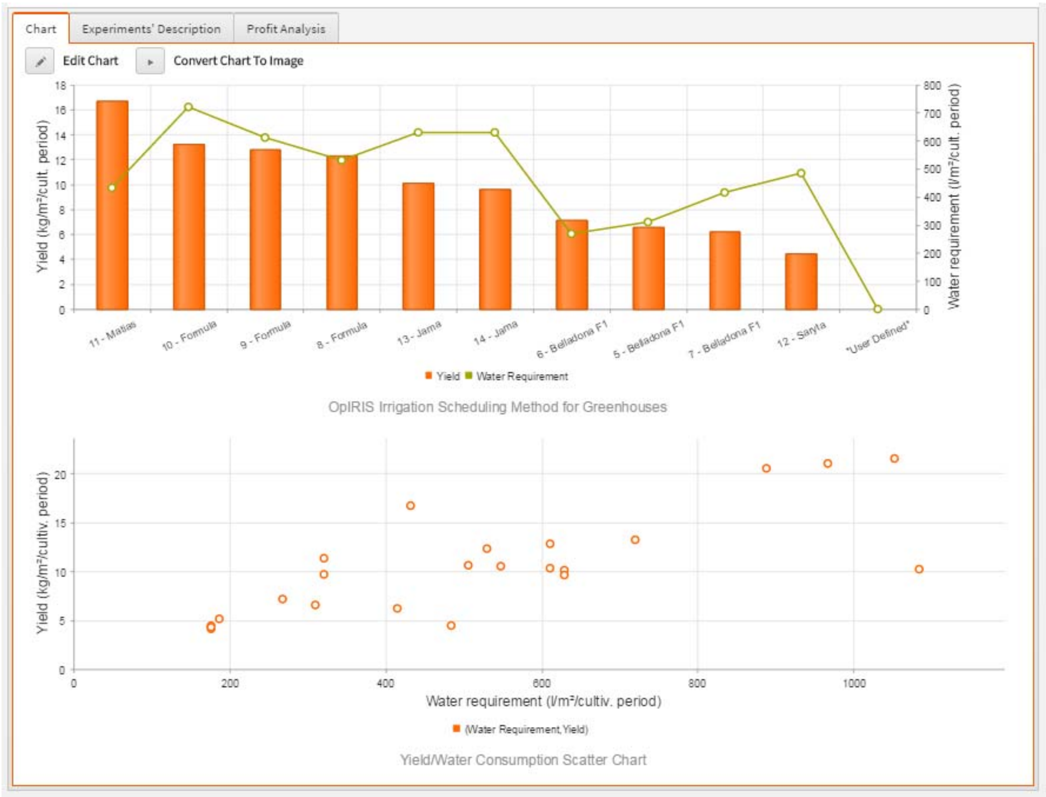


Figure 2: Correlation between the obtained fruit yield and water consumed as reported in different experimental studies for hydroponic tomato crops.

Based on the above data, OPIRIS_visitors can estimate the water needed for a fruit tree or greenhouse crop, the yield obtained under different regions (as shown in a respective map included in the OPIRIS_visitors page, Fig. 3) and water use regimes and the potential yield under optimal irrigation conditions.

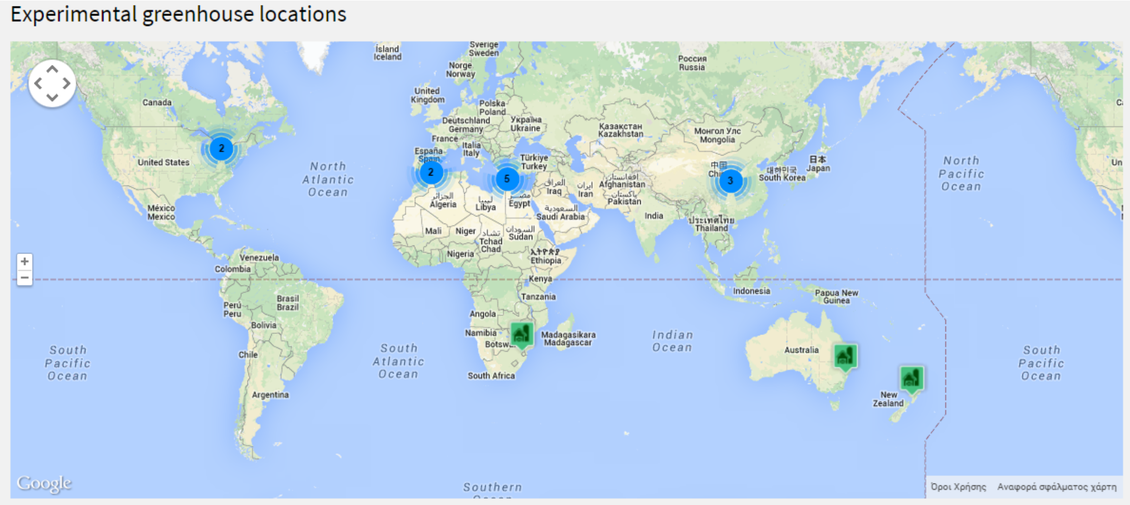


Figure 3: World map with indication of regions where data come from, for the different cases presented in OPIRIS_visitors page.

1.3.2 Work-package 2: Development of the OpIRIS methodology and Algorithm

Task 2.1: Design of OpIRIS graphic user interface (GUI) and wizard guide for end-users: a multi-level graphic user interface has been developed to offer its user a friendly access to the requested information. A total of 4 levels have been considered for each crop category (Fruit trees and hydroponic crops). The first level called "OPIRIS_Visitor" is of free-access to general public visitors and some potential clients willing to get some additional personalized comments/assessment. The remaining three levels called "OPIRIS_User (Basic Mode)", "OPIRIS_User (Advanced Mode)" and "OPIRIS_User (Data Mode)" are restricted for registered clients with purchased license. Further information about the GUI can be found in **D2.4 - Graphic-user-interface: report on structure and its interactive features.**

Task 2.2: Design of OPIRIS modules and algorithm: within this task we have revised the irrigation scheduling and control modules and subroutines already developed in the frame of CLOSYS, IRRIQUAL and SIRRIMED. Afterwards, data was structured and integrated into one algorithm to form the core of OpIRIS computation system.

Task 2.3: Development of OpIRIS system: this task dealt with the integration of the main components OpIRIS-Database, OpIRIS-Algorithms and OpIRIS-GUI into the OpIRIS-server. Detailed information about the OPIRIS system is shown in **D2.5 - OpIRIS system (database, modules, subroutines and algorithm and GUI integrated into one operational package).**

Task 2.4: OpIRIS verification and validation: the Algorithm was tested and evaluated in three commercial farms, analysing soil moisture and trunk diameter readings coming up from different agricultural conditions, to decide when and how much water to apply. Under different soil and plant conditions in the three farms, the input variables (SWCz, SWSi, etc…) and thresholds values to run properly and prevent undesired field troubles, were successful tested.

The main algorithm consists of 3 complementary sub-algorithms called “A”, “B” and “C”. After two years tested, the final schematic algorithm decision was developed. On daily basis, the main algorithm runs first sub-algorithm “A” to determine the solar schedule for this particular day (predawn, sunrise, noon and sunset). Then it runs sub-algorithm “B” which reads the values of the trunk diameter recorded during the previous 24 hours. It filters them and computes the corresponding indicator “SsTRR”. Afterward, the sub-algorithm “C” is executed. It reads the SsTRR value and decides whether to irrigate or not. In the affirmative case, it computes every 15 min the increments in the soil water content or “SWC” at different depths and estimates the advance in depth of the wetting front below the emitter. When an increment of 20% in SWC is detected at the deepest sensor installed at the lower limit of the plant root zone, the irrigation system is turned OFF. Two deliverables show results from the initial and final validation of the OPIRIS system: **D2.6 - First report on OpIRIS system validation and performance**, and **D2.7 - Final report on OpIRIS system validation and performance.**

WP2 Significant results:

The architecture of OPIRIS-system is similar for fruit trees and hydroponic corps. It consists of one or several control points/areas in the field. Each point/area is equipped with a set of soil, plant and environmental sensors which are connected to a device-to-web unit. The latter is a datalogger equipped with a radio/GSM/GPRS modems to periodically (min 1 minute) collect information from the sensors and upload them through the cloud to OPIRIS server. OPIRIS server receives this information, it stores it and makes it available on the web for worldwide controlled access. Depending on the type of information received and its utility, one or more mathematical algorithm are executed to analyze this information and elaborate practical recommendation for end-users or direct irrigation decisions to automatically be implemented at the irrigation control unit.

As it is shown in Figure 4, the OpIRIS system comprises 4 main components:

- OpIRIS Hardware
- OpIRIS Databases
- OpIRIS Algorithms
- OpIRIS Graphical User Interface

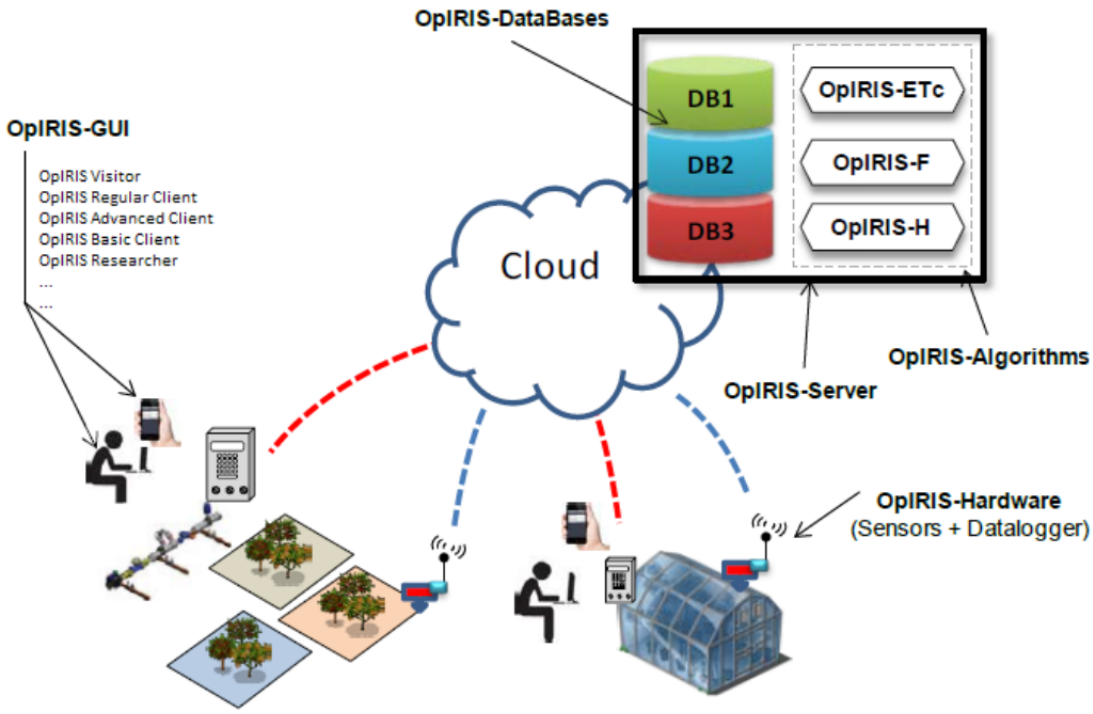


Figure 4. High-level architecture of the OPIRIS system

The hardware:

The OpIRIS Hardware component consists of special equipment needed for precise irrigation scheduling in fruit trees and hydroponic crops. The different sensors involved in the project are shown as follows:

- Soil Moisture Sensor EC-5: The EC-5 measures the dielectric constant of the substrate in order to find its volumetric water content. Since the dielectric constant of water is much higher than that of air or substrate minerals, the dielectric constant of the substrate is a sensitive measure of water content. The EC-5 has a very low power requirement and high resolution. This gives the ability to make many measurements over a long period of time, with minimal battery usage. Its two-prong design and higher measurement frequency allows the EC-5 to measure VWC from 0 to 100% and allows accurate measurement of all soils and soilless medias and a much wider range of salinities

Figure 5. Soil Moisture Sensor EC-5

- Temperature and Humidity Sensor: This sensor, measures air temperature -40°C / +60°C and Humidity 0 ... 100% RH. A professional radiation shield protects the sensor from direct sunlight and provides sufficient ventilation. Solid UV resistant elements reflect radiation on their white surface, while the black inside absorbs accumulating heat.

Figure 6. Temperature and Humidity Sensor

- Pyranometer Sensor Kipp & Zonen SP-Lite: This silicium-pyranometer was especially designed for agro-meteorology, in particular to calculate evapotranspiration for precision irrigation purposes, to monitor solar panels in energy production, for air pollution dispersion calculations and similar applications. SP-Lite can be used under all weather conditions.

- Irrigation meter: The irrigation meter is designed as a universal rain gauge, that meets the need of most applications. The measurement is done by a double tipping bucket system that's factory calibrated to remain within a <2% accuracy in water falls up to 60mm per hour. The steep angle of the buckets makes water run of quickly and thus prevents the build-up of residue, like sand or dust in the buckets. Output signal, one pulse per tip.

Regarding fruit trees, environmental sensors for continuous measurement of soil moisture and trunk diameter fluctuations have been utilized. For hydroponic crops, the respective hardware consists of sensors for continuous measurements of substrate moisture, air temperature, air relative humidity and solar radiation. All sensors are connected to device-to-web data loggers which feed the respective sensor data databases.

Data bases:

OpIRIS system incorporates a number of databases which will support various aspects of the system functionality. The different databases are presented as follows:

- Research database for Fruit Trees and Hydroponic Crops: This database contains irrigation and crop data about fruit trees and hydroponic crops from previous research projects.
- GUI database for Fruit Trees: The OpIRIS Graphical User Interface incorporates a database which will hold data regarding various Fruit Trees case studies.
- GUI database for Hydroponic crops: The OpIRIS Graphical User Interface incorporates a database which holds data regarding various Hydroponic Crops case studies.
- GUI database for general GUI functionality: generated by the Wordpress Content Management System during its installation process
- GUI database for users: to store all the user related data.
- GUI database for sensors data: This database contains the sensor values for various time intervals.

Algorithms:

OpIRIS system algorithms component involves 3 main modules:

- OPIRIS-ETc module: which estimates crop water requirements after requesting crop coefficient from DB2 and historical average ETo data from the FAO NewLocClim (Grieser et al., 2006)
- OpIRIS-F Module: which analyses soil moisture and trunk diameter readings coming up from specific orchard to decide when and how much water to apply.
- OpIRIS-H Module: which schedules irrigation through a transpiration model periodically adjusted upon real time measurements of substrate moisture and weather conditions.

The multi-level graphic user interface:

A multi-level graphic user interface, with the four levels:

- *OPIRIS_Visitor*: it is a public page with several dropdown lists, a multi-tab section and several mouseover pop-up text messages. Using the dropdown lists, public visitors have the opportunity to select different combinations of crop, variety, rootstock, soil, and irrigation system and climate zone to query OPIRIS_DB on the corresponding potential yield and crop water requirements under different irrigation scheduling method. The results of this query appear on the first tab of a multi-tab graph. Furthermore, OPIRIS_Visitor can edit the chart to introduce some personal values and compare them on the chart. On the second tab, for every irrigation-scheduling method, a graphical legend depicts the % of water supply during each phenological stage. On the third tab, an additional table shows some values related to water economic and agronomic productivity.
- *OPIRIS_User* (Basic Mode): It is the first section for registered users. It is aimed to graphically show the recent status of some indicators and provide some visual assessment at a glance. Registered users are provided with different preconfigured graphs. The **first** graph depicts the timely evolution of a specific **plant-water-status** indicator together with the corresponding thresholds representing different levels of water stress. An additional tree icon indicates whether, during the last 24 hours, the tree was happy, under mild, moderate or severe stress. The **second** graph shows the timely evolution of the **soil water store** together with the corresponding thresholds representing the upper limit above which deep percolation may take place and a lower limit below which the plant may suffer the impacts of water deficit. The **third** graph represents the amount of water applied every month and the total amount accumulated since the start of the irrigation season. Additional information is provided about the rate, amount and duration of the last irrigation-event as well as the depth reached by the wetting front under the emitter.
- *OPIRIS_User* (Advanced Mode): it is the second section for registered users. It is aimed to provide times series of each monitored parameter. Registered users are provided with different graphs similar to those presented under "Basic Mode" but showing all the raw data as they are collected from each individual sensor either on the plant, in the soil or on the irrigation system.
- *OPIRIS_User* (Data Mode): this is the third section for registered users. It provides all the registered and computed values in table format. Moreover, the user can always export them into ASCII format or excel files for later private processing.

System validation and performance:

The hardware components of the OpIRIS system were successfully installed in both greenhouse hydroponics sites. The system was tested for several months in both sites and the acquired data were reported and analyzed. The estimations performed on daily transpiration and drainage and the suggested optimal irrigation amounts were assessed and proved to be satisfactory. However, the following main improvements were suggested and have been realized and implemented into the OpIRIS algorithms during the last project period:

- The transpiration estimation model will be further calibrated based on measurements of its actual modeling error. For that to be possible, the growers will have to follow the exact irrigation doses suggested by the OpIRIS system, so that the estimated and actual drainages can be compared and the modeling errors can be calculated. Based on these error values, the model's coefficients will be tuned in such a way that the error is minimized.
- The OpIRIS suggestions for optimal irrigation management will be also based on actual scheduling of the irrigation application events and not only on the suggested amounts of water per dose. The current version of OpIRIS system assumes a fixed number of irrigation events per day and adjusts the suggested amount of applied irrigation water per event (application dose). The modified system will suggest variable numbers of irrigation events per day, leading to a more dynamic and flexible optimal irrigation management.
- As a first step, OpIRIS system suggested changes in irrigation dose based on last day data. During the next period, the OpIRIS system will be modified to take into account the weather predictions for the solar radiation intensity of the next day; and based on a user defined dose, will suggest the optimal scheduling for the coming day.
- Finally, the system will be extended to a further degree so that will be able to take action and control the irrigation events of the OpIRIS greenhouses.

1.3.3 Work-package 3: OpIRIS system testing on fruit tree exploitations

Task 3.1: Installing the system in the participant exploitations: a total of 4 trials sites in 4 different countries (Estonia, Portugal, Spain and United Kingdom) have been equipped with environmental sensors to monitor some soil, plant and irrigation related parameters. A common team from CEBAS and RITEC visited each plot where it identified the most representative tree and the appropriate place to install the sensors in the soil and on the tree trunk. The sensors were installed and connected to specific data-loggers and configured to communicate by GPRS with OPIRIS_Server.

Some pictures from the installation of the OPIRIS sensors are shown in Figure 7:

Figure 7. CEBAS and RITEC team installing environmental in the fruit-trees trials.

Task 3.2: Demo performance for fruit trees: After installing the sensors and validating the communication with the central server, a demo period of 3-6 months has been performed in each of the trial plots. During this period, the farmer was asked to keep using his traditional irrigation scheduling method while the OPIRIS devices and system were continuously collecting data series. Then the OPIRIS' algorithm were executed to process, analyse and interpret these information in order to characterise the actual performance of the farmer's water management procedure and its impact on the soil and plant water status. Finally, all the drawn observations were communicated to and discussed with the farmer in order to establish the operational protocol to be implemented during the demo-period of the next irrigation season.
D3.8 - Report on sensors' performance in hydroponic crops summarizes conclusions from this task.

Task 3.3: Analysis of users' feedback for fruit trees: The OpIRIS system developed was successfully tested and evaluated in the three commercial farms. The system offers several possibilities (visitor, consultant, scheduler and controller) to the users to evaluate the performance of their farm from the climate control and irrigation scheduling management point of view. OpIRIS offers a complete solution to the user for the irrigation management of a fruit tree crops since based on plant and soil water status and other user settings, OpIRIS algorithms estimate the optimal irrigation scheduling program. Nevertheless, comparing data observed before and after the application of OpIRIS showed that the use of the system can resulted in about 100% increase of water and fertilizers' productivity. Information performed within this task is collected in **D3.9 - Report on OpIRIS's impact on irrigation management in fruit trees orchards**

<u>WP3 Significant results:</u>
To monitor the soil-plant water status on fruit trees, 3 monitoring nodes were installed in each of the 3 orchards provided by OPIRIS' partners in 3 different countries (Estonia/SEEDRI, Portugal/DONA HORTA and Spain/VARGAS & PROGEAGRO). Two additional monitoring nodes were configured for vegetable plants in the trial plot

provided by partner 12 (FLIGHTS) in UK. Table 1 shows an overview of the different pilot sites parameters:

Country	Crop/Variety	Area (ha)	Observation node	Continuously monitored parameters /observation node
Estonia	Apple/AUKSIS GPS Coordination [58°10‘43,71"N 22°12‘37,33"E]	5	3 nodes, each with a data logger and GPRS transmission unit	-Soil water content at 6 levels -Debit of the irrigation emitter -Fluctuations of the tree trunk diameter
Portugal (Alcobaça)	Apple/Jonagold red GPS Coordination [39°33'38.68"N; 9° 3'35.24"W]	1.5	3 nodes, each with a data logger and a Radio Transmission Unit + 1 GPRS transmission unit	-Soil water content at 6 levels -Debit of the irrigation emitter -Fluctuations of the tree trunk diameter
Spain (Jumilla)	Peach/paraguayos GPS Coordination [38°23'51.28" N; 1°23'9.61" W]	2.6	3 nodes, each with a data logger and a Radio Transmission Unit + 1 GPRS transmission unit	-Soil water content at 6 levels -Debit of the irrigation emitter -Fluctuations of the tree trunk diameter
UK (Ledbury)	Vegetables under plastic tunnels GPS Coordination [52°02'10.84" N; 2°27'25.82" W]	1	2 nodes, each with a data logger and a GPRS Transmission Unit	-Soil water content at 6 levels -Debit of the irrigation emitter -Solar Radiation -Relative Humidity -Air temperature -Leaf temperature

Table 1. List of the project's field trials and the parameters to be monitored for evaluating the productivity of water in fruit trees.

Conclusions from the first assessment period aimed to insure their appropriate performance and then to characterize the current irrigation water management methodology in use by the farmer, are shown as follows:

- Multi-sensor capacitance probe: The curves on Figure 8 depict the evolution of the soil water content at different depths (10, 20, 30, 40, 50 and 60 cm) during 24 hours. The yellow arrow indicates the moment at which almost all the SWC started decreasing. This observation took place few minutes after sunrise and thus indicates the start of an active root water uptake being mostly active at 50 cm depth. Late in the afternoon, am irrigation event took place. The red circles on the curves indicate the progressive advance of the wetting front down in the soil to reach the lowest sensors after 2.5 hours of irrigation. This behaviour has been observed every day in the same place but with different magnitude depending on the actual water flow in the soil-plant system. Similar observations were recorded in all trial plots. **This highlights an excellent performance of this kind of probes especially after being properly installed in the right place as suggested by OPIRIS expert team.**

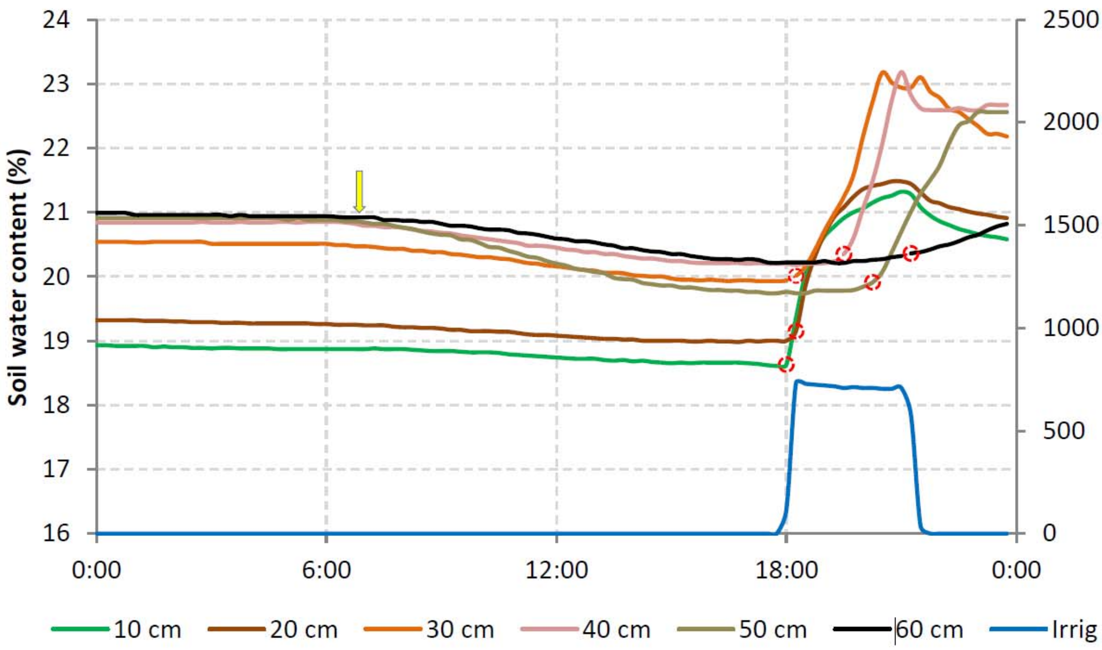


Figure 8. Evolution of the soil water content at different depths (10, 20, 30, 40, 50 and 60 cm) during 24 hours. The blue line represents an irrigation event during 3 hours (03 Aug 2014).

Figure 9 shows the time evolution of the water layer (expressed in mm) stored in the soil profile down to 0.6 m together with the series of irrigation events. The black curve shows different tendencies of the SWS as far as it is affected by the mismatch between amount of water applied by irrigation and that extracted from the soil by root water uptake. Although, during August, the farmer had maintained a constant irrigation schedule, the SWS showed a decreasing tendency during the first 15 days than an increasing tendency until the first week of September when the farmer changed his irrigation frequency from daily to each other day.

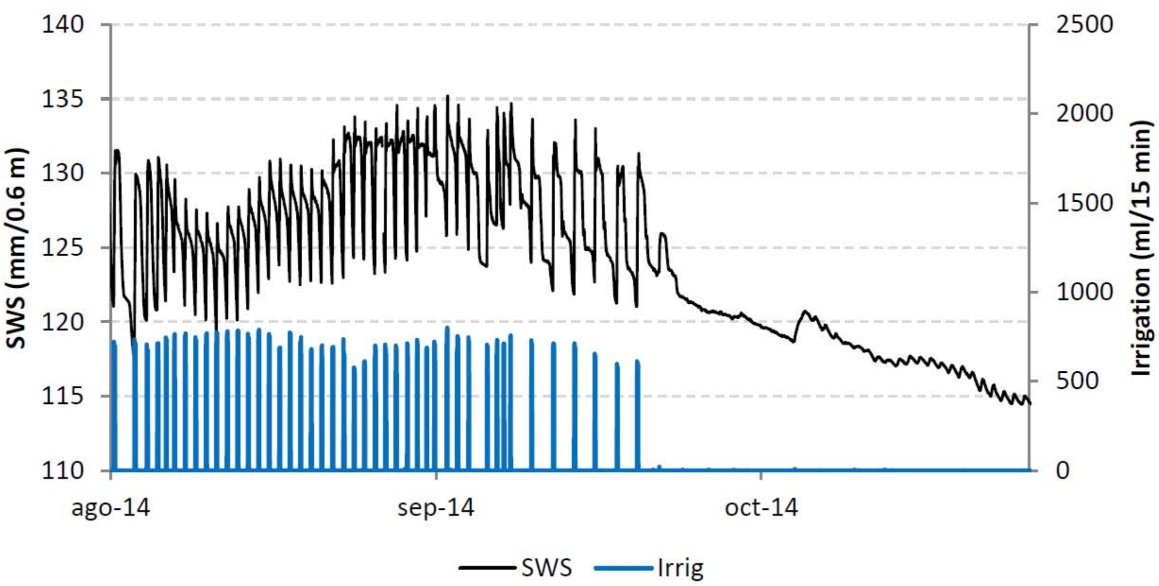


Figure 9. Evolution of the soil water store within the soil profile from down to 0.6 m depth. The bars indicate the series of irrigation event applied during this time period of 3 months.

- Linear variable displacement transducer (LVDT): The LVDT sensor accurately detected the instantaneous variation of the trunk diameter. Figure 10 shows a progressive increase of the trunk diameter during the night up to the sunrise time when an inflection point indicates the start of the shrinkage phase induced by the mismatch between water uptake at the plant root level and water losses to the atmosphere at the leaves level.

  After solar noon, the climatic demand starts progressively decreasing which permits the trunk cells to recover its turgor state and growth rate process which progressively increase the diameter. However, the configuration of the metallic structure supporting the sensor, its position on the trunk and its high measuring resolution makes its vulnerable to physical disturbances produces either by one or all of the following factors in the field:

  - Undesired external contact with the sensor (animal or human although these are not frequent)
  - Deviation of the radial growth vector out of the axial movement of the sensor’s needle within the solenoid.
  - Some insects (mainly small spiders) may lay their eggs inside the solenoid and restrain the free movement of the sensor’s needle.

  The impact of any of these factors can be easily identified on the recorded data series and thus a field visit for maintenance is scheduled. On average these problems may occur once per month.

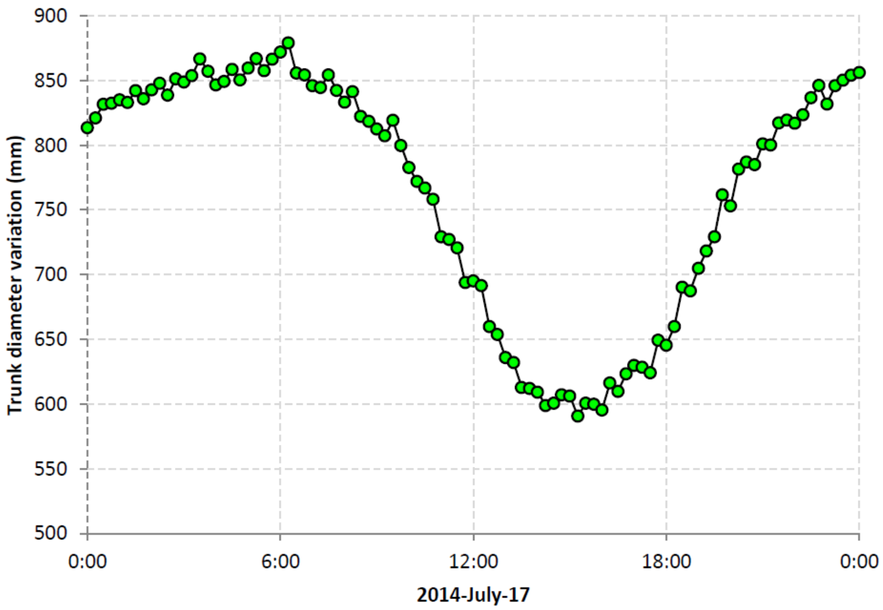


Figure 10. Daily evolution of the trunk diameter of adult flat peach tree

- Water emission-rate meter: The sensor’s outputs are electric pulses automatically converted into ml of water applied during a specific time period (for example x ml/15 min). Then, at the end of every irrigation event, the recorded data series are used to compute the precise duration of every irrigation event, the actual application rate and the total volume of water applied. It is an accurate sensor which helps keeping an eye on the daily performance of the irrigation system.

The users (Frutas Vargas, Dona Horta and Seedri) applied the suggestion of the system, as far as possible. Nevertheless, comparing data observed before and after the application of OpIRIS showed that the use of the system can resulted in about 100% increase of water and fertilisers productivity. Should the users completely follow the suggestions by OpIRIS (as was the case of Seedri farm) could lead to optimal irrigation scheduling management.

Finally, OpIRIS has developed an expert system based on an irrigation scheduling algorithm based on a combined interpretation of real-time readings from different soil and crops indicators and/or weather information.

1.3.4 Work-package 4: OpIRIS system testing on hydroponic exploitations

Task 4.1: Installing the system in the participant exploitations: In the very first project period, WP4 was committed to install the OpIRIS relevant hardware in two Greenhouses in Greece with Roses and Cucumber cultivations. Equipment consisted of an RTU (remote transmitting unit) which transmits sensors data via GPRS to the OpIRIS server, and a set of sensors that measure climatic and irrigation parameters.

Figure 11. Communication equipment and environmental and irrigation sensors installation in the "Agroktima Kalliantzis" greenhouse.

Figure 12. Communication equipment and environmental and irrigation sensors installation in the "Strogilis" greenhouse.

Task 4.2: Demo performance for hydroponics and **Task 4.3: Analysis of users' feedback for hydroponics:** During the second project period, the Greenhouse sensors data were collected and stored in the data base of the opiris4u.com site. In parallel, the two greenhouses operators followed the OpIRIS irrigation suggestions. Therefore in the second period we observed in daily basis the crops productivity as well as the water, fertilizers consumption and crops health. Based on the data observed and taking into account farmers' feedback, some software and hardware adaptations were made.
The analysis of the results showed that following the OpIRIS irrigation plan the water and fertilizers consumption were significantly lower compared to the conventional practice, without any loss of crop productivity and quality.
Both, performance and users' feedback are reported in deliverables **D4.10 - Report on sensors' performance in hydroponic crops** and **D4.11 - Report on OpIRIS impact on irrigation management in hydroponic crops.**

WP4 Significant results:

To monitor the soil-plant water status on hydroponic exploitations, the OPIRIS system was successfully installed in two trial greenhouse sites (AGROKTIMA and STROGILIS). Table 2 shows an overview of the different pilot sites parameters:

Country	Crop/Variety	Area (ha)	Observation node	Continuously monitored parameters /observation node
Greece (Sikeonas)	Cucumber/Columbia GPS coordination [39º 55´12´´N; 22º 35´27´´E]	0.5	2 nodes, each with a data logger and a GPRS Transmission Unit	-Substrate water content -Debit of the irrigation emitter and drainage system -Solar Radiation -Relative Humidity -Air temperature

Greece (Pirgetos)	Roses/Naranga, Avalance and others GPS coordination [39º 29´13´´N; 22º 12´49´´E]	1.5	2 nodes, each with a data logger and a GPRS Transmission Unit	-Substrate water content -Debit of the irrigation emitter -and drainage system -Solar Radiation -Relative Humidity -Air temperature

Table 2. List of the project's field trials and the parameters to be monitored for evaluating the productivity of water in hydroponic crops.

Conclusions from the first assessment period aimed to insure their appropriate performance and then to characterize the current irrigation water management methodology in use by the farmer, are shown as follows:

- <u>Soil Moisture sensors (DECAGON DEVICES/ P/N EC-5):</u> The decagon sensors showed a satisfactory performance with fast response to any instantaneous water-content variation within the substrate as affected by irrigation events, drainage and root absorption rate.

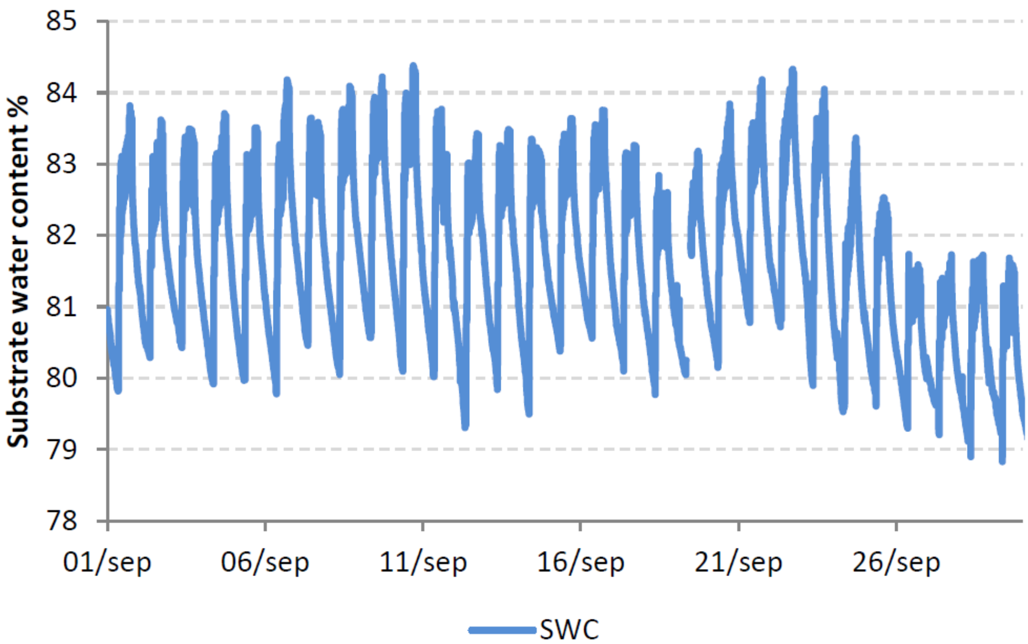


Figure 13. Monthly evolution of the water content within the plant substrate

- <u>Water emission-rate meter:</u> The sensor's outputs are electric pulses automatically converted into ml of water applied/drained during a specific time period (for example x ml/5 min). Then, at the end of every irrigation event, the recorded data series are used to compute the precise duration of every irrigation event, the actual application rate and the total volume of water applied. It is an accurate sensor which helps keeping an eye on the daily performance of the irrigation system.

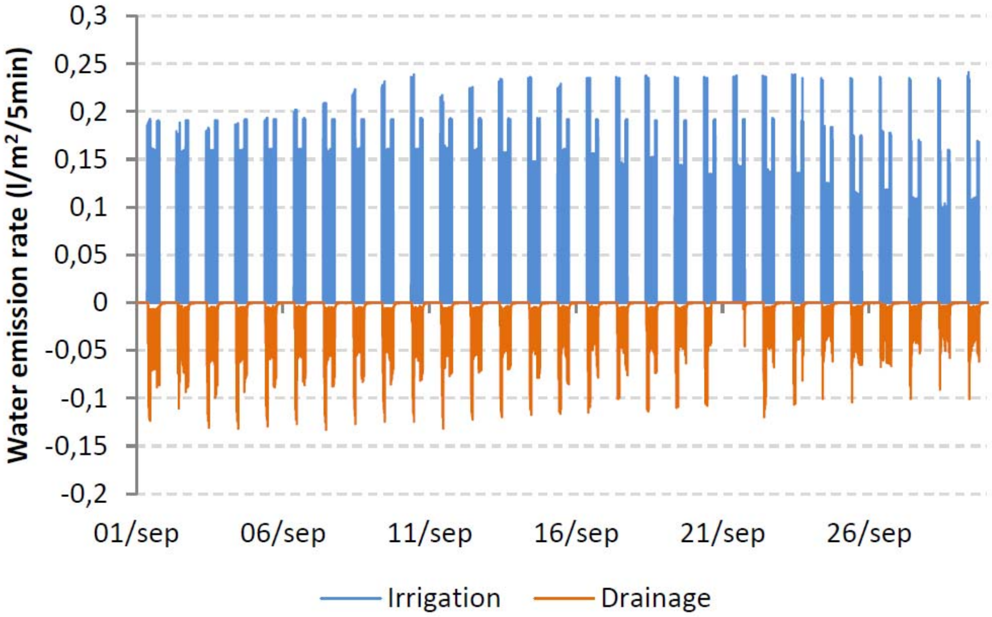


Figure 14. Monthly records of the water emission rates from water drippers and drainage system

- Air temperature and relative humidity: The temperature and the relative humidity sensors performed accurately during the trial period.

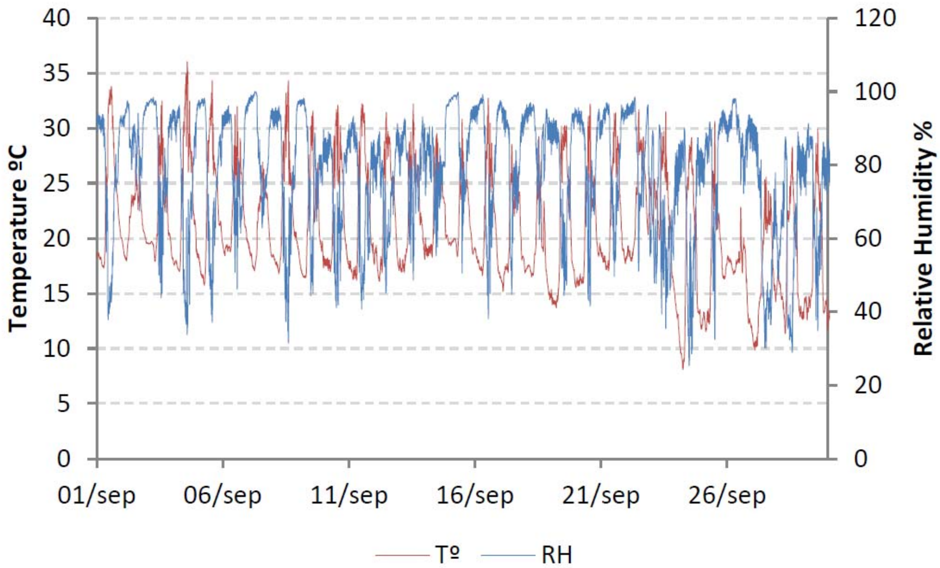


Figure 15. Monthly evolution of the air temperature and relative humidity within the greenhouse

- Solar radiation: The solar radiation sensor performed accurately during the trial period

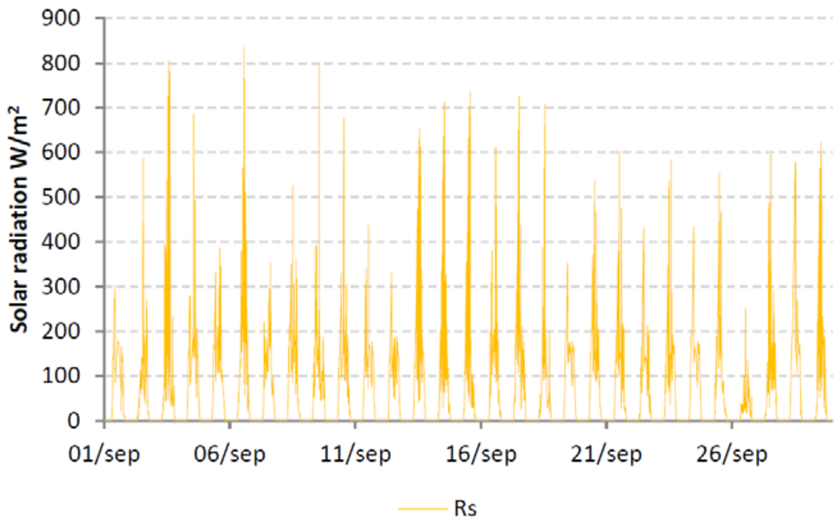


Figure 16. Monthly evolution of the solar radiation within the greenhouse

The performance of the system during the initial, trial period was satisfactory as the accuracy of the collected data was high and their transmission to the servers was constantly successful. The collected measurements were adequate for the proper estimation of optimal amounts of irrigation water consumption and the corresponding amounts of drainage in the hydroponic systems.

The performance of the system was evaluated during the period of the project and the results showed that OpIRIS is fairly accurate in the predictions of nutrient solution consumption and thus can accurately produce the irrigation scheduling program of the next day.

The users (Agroktima Kalliantzi and Strogilis & SIA OE) applied the suggestion of the system but kept a higher rate of drainage than the one set by the researchers of CERTH.

Nevertheless, comparing data observed before and after the application of OpIRIS showed that the use of the system can resulted in about 100% increase of water and fertilisers productivity. Should the users completely follow the suggestions by OpIRIS (as was the case of CSIC Roldan greenhouse) could lead to optimal irrigation scheduling management.

1.4 Impact

Modern agriculture now feeds 6,000 million people. By 2050, global population is projected to be 50% larger than at present and global grain demand is projected to double. Forty per cent of crop production comes from the 16% of agricultural land that is irrigated. Irrigated lands account for a substantial portion of increased yields obtained during the Green Revolution, but still need for an increasing water and nutrients use efficiency. OpIRIS has demonstrated to be a useful irrigation water saving and management tool for the future agriculture on open air fruit trees and vegetables under greenhouse.

Under greenhouse, the use of the OpIRIS system resulted in about 100% increase of water productivity and accordingly of fertilisers productivity, reducing the amount of water applied to 50%. On open air fruit trees OpIRIS system led to the discovery of under irrigated performed by the grower, and help as a useful tool to forecast medium to long term soil salinization risk with the consequent fruit reduction. From other side, OpIRIS recommendations on agricultural practices change rainfed agriculture with irregular soil humidity to irrigated agriculture with uniform soil humidity. Consequently, OpIRIS tool helped the grower to increase the yield from 6 kg/tree to 16 kg/tree (266%).

Both water savings and recommendations for best agriculture management practices (soil salinization, yield reduction, etc…) on open air and greenhouse crops, led into indirect benefits as the reduction of fertilizers leached and consequently reduction of deep water and contaminants percolation to underground aquifer From the knowledge point of view, OpIRIS provide information on the current crop development and growing stages, creating a closer relationship between the farmer and his production system.

1.5 Dissemination and exploitation activities

Since the beginning of the project, OpIRIS members reached thousands of people and disseminated the project through different events as well as printed & online media. We have contacted and introduced OPIRIS project to around 45.518 people. Amongst them, the main stakeholders are economic stakeholders, users, irrigators' community, water utilities, policy makers, scientific community and media channels, who were engaged in the project directly and indirectly during the dissemination actions.

Partners also achieved the main objectives of the dissemination defined in the Dissemination plan which were:

- Showing the role of the EU in supporting R&D in building Europe's future as a competitive and sustainable society.
- Facilitating the market deployment and exploitation of OpIRIS technologies.
- Ensuring a successful spread of information of the project results to all relevant stakeholders and interact with them in order to increase and maintain their interest and awareness of the project.
- Ensuring transparency and visibility of the project activities to acquire the required support from crucial stakeholder.

Finally, the project outcomes will be available in the market, and we will support it via dissemination activities, guaranteeing their sustainability and continuity even after the termination of the EC project.

Dissemination products

- OpIRIS explanatory brochures: OpIRIS explanatory brochures were produced and distributed during the whole project. They were originally written in English and then translated by partners into four languages: French, Greek, Portuguese and Spanish
- OpIRIS posters: Different posters were produced for the dissemination of the project.

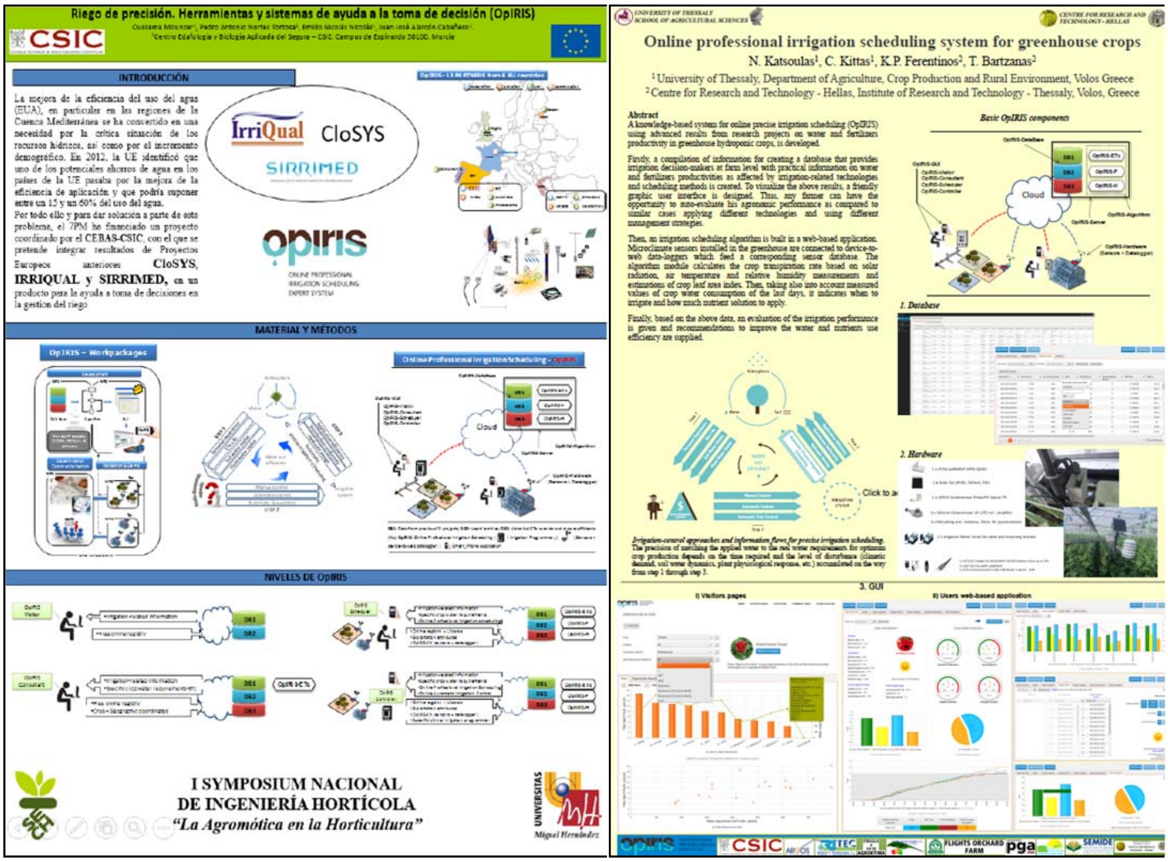


Figure 17. Examples of the different posters that have been prepared

- OPIRIS video: OpIRIS video was created, promoted and uploaded on YouTube showing the main results of OpIRIS service for greenhouses and fruit trees.
- Project website: A general summary of the project, its main objectives, activities, the expected products and services are exposed in an official web page. It is available in three languages (English, Spanish and French) and public deliverables are also accessible. About 4623 users visited our webpage and 5210 sessions were opened between December 2013 and November 2015.

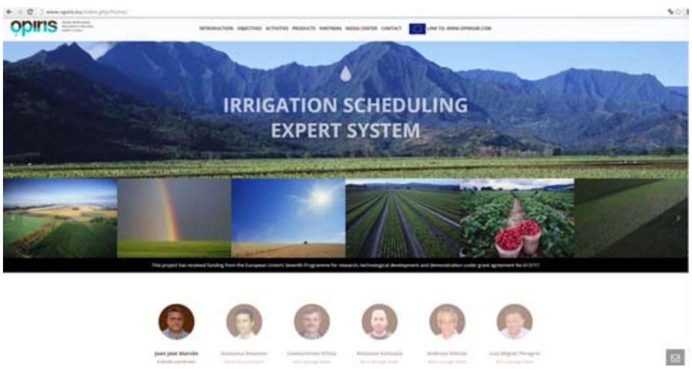


Figure 18. OPIRIS website screenshot

- OpIRIS tool website: it is available in four languages, containing OpIRIS tool demonstration, clients’ websites and dissemination material in the Gallery section.
- Social networks: A dedicated facebook web-page was created for the promotion of OpIRIS project. The link to the page is found on the official website of the project.

There is the possibility to share content and pages by email and through social and professional networks as well as to print it, etc. SEMIDE is in charge of regularly updating this page with contributions from partners.

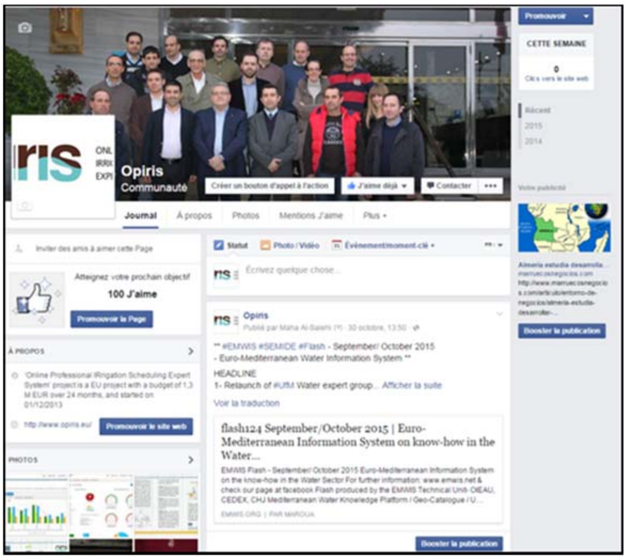


Figure 19. OPIRIS facebook screenshot

<u>Dissemination activities:</u>

- <u>Published articles, press releases and newsletters</u>: different newsletters and press releases have been prepared and distributed:
    - Several announcements in SEMIDE’s and FENACORE newsletter’s newsletters.
    - Publication of the article “L'innovation pour répondre aux défis méditerranéens sur l'eau” in the magazine les nouvelles, no. 25.
    - Publication in the EIP Water newsletter (European Commission) about the OpIRIS tool.
    - o An article in the Journal Agricultura titled “Optimización de Recursos Hídricos de Precisión: Indicadores, Herramientas y Manejo”.
- <u>Organization and participation in events:</u>
    - “2nd Mediterranean Water Forum”.
    - Workshop on “Irrigation Advisory Service”.
    - “2nd National meeting of new growers community”.
    - “Modern technologies, strategies and tools for sustainable irrigation management and governance in Mediterranean agriculture”.
    - “IRLA2014 International Symposium”.
    - Seminars in Puglia for “Irrigation efficiency in greenhouses”.
    - “VIII International symposium on irrigation of horticultural corps”.
    - “V International Symposium on Applications of Modelling as an Innovative Technology in the Horticultural Supply Chain - Model-IT”.
    - “Regional cooperation for innovation on water management in horticulture”.
    - Workshop: “Spanish Irrigators Meeting in Cartagena”. FENACORE annual assembly.

- “Brazilian and Latinoamerican Congress of Agrometeorology – 2015”.
- FAO Meeting.
- EIC General Assembly and with EUWMA annual general assembly (European Union Water Management Association).
- WssTP H2020 Brokerage & WGs Event, SEMIDE.

- Organization of Open days
    - Open Day organized by PGA and VARGAS in Jumilla Murcia. CSIC made a presentation about “Precision irrigation: Concepts and tools” (OpIRIS), in March 2015.
    - Open Day organized by RITEC in Águilas, Murcia. CSIC did a presentation about OpIRIs tool, in March 2015.
    - Open day organized by CERTH and ARGOS in Kalliantzis partner’s Greenhouse in Tempi, in April 2015.
    - Open Day organized by SEEDRI in Estonia, in July 2015.
    - Open Day organized by DONA HORTA in Portugal, in November 2015.
- Promoting the tool at universities and companies
    - Presentation at Alcobaça Farmer’s Cooperative made by Dona Horta in Portugal. The target audience was the farmers.
    - Presentation at the Mexican Centre of Research in Applied Chemistry made by CSIC in February 2014. The target audience was students in agriculture.
    - Presentation at HuangShan University in China made by CSIC in September 2014. The target audience was students in agriculture.
    - Presentation in Chios Island made by ARGOS in February 2015.The target audience was the greenhouse farmers.
    - Presentation at the Agriculture University of Athens done by CERTH and ARGOS in March 2015. The target audiences were professors and students in agriculture sector.
    - Presentation and documentary at AFOI BRATI-Irrigation company- Athens made by ARGOS in September 2015. The target audience was the sales department staff.
    - Presentation in Nea Anchialos Greece made by CERTH and ARGOS in October 2015. The target audience was the greenhouses farmers.
    - Presentation at KSA company-Athens in October 2015 made by ARGOS. The target audience was technicians.
    - Meeting with Prof. Uwe Schmidt team from Biosystems Engineering, Humbolt University in the frame of IKYDA2014 project in November 2015 in Berlin. The target audience was the scientists.

1.6 Contact details

Project acronym: OPIRIS
Project title: Online Professional Irrigation Scheduling Expert System
Grant agreement No.: 613717
Project start: 1st December 2013
Project end: 30th November 2015
Website: http://www.opiris.eu/
Project coordinator: Mr. Juan José Alarcón (AGENCIA ESTATAL CONSEJO SUPERIOR DE INVESTIGACIONES CIENTIFICAS)
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