SIXTH FRAMEWORK PROGRAMME
FP6-2005-Global-4, Priority II.3.5
Water in Agriculture: New systems and technologies for irrigation and drainage

Farm Level Optimal Water management: Assistant for Irrigation under Deficit

Publishable Final Activity Report

Date: 17/8/2010
Revision: Final
Dissemination level: Public
Project coordinator: J. Balendonck

Project coordinator organisation name:
Praktijkonderzoek Plant en Omgeving BV
P.O. Box 16, 6700 AA Wageningen, the Netherlands
Tel. +31(0)317-483279 ; jos.balendonck@wur.nl; www.flow-aid.eu

Period: Oct 1st, 2006 – Dec 31st, 2009
Start date of project: Oct 1st, 2006 Duration: 39 months

Contract no.: 036958

Project co-funded by the European Commission within the
Sixth Framework Programme (2002-2006)

SUMMARY

FLOW-AID is a 6th Framework European project which started in autumn 2006. Its objective is to contribute to sustainability of irrigated agriculture by developing, testing in relevant conditions, and then optimizing an irrigation management system that can be used at farm level. The system will be used in situations where there is a limited water supply and water quality. The project integrates innovative sensor technologies into a decision support system for irrigation management, taking into consideration relevant factors in a number of Mediterranean countries. Its specific objectives are to develop and test new and innovative, but simple and affordable, technical hardware and software concepts for irrigation under deficit, at farms in a large variety of set-ups and constraints. It focuses on a maintenance free tensiometer; wireless, low-power sensor networks; an expert system to assist farm zoning and crop planning, in view of expected water availability, amount and quality; and a short-term irrigation scheduling module that allocates available water among several plots and schedules irrigation for each one. The developed concepts will be evaluated in four test-sites, located in Italy, Turkey, Lebanon and Jordan, where the large future market for deficit irrigation systems will be. The test-sites are chosen in such a way that they differ in the type of constraints, irrigation structures, crop types, local water supplies, availability of water and water sources in amount and quality, the local goals, and their complexity.

OBJECTIVES

The general objective of this project is to contribute to sustainability of irrigated agriculture by developing, testing in relevant conditions, and fine-tuning through feed-back, an irrigation management system that can be used at farm level in those situations where there is a limited water supply and water quality. The system can also serve as an assistant for communication with higher level water management systems at basin scale for long and short term water use planning and prediction. This project integrates innovative sensor technologies into a decision support system for irrigation management, taking into consideration relevant factors in a number of third country partners. The involvement of SME`s in the development ensures a fast application of the results.

CONTRACTORS

Participant organisation name	Short name	Country
Wageningen University & Research Center Plant Research International	PRI	NL
Rothamsted Research	RRES	UK
Lebanese Agricultural Research Institute Department of Irrigation and Agro-Meteorology	LARI	LB
University of Castilla La Mancha Regional Center of Water Research	UCLM	ES
Ege University Faculty of Agriculture Dept. of Agric. Structure and Irrigation	EUFA	TR
University of Pisa Dipartimento di Biologia delle Piante Agrarie	UNIPI	IT
Delta-T Devices Ltd.	DELTA T	UK
Geomations S.A.	GEOMATIONS	GR
Spagnol Srl	SPAGNOL	IT
Jordan University of Science and Technology	JUST	JO
Wageningen University & Research Center Applied Plant Research	PPO	NL

CO-ORDINATOR CONTACT DETAILS

J. Balendonck
Wageningen-UR; Applied Plant Research
P.O. Box 16, 6700 AA Wageningen, the Netherlands
Tel. +31(0)317-483279 ; jos.balendonck@wur.nl; www.flow-aid.eu

EXPECTED RESULTS

The project is expected to yield the following three major results, to be achieved within nine specific work packages.

1. Sensor technology (hardware)

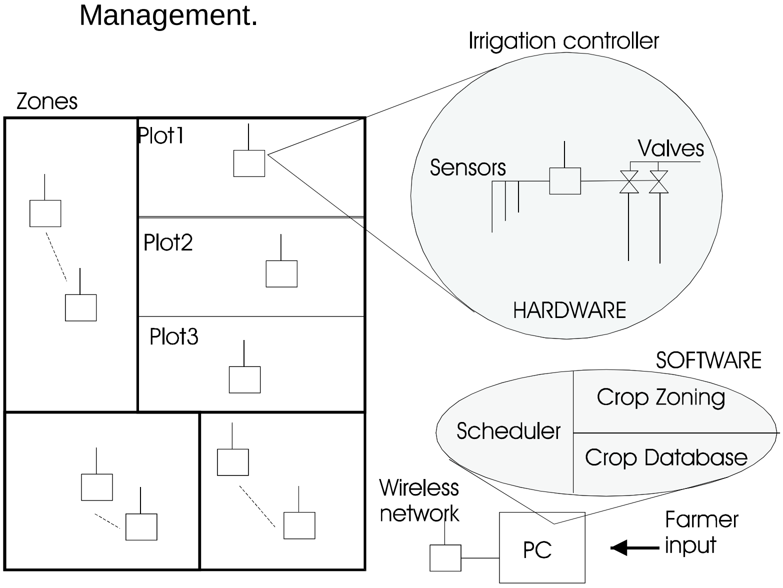
Develop and test new and innovative, but simple and affordable, technical concepts for irrigation under deficit conditions, that can be used at farm level in a large variety of set-ups and constraints, particularly:

WP1: Innovative monitoring tools (a dielectric solid-state tensiometer).
WP2: Wireless, low-power sensor networks.

2. Decision support (software)

Develop a water management decision support system (DSS) that contains:

WP3: An expert system (off-line/long-term) to assist in farm zoning and crop plan, in view of expected water availability (amount and quality), with link to Basin Management.
WP4: A crop response module that can be incorporated into the irrigation scheduler.
WP5: An irrigation scheduling (on-line/short-term) module that allocates available water(s) among several plots and schedules irrigation for each one, with link to Basin Management.



3. Calibrate modules in view of relevant factors

Set-up four test-sites in various market conditions, with different irrigation structures, crop types, local water supplies and constraints. Adapt the general concept of water management to the local situation by using appropriate parts of it, and integrate and test this hard- and software at the test-sites in:

WP6: Pressurized versus surface irrigation (Lebanon);
WP7: Dual water quality irrigation (Jordan);
WP8: Own wells with leaching limitations (Turkey);
WP9: Container crops with limited and dual water supply (Italy).

More Crop per Drop

Technology supports growers to cope with water shortage challenges

Water shortage forces growers to adopt deficit irrigation practices. They tend to irrigate with less water at a lower quality. To avoid crop damages and income losses, they need to manage their water and nutrients more precisely. New technology based tools might help them by making the most optimal operational decisions. The extra income, due to slightly higher yields and use of less fertilizers, might help to invest in these new technologies.

<u>The Problem</u>

Agriculture is the largest user of water, making it a big competitor for domestic and industrial users. To secure our food production for future generations, the irrigation water use efficiency must be increased drastically, in other words: we need “more crop per drop”.
Generally the way to go is to avoid spilling of water, and to ensure that all the irrigation water is being used by the crop. Over-irrigation invokes leaching of water and fertilizers affecting the environment. This can be ensured by optimizing irrigation equipment and irrigation management.

However, in many cases this step is not enough, and currently growers need to adopt a deficit irrigation strategy in which they supply water under the advised FAO amount or even use non-fresh water resources. Crop yield is closely related to water and fertilizer use. Limiting water supply or using marginal water resources might result in yield and quality losses. Working under deficit conditions means that the grower needs to operate his water management more precisely to prevent income losses. He cannot longer rely on his common sense, but needs help from technology.

Container grown ornamental plants grown under high saline conditions show crop damages: brown leaves (Italian case study)

<u>Objectives</u>

FLOW-AID contributes to sustainable irrigated agriculture by developing a deficit irrigation management system for farm-level crop production in cases with limited water supply and marginal water quality. It integrates innovative sensor technologies into a decision support system, taking into consideration boundary conditions and constraints for a number of practical growing systems in the Mediterranean. It focuses on innovative, simple and affordable, hard- and software concepts; particularly a maintenance free tensiometer, a wireless and low-power sensor network; an expert system for farm zoning and crop planning in view of expected water availability and quality; and an irrigation scheduler for allocation of multiple water sources. The system is being evaluated at five sites located in Italy, Turkey, Lebanon, Jordan and the Netherlands, which differ in the type of local constraints, irrigation structures, crop types, local water supplies, availability of water and water sources in amount and quality, the local goals, and their complexity.

Methodology

The FLOW-AID system consists of irrigation controllers, distributed over the irrigated farm zones. They are connected via a wireless link to a local computer that regularly reads out sensor data and updates the scheduling programs running autonomously in the controllers. A Decision Support System containing an expert system with "best practice irrigation rules", running either on the local or remote (connected via internet) computer helps growers to optimise their scheduler programs in view of the expected water availability and climatic conditions on a long-term as well as short-term basis. During three growing seasons, the system components are mainly being evaluated at Mediterranean test-sites. Over the years, the system is enhanced and the final system was shown to farmers during the 3rd year at the test-sites. The FLOW-AID system is being developed through a close partnership between research institutes, universities and SME's.

Intensified use of technology in the field (Lebanese case study)

Results

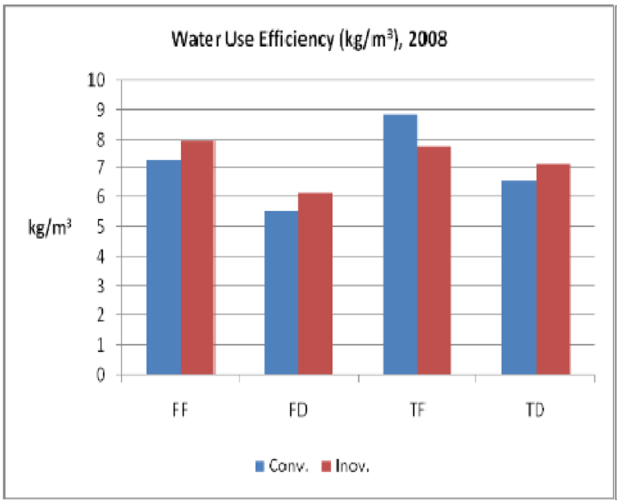
Industry and SME's may take up the following research results to build new hardware and software for deficit irrigation systems:

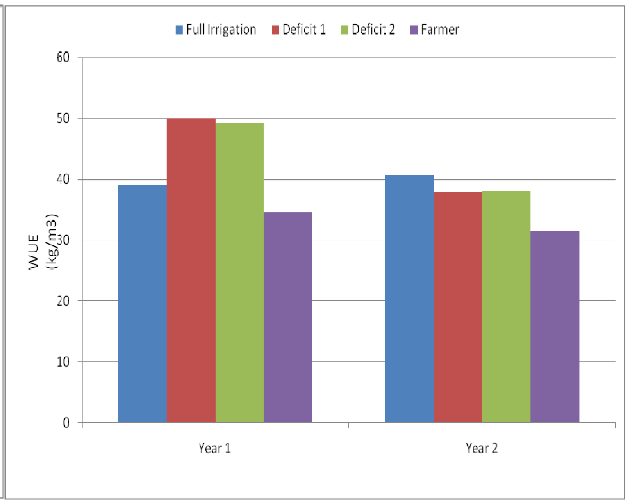
1. Low-cost sensor and controller technology: a solid-state tensiometer; a wireless, low-power sensor network for soil moisture and EC sensors; an irrigation controller for optimal irrigation scheduling.
2. A Decision Support (Expert) System to assist in farm zoning and crop planning, in view of expected water availability (amount and quality); a crop response model for deficit irrigation; and a deficit irrigation scheduling module that allocates available water(s) among several plots.

The SME partners involvement already ensures that the results will be implemented in a short time into adequate and appropriate products for the end-user irrigation market. The participation of the Mediterranean test-sites ensures that the final products will also be fine-tuned to the [economic and physical] conditions of non-European markets, where the largest growth for irrigation equipment is expected.

Case studies have shown that compared to current practices, by using innovative technologies, the water use efficiency can be raised up to 10% while maintaining the existing crop yields.

Application of new technologies cost money. Some case studies have shown that by using technology and adapting strategies one could even raise the productivity up to 10%, while the amounts of water and nutrients being used where less than current practices. By using treated waste water resources farmers could benefit from the already available nutrients in these water sources. Farmers might use this extra income for investing in new technologies.





Result of the Jordan case study (left) in which conventional and innovative irrigation practices are compared under standard and deficit regimes. It was shown that when using fresh water sources the water use efficiency can easily be raised with 10%. When using marginal water resources (treated waste water), irrigation management is more complex, but one can make use of the extra nutrients in the water source. Result of the Turkey case study (right) show that innovative irrigation practices, whether with full irrigation or under deficit, give a better (10-40%) water use efficiency compared to farmer practice.

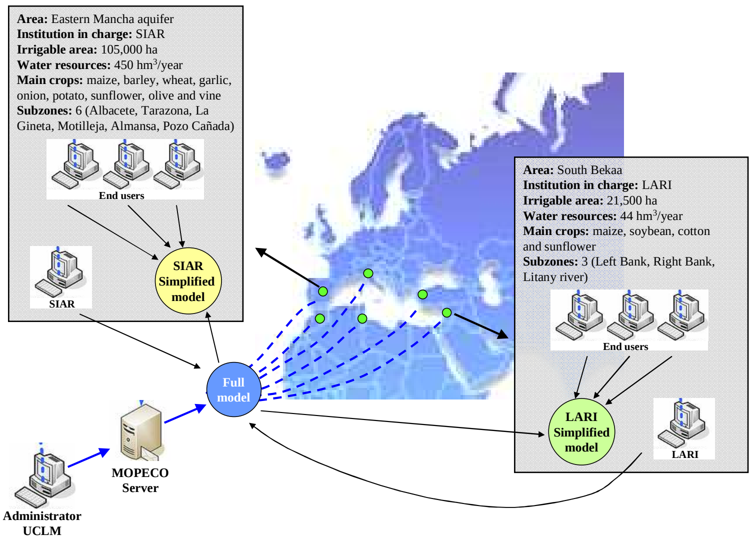
RESULTS ACHIEVED (1st year)

WP1: Dielectric Tensiometer. Prototypes of dielectric tensiometer sensors have been produced and tested both in the lab and in a greenhouse (cucumber) at the Turkey test site (Izmir). Good results have been achieved with a sensor prototype produced that is able to measure soil tension over a measurement range far

wider than achieved with a water-filled tensiometer (typically 0 to -85kPa). Field data showed, in an irrigation environment, that the soil conditions at the Turkey test site regularly exceeded the measurement range of a water-filled tensiometer, with the water-filled tensiometers requiring maintenance. The dielectric tensiometer prototype sensors exhibited no such issues.

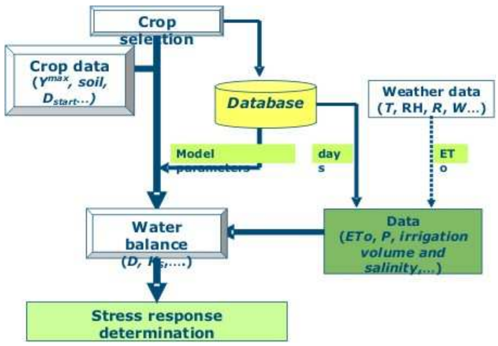
WP2: Wireless Sensor Network.

A literature review and product search on wireless sensor networks (WSN) with special attention to communication protocols, network topologies and reliability has been carried out by PRI. The Flow-aid system requirements and specifications for a WSN have been outlined. A WSN with 8 nodes and equipped with soil moisture sensors (SM200, Delta-T Devices) was built, installed and tested for 5 months in a container crop field trial in Pistioa (Italy), in collaboration with UNIPI. Remote access to the WSN using internet worked very stable and data transport from Italy to the Netherlands for further analysis worked fluently. The battery lifetime of the sensor nodes was adequate, but the defined requirement of a maximum of 5% data loss could not be fulfilled since to the transmitter/receiver power was preset to a too low power use. Weak points of the overall system, including the packaging, were identified and form the fundamentals of the next generation WSN which is currently designed for the next season.

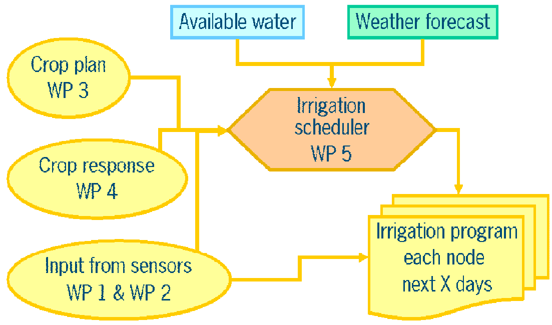


WP3: Crop planning and farm zoning tool. This year UCLM worked on improving the previous MOPECO version (Economic optimization model of irrigation management), in order to adapt it to the requirements of Flow-Aid. This MOPECO-FLOW model, which has been programmed with friendly software design through C++, uses a new optimizer methodology for selecting the distribution of crops that maximizes the Gross Margin of the farm. In addition, it includes a new module to asses the risk related to climatic variations or harvest sale price. In the same way, the model incorporates a

procedure to optimize regulated irrigation in order to maximize the Gross Margin of each crop. This model is valid for a wider range of scenarios, and currently it is enhanced by incorporating a module of salinity and another one to determine the daily progression of LAI and Biomass. It has been used to study the Agricultural System Eastern Mancha (Albacete, Spain). Currently the Lebanese test-site is collecting all compulsory data for the model (climatic data series and variable costs of each selected crop), to make it possible to utilize the model for the Lebanese test-site. The new tool can be very useful for improving the income of any irrigated farms of the world. For using it, the user must introduce a set of compulsory data related with his farm, which can be uploaded via the internet (web-based tool).



WP4: Crop response model. UNIPI defined a crop response model and started to gather for all relevant crops model parameters. An experiment was conducted in spring by UNIPI to investigate the response of greenhouse tomato to the degree of salinity oscillation of the recycling nutrient solution in semi-closed systems. The degree of EC variation up to 5.0 dS/m did not affect fruit yield and quality, which was more dependent on the average salinity level in the root zone. Therefore, the choice of the procedure for managing fertigation in semi-closed systems must consider the operational (labour for the renewal of recycling nutrient solution) and environmental implications (water and nutrient runoff).



WP5: Irrigation scheduler DSS. PRI, together with Geomations and UNIPI, has achieved to describe the FLOW-AID system in a more detailed way. Next, the objectives of this work package were redefined and detailed into achievable targets, and a workable methodology was defined. The specific objectives of WP5 for the 1st year of the project can be described as follows:

1. Define the structure of the scheduler in terms of a. knowledge use and b. interfacing with the other modules of the system.
2. Have a prototype of the (web-based) data-base functioning.
3. Use the results of the 1st irrigation tests of the sites to evaluate the feasibility of various [model based] indicators, to supplement the reading of the root-zone sensors within the DSS, in terms of improved water use efficiency or decreased environmental impact.

The first two objectives have been achieved and the analysis of the results of the test-sites is in progress.

WP6: Pressurized versus surface irrigation. LARI defined the experiments. However, due to the local political and economical situation in Lebanon, LARI was not able to set-up the experimental test-site as planned in the experimental farm in the Bekaa valley. Instead, a smaller irrigation experiment with potato at the Tal Amara Station, and benchmarking activities for 30 growers were performed. The planned irrigation nodes from DeltaT will be installed next year, and the full field test at LARI is postponed until the 2nd growing season. The acquired data was made available for PRI to define the irrigation management strategy for the next growing season. Data from previous experiments on three crops (maize, potato and sunflower) will be made available to UCLM for evaluating the Crop Planning module.

WP7: Dual water quality irrigation. Two field experiments on tomato were conducted at JUST in the summer of 2007. Each experiment had four treatments, combined from either “full irrigation” or “deficit irrigation” and “potable water” or “treated water”. The irrigation nodes from Delta-T were installed to control and optimize the irrigation as well as for testing innovative technologies under field conditions and local circumstances in the Jordan test site. The test site was set up and all devices were installed and tested during the growing season. Due to the late availability of all instruments, the field experiment was conducted in the summer time, which is not the appropriate time for the tomato growing season. The acquired data was made available for PRI to define the irrigation management strategy for the next growing season. During the growing season, local farmers, advisors and governmental agencies were invited at the test-site and the equipment was demonstrated.

WP8: Own wells with leaching limitations. The first step was to build the site (cucumber experiment in a greenhouse) in close co-operation with the SME’s and RRES. DELTA-T installed GP1 controllers that can accommodate the sensors and SPAGNOL supplied fertigation equipment. Also first prototypes of the dielectric tensiometers were installed (RRES). Different irrigation programs based on soil moisture levels were tested. Two

deficit irrigation treatments in which soil water content was allowed to be depleted to 40 and 60% of available water content of the plant root zone respectively were compared with full irrigation and farmer's practice as well. Representative plants were grown in containers in order to measure the drained water, and yield and quality of the cucumber crop was studied. The highest yield was obtained from the full irrigation treatment. The lowest yield was obtained from the plants that received the lowest amount of water (deficit 1 program). The acquired data was made available for PRI to define the irrigation management strategy for the next growing season. Results of the field experiment showed that the variations of soil moisture in the plant root zone in farmer's treatment was higher than the treatments controlled by the GP1 controller and sensors. Therefore, it seems that the use of new technology can be easily adapted to the farmer conditions. The environmental impact due to the excess use of water and fertilizers could be decreased with the proper programs including deficit irrigation. Additionally, during the growing season, local farmers, Agric. Engineers, Officials of Min. of Agric. & Municipality, were invited at the test-site and the equipment was demonstrated.

WP9: Container crops with limited and dual water supply. Most of the experimental work for this work package was conducted at the Centro Sperimentale per il Vivaismo (CESPEVI) in Pistoia (Italy), along with some short-term studies at UNIPI on irrigation control strategies (f. i. zero-runoff irrigation). A series of experiments were conducted with WET sensors provided by PRI to calibrate them for the typical substrates used in greenhouses and nurseries for pot plants and to identify the main difficulties for the operational point of view.

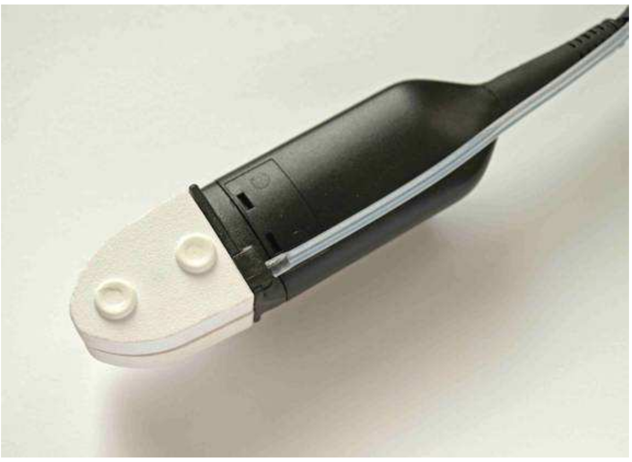
Two experimental nurseries were installed both at UNIPI (Pisa) and at CESPEVI (Pistoia). A customer-made fertigation unit was set up in Pisa, while a commercial device manufactured by SPAGNOL was mounted in Pistoia, and at present the two nurseries work correctly and seem adequate for the planned activities.

The experiment was conducted on four ornamental species (*Photinia x fraseri*, *Viburnum tinus*, *Prunus laurocerasus* and *Forsithia intermedia*) to test the performance of a root zone sensor

based control of irrigation as compared to the conventional "timer" approach; and to model the seasonal changes in lead area index and crop coefficient for the selected species. More specifically, it was assessed the inter-pot variability in terms of: daily water balance; EC and pH of drainage water; nutrient leaching; plant growth by means of non-destructive or destructive measurements. The experiment was concluded at the end of October 2007. On the basis of a rough analysis of available data the following conclusions can be drawn: i) irrigation strategies did not affect plant transpiration (ET) and influenced only slightly dry matter accumulation and LAI evolution; ii) the reduction of the overall water application and of the average drain fraction in tensiometer-controlled irrigation treatment was the result of a reduction in the frequency of watering; iii) huge differences in plant daily water demand were observed as a consequence of both inter- and intra-specific variability in ET, the former resulting from different plant size (LAI) and habitus; *Forsithia* was the most water consuming species with an average daily ET over the growing seasons more two times higher than Viburnum;iv) the variability coefficient for the mean daily ET values calculated for each species was as high as 60% and averaged 19%. Figure: The effect of saline water (left) compared to clean water (right).

RESULTS ACHIEVED (2nd year)

WP1- Dielectric Tensiometer



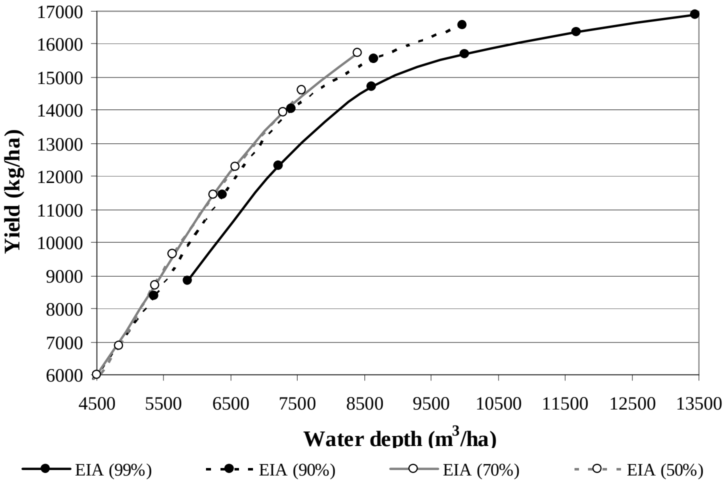
Prototypes of dielectric tensiometer sensors (Delta-T) have been produced and tested both in the lab and in a greenhouse (cucumber) at the Turkey test site (Izmir). Good results have been achieved with a sensor prototype produced that is able to measure soil tension over the nominal range -3kPa to -250kPa, a measurement range far wider than achieved with a water-filled tensiometer (typically 0 to -85kPa). Field data showed, in an irrigation environment, that the soil conditions at the Turkey test site regularly exceeded the measurement range of a water-filled tensiometer, with the water-filled tensiometers requiring maintenance. The dielectric tensiometer prototype sensors exhibited no such issues. For the next year a large number of sensors will be produced and these will be further tested in test-sites in Turkey, Italy and the Netherlands.

WP2: Wireless Sensor Network

Based upon experience of the 1st year experiment the 8 Wireless Sensor Nodes (Mesh-Star network, SOWNET) with soil moisture sensors were modified to have a higher signal strength and a more robust housing. Another set with a solar power system (Mesh-type) WSN was obtained from Crossbow Systems and equipped with Watermark sensors. Both systems were tested for functionality and next installed for practical evaluation at the Pistoia test-site in Italy. The operation was monitored remotely from the Netherlands using an internet link. Preliminary results showed that the Crossbow system had a larger working range and worked to a nearly 100% satisfaction, and was far favorable above the SOWNET system. Next year this system will be used and it will be adapted to accommodate a combined soil moisture and EC sensor.

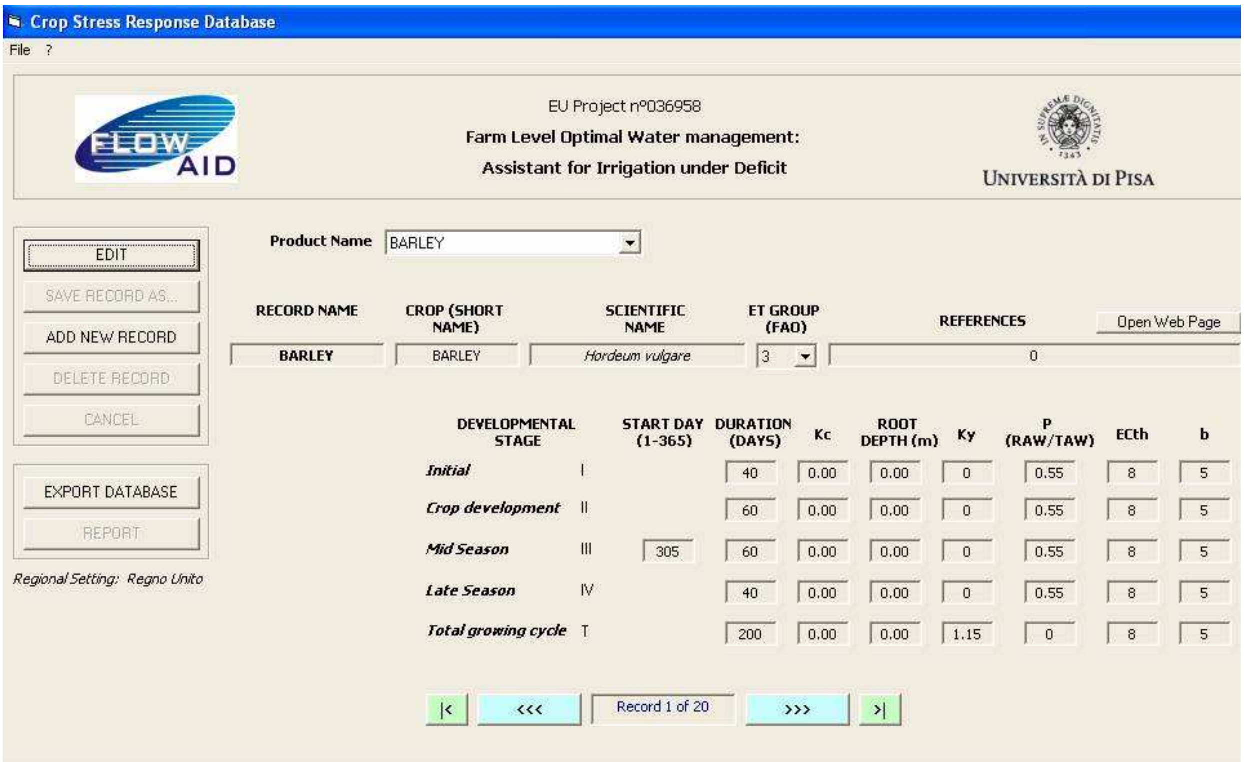
WP3: Crop planning and farm zoning tool

The first version of the web-based tool of MOPECO-FLOW was developed. Two new modules were added ensuring a wider range of scenarios that can be simulated. Now the model can simulate effects on water use and crop yield due to non-uniformity of the irrigation systems as well as the use of salt irrigation water. The model was developed and tested, based upon data obtained from the Mancha Oriental region in Spain. This year no practical data could be obtained from the Lebanese test-site. Alternatively, the functionality of the model was further improved through an end-user β-test performed at the Research Institute for Knowledge Systems (RIKS) in the Netherlands. The new model will be tested and validated next year using practical data from the Jordan test-site.



WP4: Crop response model

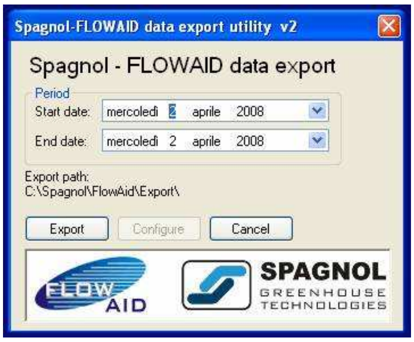
A draft version of the database (EXCEL based) was presented before the growing season. Based upon this, a first version executable database was developed using Microsoft Visual Basic with ActiveX Objects. The crop response database now contains quantitative information on the response to water and/or salinity stress for 20 selected crops. A user may retrieve, edit, extend and export data from the database with the new program. Next year the database will be calibrated and extended with additional information on the basis of the field tests and finalizing the reference manual and the final version of the database.

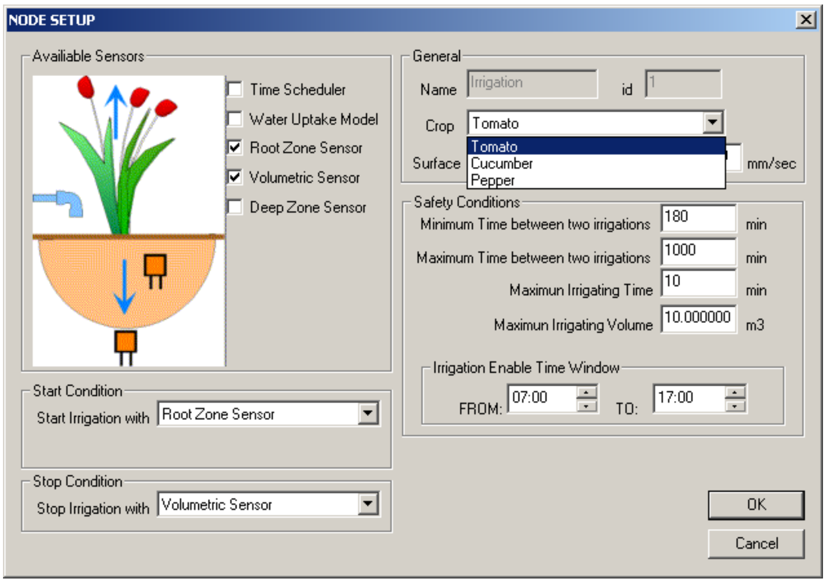


DEVELOPMENTAL STAGE		START DAY (1-365)	DURATION (DAYS)	Kc	ROOT DEPTH (m)	Ky	P (RAW/TAW)	ECth	b
Initial	I		40	0.00	0.00	0	0.55	8	5
Crop development	II		60	0.00	0.00	0	0.55	8	5
Mid Season	III	305	60	0.00	0.00	0	0.55	8	5
Late Season	IV		40	0.00	0.00	0	0.55	8	5
Total growing cycle	T		200	0.00	0.00	1.15	0	8	5

WP5: Irrigation scheduler DSS

A central database, accessible through internet, has been established. This database, hosting actual and local measured soil and climate data, is up and running and has been successfully used by all partners using a "Data Upload Facility".





For the Irrigation Scheduler, which will run either remotely on a central computer or locally at the farmer-site, a common Glossary and Ontology has been prepared as reference for all partners. An off-line version of the scheduler is ready and was demonstrated at the 2nd annual meeting by Geomations. An instruction manual is being circulated among the partners for comments. Early next year, and based upon the results from the 2nd year experiments at the test-sites, an "Irrigation Knowledge Database" containing "Best Practice Rules for Deficit Irrigation" will be made. This database will then be incorporated into the final version FLOW-AID Irrigation Scheduler DSS.

WP6: Pressurized versus surface irrigation

During the 2008 growing season a test was performed with two irrigation controllers and soil water content sensors (GP1 and SM200, Delta-T Devices) in a greenhouse using micro-sprayers for pot-grown ornamental plants in the winter season, and with field-grown egg-plants using drip-irrigation in the summer season. The tests showed a "proof of concept" and viability of a low-cost simplified automated irrigation system. The next year a calibration of this irrigation controller concept will be performed again in a greenhouse and in a field-trial on other drip-irrigated vegetable crops. The DSS-irrigation scheduler will be tested in full with drip-irrigated lettuce under rain-fed as well as simulated semi-arid conditions in a field experiment conducted in the Netherlands.

WP7: Dual water quality irrigation

Two field experiments with a drip-irrigated tomato crop were conducted at the Jordan test-site in spring/summer 2008. In each experiment four treatments with four replicas were performed by making combinations from “fresh or treated water” and “full or deficit irrigation”. Soil moisture status (WET-sensor), climate conditions as well as all relevant crop parameters were monitored (yield). The treatments were controlled by using the sensor activated (SM200) irrigation controllers (GP1). A reasonable effect was observed for both full versus deficit irrigation strategies as well as fresh versus treated water on plant growth development and yield productivity. It showed that using innovative technology to control irrigation scheduling resulted in higher Water Use Efficiency (WUE) for most of the treatments evaluated. Some sensor inconsistencies were observed. The WET-sensors performed well in comparison with the Neutron Probe, which encourages the further use of these sensors. Next year the experiment will be repeated to evaluate it together with the DSS-irrigation scheduler and to obtain further best practice rules for irrigation under local conditions.

WP8: Own wells with leaching limitations

In a polyethylene greenhouse with cucumber, two irrigation experiments were conducted in spring/summer at a farmer site in Yeniköy-Menderes near Izmir (Turkey). The main goal was to prevent leaching and reduce the use of water. The greenhouse was equipped with fertigation equipment (Spagnol), and irrigation controllers (GP1, Delta-T), as well as the new dielectric tensiometers (SM160) and other soil moisture sensors. Three treatments: one “Full” (20% depletion) and two “Deficit” (40 and 60% depletion) were compared with standard farmer practice, by monitoring water consumption and crop yield and quality in first experiment. The highest yield was obtained from the Full irrigation treatment whereas it was the lowest in Farmer’s treatment. Irrigation management was performed by SM160 sensors during the second experiment. Same experimental design were realized with the same equipment. It showed that the farmer treatment had the highest crop yield in second experiment, but he used the largest amount of water of which a large portion drained to deeper layers. The automated controlled treatments showed higher water use efficiencies with slightly smaller crop yields. It seems that excess use of water and fertilizers and their possible environmental impact by leaching can be easily decreased by the use of sensor activated irrigation technologies. Next year the experiment will be repeated to evaluate it together with the DSS-irrigation scheduler and to obtain further best practice rules for irrigation under local conditions.

WP9: Container crops with limited and dual water supply

Analyses of data from the first year experiment at Cespevi (Pistoia, Italy) was concluded including a simulation of water use efficiency of container cultivations irrigated with a timer, a crop ET model or with soil moisture sensors. During summer an irrigation/fertigation experiment was conducted with the use of two water sources: ground water with low salinity and waste water with high salinity. WET-sensors, placed in sentinel pots (Prunus), were used to control soil moisture as well as EC, by applying a “stress index” based control strategy which was implemented by Spagnol. It showed that the sensor-activated controller fairly well maintained a given salinity level in the pots, and reduced the water consumption while using the dual water source. Although the overall system worked well, one treatment received markedly less water due to a bad working sensor/sentinel pot. Visual observations of plant heights suggest that the use of saline water could reduce plant growth in some species. During summertime more than 50 growers and consultants attended an Open Day at the test-site. Next year the experiment will be repeated to evaluate it together with the DSS-irrigation scheduler and to obtain further best practice rules for irrigation under local conditions.

INTENTIONS FOR USE AND IMPACT

The central role of the SME’s will ensure that the most promising and relevant project results will find a fast way to the irrigation market. The participation of Mediterranean Partner Countries (where most field tests will be located) ensures that the final products will be fine-tuned to the [economic and physical] conditions of non European markets, where the largest growth in irrigation requirement is expected. SPAGNOL will focus on the off-line DSS system for their fertigation unit, using crop models, irrigation scheduling and new sensor technologies. Their software will be available to mostly horticulture growers (greenhouses and container crops). DELTA-T Devices will focus on the global market for hardware and the irrigation scheduling programs (irrigation nodes) including new sensors, wireless interfacing, and will use the results from all three test sites in Turkey, Lebanon and Jordan. GEOMATIONS will develop the FLOW-AID overall software system including the irrigation DSS, interfacing with several hardware platform through an open interfacing structure, an internet facility for remote data uploading and reporting as well as the Crop Planning module. They will incorporate these tools into their irrigation and management software for the horticultural market, especially in the Mediterranean but as well on a global market. The developers of hardware and software will make sure to take actions for protecting their rights (IPR actions) and for contract agreements to ensure further industrialization and commercialization of the developments of the project, as agreed upon with in the management board.

FINAL ACHIEVEMENTS (3rd YEAR)

Reprint from paper published: FLOW-AID, a Deficit Irrigation Management System using Soil Sensor Activated Control: Preliminary Results of 5 Case Studies

Reference: Balendonck, J.; A. Pardossi, H. Tuzel, Y. Tuzel, M. Rusan, F. Karam, D. Jenkins. FLOW-AID, a deficit irrigation management system using sensor activated control: results of five case studies. Third International Symposium on Soil Water Measurement Using Capacitance, Impedance and TDT, Murcia, Spain, April, 7–9, 2010.

J. Balendonck[1*], A. Pardossi[2], H. Tuzel[3], Y. Tuzel[4], M. Rusan[5], F. Karam[6]

[1] Greenhouse Horticulture, Wageningen University and Research Centre, Wageningen, the Netherlands
[2] Dept. of Biology of Crop Plants, University of Pisa, Pisa, Italy
[3] Dept. of Agriculture Structure and Irrigation, Ege University Faculty of Agric., Bornova-Izmir, Turkey
[4] Dept. of Horticulture, Ege University Faculty of Agriculture, Bornova-Izmir, Turkey
[5] Faculty of Agriculture, Jordan University of Science and Technology, Irbid, Jordan
[6] Dept. of Irrigation and Agro-Meteorology, Lebanese Agric. Research Institute, Tal Amara - Zahle, Lebanon

Abstract

The FLOW-AID concept is a deficit irrigation management system that can be used at the farm level, when there is a limited water supply, poor water quality or when leaching is prohibited. It consists of a network of in-field irrigation controllers equipped with soil sensors, all connected via a wireless link to the farmer's computer. Further, a decision support system (DSS) that helps farmers to choose an appropriate irrigation scheduling strategy in view of the amount and quality of available irrigation water, plant status, weather data and local constraints. The irrigation scheduling strategies, including sensor thresholds, can be programmed into the remote irrigation controllers. The concept was implemented and evaluated for high value vegetable or ornamental crops in five case studies located in Italy, Turkey, Lebanon, Jordan and the Netherlands. These cases differed in local goals and constraints like the irrigation infrastructure and the availability and quality of irrigation water. This paper describes the concept and the preliminary experimental results obtained during three growing seasons in 2007-2009. It was concluded that sensor-activated deficit irrigation scheduling may largely enhance water use efficiency and save from 16% up to 69% of water, compared to common grower practices. Leaching can be reduced, or even be prevented. A good marketable crop quality can be obtained when applying moderate deficit regimes. Acceptable marketable yields can be obtained at higher depletion values or while using poor-quality irrigation. However, the applied deficit depth must be chosen very carefully, and an optimized fertigation strategy is a prerequisite to maintain sustainability. The irrigation controllers, the wireless system and the DSS worked well, but to ensure a fail-safe operation, it must be extended with an automatic fault and error detection and warning system.

Introduction

Fresh water (FW) sources are becoming scarce, and since agriculture is the largest water user, it is the main competitor for domestic and industrial water users. Therefore, farmers try to avoid spilling of water and ensure that all available irrigation water is being used by the crop. To

[*] Corresponding author: jos.balendonck@wur.nl

compare cropping system efficiencies, Water Use Efficiency (WUE) defined as the dry matter production per water loss (g/kg) is being used an index. To raise WUE, and to achieve “more crop per drop”, growers may implement fairly simple changes to their irrigation equipment and cropping system. For instance, to avoid leakage and evaporation, closed pipes instead of open channels; to enhance water application, drip instead of furrow or sprinkler irrigation; to avoid evaporation losses, a soil-coverage could be used. To further improve WUE, and after optimizing the irrigation and cropping system, growers can match water supply with actual crop water demand. A common approach for this is to estimate daily crop water demand by using a water balance model like e.g. the Penman–Monteith equation (PMe) (Allen et al., 1999), or derivates such as the CIMIS (California Irrigation Management Information System) equation proposed by Pruitt and Doorenbos (1977). Besides climatic data, these models require input for crop and phenological stage dependent parameters like the crop coefficient (K_c), as can be obtained from a FAO database (Allen et al., 1999). Though less used by growers, another method based upon an estimate of the crop available water in the root zone, is soil moisture sensor (SMS)-activated irrigation scheduling (IS) (Meron, 2001 and Pardossi et al., 2009b).
Growers not having access to sufficient FW resources can not use this water saving approach. To secure crop production, their WUE must be increased even further and they need to adopt a deficit irrigation (DI) practice (FAO, 2000 and 2002). They need to use higher values for the Management Allowable Depletion (MAD) factor, and apply lesser water or additionally use non-FW resources like saline, treated or reclaimed wastewater (RW). Geerts and Raes (2009) state that DI is successful in increasing water productivity for various crops without causing severe yield reductions. However, limiting water supply or using marginal water resources, easily can have negative effects on crop yield and quality. To prevent income losses, growers using DI must be very careful with water and fertilizer management. They need tools informing them about crop health, soil water availability, water quality and the climatic conditions, and helping them to make sound decisions about water and fertilizer doses, water source and irrigation timing. In this paper we present a generic concept – called FLOW-AID[†] – of a farm-level DI system based upon a distributed control concept for SMS-activated IS and the allocation of multiple quality water sources. For different crops, and with implemented versions of the concept, we will demonstrate the potential to save FW as compared with common grower practices.

Methods and materials

The generic FLOW-AID concept (Fig. 1) consists of irrigation controllers (IC), placed in each individual controllable area (a plot) for all irrigated crops at the farm (zones). IC’s, working continuously and autonomously, regularly read-out SMS’s and based upon a set of irrigation rules and set-points, can initiate irrigation events through opening and closing a valve. They have safe-guard the system by employing a set of safety rules. More sophisticated IC’s might have added complexity like data logging and advanced calculating options, to be able to perform e.g. ET-model based irrigation. They can drive multiple water sources of distinct water qualities through a set op valves. The IC’s are connected via a wireless link to a local (farm) computer (Balendonck et al., 2008). A Decision Support System (DSS) helps growers to optimise their irrigation and fertilizer management in view of their selected crop, cropping system, the expected water availability, climatic conditions as well as crop development on a day-to-day basis (Anastasiou et al., 2009). For this, the DSS incorporates a database of crops and “best practice irrigation strategies” as well as a crop stress model for DI. It further contains an advisory module (Incrocci and Pardossi, 2009) that computes an optimal fertigation recipe based upon cropping stage, deficit depth and water quality. Further, it incorporates a farm zoning and economic crop planning tool which advises growers upon selecting crops giving the largest gross margin under given constraints (Dominguez et al., 2008). The DSS may run either on the same local computer or on a remote host computer located at a service provider (e.g. an advisory service, river basin water management, growers association or a computer/software

[†] FLOW-AID is the acronym for: Farm-Level Optimal Water management, an Assistant for Irrigation under Deficit.

supplier). On a day-to-day basis, but not necessarily strict regularly, growers may check IC performance, crop status and water availability. In addition, they can consult the DSS and, if needed, they may decide upon changing the IS strategy.
During three growing seasons (2007 – 2009), implementations of the concept were evaluated at five case studies in Italy, Turkey, Lebanon, Jordan and the Netherlands, in several trials. Sites differed in constraints like climatic condition, irrigation structure, crop, water supplies, availability and quality of irrigation water and local goals. Each trial was performed as a randomized-block experiment with at least 4 replicates per treatment. The distributed controller network was implemented by using standard irrigation equipment, like WET-sensors and programmable IC's (GP1), both from Delta-T Devices (UK) as shown in Figure 1. More equipment was added as required by the specific case study needs. As a consequence, the systems were all different and covering a wider scale of complexities, especially the way fertigation was handled. In Italy and Turkey a modern fertigation computer (Spagnol Automation, Italy) was used, and in other cases it was done according to common practices. After assembly and installation, a wired or wireless connection (Crossbow-Eko, US) was established with a PC, and the DSS (Geomations S.A., Greece) was set-up to control the IC network.

Case Study: Container-grown landscaping ornamentals in a Mediterranean climate (Italy)

In Tuscany (Italy), the major European region for container-grown ornamentals in outdoor nurseries, growers use drip or sprinkler irrigation, but WUE is low because of over-irrigation (Pardossi et al., 2009b). The quality of available water is getting worse every year, especially along the coast with rising EC levels. In future, probably high saline waste water may be the main source for crop irrigation.
A prototype fertigation controller (Incrocci et al., 2010) was developed making use of a WET-sensor to obtain volumetric water content and electrical conductivity (EC) of the substrate. A dual water source was used with low-salinity groundwater (GW) and saline reclaimed wastewater (RW) and the IS strategy was based upon using as much RW as possible, and using GW only when the EC passed a pre-defined threshold. The water source and fertigation regime were chosen based upon a crop stress index derived from the pore water EC in the substrate. WET-sensors were calibrated for pore water EC for the peat-pumice growing media used in this area as an alternative for the Hilhorst-equation which is defined as:

$$EC_p = \frac{\varepsilon_{water}}{\varepsilon - \varepsilon_{\sigma=0}} EC \quad , \qquad (1)$$

where ε is the measured permittivity, ε_{water} the permittivity for pure water corrected for temperature and $\varepsilon_{\sigma=0,}$ a constant depending on the substrate material (Hilhorst, 2000). The prototype was evaluated at the experimental research station Centro Sperimentale Vivaismo (CeSpeVi) in Pistoia, and the cultivation of different species in the same plot (*Photinia x fraseri, Viburnum tinus, Prunus laurocerasus* and *Forsythia intermedia*) was simulated following an accustomed practice in the Pistoia nurseries (Incrocci et al., 2010, these proceedings). This approach was compared with three IS strategies using only GW: Timer control (standard farmers practice), an ET-model and SMS-activated IS with hydraulic tensiometer (SWT4, Delta-T Devices, UK) or WET-sensor (Pardossi et al., 2009a).

Case Study: Drip-irrigated cucumber grown in greenhouses under a mild-winter climate (Turkey)

The Tahtalı Dam supplies fresh drinking water to Izmir, the third largest city in Turkey. Due to pollution risks, authorities have issued a regulation discouraging leaching into the catchment area of the dam, affecting largely local greenhouse vegetable production, being the major local agricultural activity.
To introduce SMS-activated IS and to define practical recommendations to prevent leaching while keeping acceptable crop yields, five on-farm trials were conducted in a poly-ethylene greenhouse in Yeniköy-Menderes/İzmir (Tuzel et al., 2009) with cucumber (*Cucumis sativa* L.). The cultivar was 'AT 191' in first trial, being suitable for a long crop cycle, and in the remaining

4 trials it was ‘Champion’ because of the short cycle. Fertilizers were applied automatically (Spagnol Automation, Italy) via a pressure compensated drip irrigation system. Besides water use, crop growth, water stress and drain (lysimeter), soil and irrigation conditions were monitored at 15 - 20 and 40 cm depths with WET-sensor, SM200, water-filled-tensiometers, thetaprobes (Delta-T-Devices, UK) and dielectric tensiometers (Whalley, 2009). Three DI strategies (MAD = 20, 40 and 60%) were compared with current farmers practice. IS was based upon a WET-sensor placed (15-20 cm) in the first two trials. In other trials, irrigation started based upon a dielectric tensiometer and stopped at a certain water dose. In the fourth trial this dose was modulated on-the-fly by the DSS.

Case Study: Drip-irrigated tomato in arid climate (Jordan)

Jordan has very limited fresh surface and ground water resources. The demand on water is ever increasing and the average yearly rainfall, of which 94% evaporates, leaves very little addition to available water. The government promotes efficient water use through improvement of water supply management, waste water treatment and water reuse. As a consequence, farmers need to adopt their irrigation practices.
At the Research Centre of Jordan University of Science and Technology in Irbid, two field trials with drip-irrigated tomato (*Solanum Lycopersicum* L.) cultivar ‘Super Red’ were conducted (Rousan et al., 2008). Automatic SMS-activated IS for different water quality and deficit levels using SM200 and WET-sensor (Delta-T devices, UK) were compared with farmer practice using tensiometers and Watermarks (Irrometer, Co. Riverside California). The standard FAO advice (MAD = 40%; Allen et al., 1999) was used as a reference (Full 1 and 2) and compared with a DI strategy (MAD = 60%), while using two water qualities (Deficit 1 and 2): fresh ($EC_{average}$ = 0.8 dS.m^{-1}) and RW ($EC_{average}$ = 2.0 dS.m^{-1}). Soil was prepared according to common growers practice and covered with a black foil after planting to prevent evaporation losses.

Case Study: Drip-irrigated eggplant in semi-arid climate (Lebanon)

The Bekaa Valley is a semi-arid area accounting for about half of the agricultural production in Lebanon. A quarter of the area is used for irrigated agriculture using surface, furrow, basin and flooding techniques (64%), sprinkler irrigation (28%) and drip-irrigation (8%). About 52% of the water comes from deep-well GW sources. Irrigation costs have gone up drastically (energy) and water quality has shown a gradual deterioration. Farmers with an improper farm-level water management need to adopt new water saving techniques.
In summer 2009 (May-September), at the Tal-Amara Research Station, a field trial with drip-irrigated eggplant (*Solanum melongena* L.) cultivar ‘Baladi’, was conducted on a fairly-drained, clay soil with an average bulk density of 1.41 g cm^{-3} in the 90 cm top layer (Chazbeck, 2008; Saliba, 2009). The field capacity (FC) at −0.33 bar and permanent wilting point at −15 bar averaged 29.5% and 16.0% respectively by weight, resulting in a plant available water holding capacity of 170 mm. SMS-activated irrigation was used with GP1 controllers and SM200 sensors (Delta-T-Devices, UK) with a MAD of 30%. As a reference strategy, a well-watered treatment at 100% was used. Three deficit treatments were evaluated at respectively 75%, 50% and 25% of the gross irrigation volume.

Case Study: Drip-irrigated lettuce under rain-fed conditions (The Netherlands)

Water and fertilizers drain very rapidly into the sandy soils found in Limburg, in the south of the Netherlands. Crops suffer rapidly from drought and nutrients leach into the ground water during heavy rain-fall. To reduce nitrate emission, while keeping a high crop quality and yield, growers must apply water and fertilizers more precisely.
In summer 2009 (48 days), an experiment was conducted at the PPO Research Station at Vredepeel evaluating the use of SMS-activated IS, controlled fertigation and drip irrigation. Iceberg lettuce (*Lactuca sativa* L.) was grown on loamy-sandy soil beds covered with black plastic foil preventing infiltration of rain. aim was to prevent leaching by maintaining a constant

water level in the root zone at two depths. Irrigation was triggered with a WET-sensor at 15 cm, and the threshold level and initial dose (3 mm) were set using a MAD = 35%. After well rooting (21 days), the dose was computed by the DSS using a WET-sensor just underneath the root-zone at 30 cm. With an upward trend in water content the dose was lowered, and with a downward trend the dose was raised. Standard farmer practice (no foil; granular fertilization at 100 kg N/ha) was compared with three fertilizing strategies: (1) granular fertilization (100%) and two fertigation (83%, 58%) strategies (2 and 3) for which the weekly dose matched crop growth.

Results

Table 1 gives a summary of the most important data related to water use. Instead of using the standard definition for WUE, we used the Fresh, Marketable WUE (Geerts en Raes, 2009) defined as the total fresh crop weight produced per volume of the total applied water including rain water (in kg/m^3). To compare case studies results, we computed a water saving index (in %) by comparing the WUE for each deficit treatment to the WUE of the reference.

Ornamentals

For the peat-pumice mixtures a new calibration was obtained for the pore water EC (Incrocci et al., 2009). It yielded the following equation (see Fig 2):

$$EC_p = \left(2088.5 \cdot \varepsilon^{-1.836}\right) \cdot EC \quad , \tag{2}$$

which is different from Hilhorst (2000). As crop yields were not recorded, WUE could not be obtained and instead, to obtain the Water Saving Index, we used the Water Use. Compared to farmer practice (timer), all DI strategies did not influence significantly plant growth. They all reduced significantly the seasonal water consumption of (24 – 30%) as well as the drainage fraction because of a lower irrigation frequency (85 – 119 mm compared to 237 mm). For both the ET-model as well as SMS-activated IS the water saving performance was similar. The dual water source approach had a slightly higher drain fraction.

Cucumber

With the Deficit 1 treatment a higher marketable crop yield (14%) than with farmer's practice was obtained. The Deficit 1 regime reduced the leaching considerably (10.3 mm) compared to farmers practice (92.4 mm). Deficit 2 and 3 gave slightly smaller yields, but with nearly no noticeable percolation losses. All deficit treatments lead to similar water saving results (17 – 19%). Due to the larger dynamic range, the new dielectric tensiometer (Whalley et al.,2009) performed better than hydraulic tensiometers, especially in the drier deficit regimes (Fig. 3).

Tomato

The marketable yield was highest with FI (1.8 – 2.3 kg/m^2), both for FW and RW. The Water Use was significantly smaller for the deficit treatments (275mm compared to 410 – 425mm). Deficit 1 with FW gave a small water saving of 13%. Water Use Efficiencies were slightly higher (12 – 13%), and higher nitrogen, phosphorus and potassium contents in the plant tissue were found, when RW was used. Compared to FI, smaller size and more injured fruits (non-marketable) were found with DI (Fig 4). Use of RW resulted in accumulation of salt in the top soil, which was observed more under DI (Fig 5). A continuous control was not possible because water availability was limited to two times per week.

Egg-Plant

The Deficit 1 regime (75%) had the highest yield (3.9 kg/m^2) and water saving index (35%). The yield is slightly more than with FI (3.4 kg/m^2), but considerably more than common farmer's production levels with a traditional furrow irrigation system (1.5 – 2.0 kg/m^2). The Deficit 1 regime led to less fruits (about 33%) but with a 50% higher mean fruit weight. DI with 50% and 25% dose, gave considerably lower yields, even resulting in a negative water saving index for a dose of 25%.

Lettuce

For all treatments the crop quality was high and similar, and most of the produce (97.2 – 98.8%) was ranked as Class 1. Marketable crop yield was about 15% higher for the fertigated deficit regimes. During heavy rainfall events, infiltration through the foil occurred in the DI plots, and an estimated amount of 30% of the rainfall was added to the Water Use. The SMS-activated treatments used considerable less water (65.6 – 67.6 mm) compared to farmer practice (186 mm). For the farmer treatment, after harvest, nearly no Nitrogen was found in the top soil-layer (0 – 30 cm), while in the DI treatments still some Nitrogen was found, the most in Deficit 1 for which bulk fertilizers were used. For Deficit 1 crop yield was slightly smaller than for Deficit 2 and 3, in spite of the Nitrogen left in the soil. This was probably due to the dryer regime and granular fertilizer that did not mineralize. Compared to farmers practice, the SMS-activated DI treatments started irrigation more frequently and used a smaller dose, which lead to a significant large water saving (64 – 69%) and a lesser dynamical trend in soil water contents. The results of the automatic dose calculation by the DSS to prevent leaching are shown in Fig. 6. Based upon these observations, and although actual drainage was not measured, we concluded that in farmers practice a fairly large portion of Nitrogen leached to deeper layers, as well causing a smaller yield.

Discussion

Saving water

Geerts and Raes (2009) state that DI is successful in increasing water productivity for various crops without causing severe yield reductions. Indeed, we see in our case studies that DI leads to higher water use efficiencies, with maximum values ranging from 19% to 69% for moderate DI regimes with MAD-values ranging from 30 – 40%. Over this range, product quality may vary largely, as e.g. fruits may vary in total and sizes. Marketable yields vary from -11% up to +17%, compared to farmers practices or FI. Maximum marketable yields are not necessarily obtained using the DI strategy with the highest water saving ratio. It was seen that farmers sometimes tend to overirrigate their crop, resulting in leaching of fertilizers and consequently a yield reduction, which was observed by Geerts and Raes (2009) as well. Therefore, when using DI, farmers must choose the DI-depth based upon local situations like availability and costs of water as well as market prices.

Prevention of leaching

For cucumber and lettuce, compared to farmers practices, we were able to reduce leaching with a considerable amount by using moderate DI. By using optimized (drip-irrigated) fertigation, compared to bulk fertilization, slightly higher yields could be obtained taking advantage of non-leached fertilizers. In container ornamental crops, SMS-activated IS reduced considerably the leaching of nitrates and phosphates compared to the conventional grower's practice. With more severe DI zero leaching could be obtained, but this implies that the composition of the irrigation water must match exactly crop nutrient uptake. Zero leaching is not sustainable when a saline water source is used. In the ornamental trial we allowed for a small leaching fraction to prevent salinity build-up. To make such a system sustainable, the drain water could be collected and re-used after mixing and desalinization. We showed that while irrigating with a saline water source, and by monitoring substrate salinity using WET-sensors, we were able to maintain a pre-set EC-level in the growing media, making only minimal use of a FW source. In rain-fed agriculture, as was observed in the lettuce trial, rain and over-irrigation are the main cause of leaching,. The foil only partly blocked the rain, but it reduced leaching considerably. However, farmers have indicated not to be keen on implementing the foil because of the short cropping time, material costs and labour intensive handling.

Use of reclaimed wastewater

A high water saving ratio (25%) was obtained in tomato trials with a DI strategy. Use of RW led to higher yields due to higher organic compounds and plant nutrients. However, it is not likely that farmers will use RW in combination with such a DI strategy, due to the lesser fruit quality and yield and the fact that IS is more critical. Nevertheless, even when using RW, a moderate DI regime can be used for which acceptable fruit quality and yield, as well a lower water use can be obtained. As such, SMS-activated DI is a good tool. However, a straightforward programmed SMS-threshold with a preset dose was not optimal due to a non-continuous water supply. We suggest to make use additionally of ET-forecasting to find an optimal dose or to use a local water buffer. Considerable FW savings were obtained in the ornamental trials, when using high saline RW in combination with a small leaching fraction. A FW source was used only when the crop approached a salinity stress threshold level. This was made possible by using WET-sensors giving feedback about salinity, which was not possible IS using a timer or an ET-model.

<u>Decision Support System</u>

A minimal version of the DSS was implemented at a remote host computer (Anastasiou et al., 2009) and tested in the lettuce and cucumber trials with a limited set of DI-rules. On a daily basis, or upon reception of new data, the DSS computed new irrigation control parameters (thresholds, doses and timing) which were send via e-mail to the farmer, who set the irrigation controllers manually. The DSS could have updated the irrigation schedulers directly and without growers intervention. However, it showed that to make such a system fail-safe and robust, the DSS should not only incorporate DI expertise, a crop database and stress model, but as well an observer of the performance of the irrigation controllers, detecting any faulty conditions (leakage, power failures etc.) and major changes in crop development and growing media. The DSS should use, combine and analyse all available data, and alert the grower upon any critical event needing his intervention. Such warming system would be very beneficial for growers, even while using a manual control. The full capabilities and flexibility of the DSS and the crop stress database upon reprogramming the irrigation controllers on-the-fly and adapt the DI-strategy to changing contraints was not explored in the case studies. We anticipate that by doing so, the water saving performance, crop yield and crop quality could be enhanced even more.

<u>Costs and farmers use of the DSS and SMS</u>

With respect to the aim to save water or reduce leaching, the FLOW-AID concept worked. In general, the concept could be adapted to several different farmer practices, and apart from a few minor failures, the technical implementations of sensors, controllers and wireless systems performed well. However, investments, operating and maintenance costs are relatively high. Therefore, successful implementation will depend solely on the outcome of an economic evaluation. Costs must be covered by extra income from savings on water, fertilizer and energy and benefits from a higher product yield and quality. All depends on local constraints and especially on the price for FW and water treatment besides the enforcement of legislation. In many cases water is still too cheap to change over to SMS-activated DI, but in cases where farmers use RW we feel that the break-even point has been reached already. SMS’s are useful for IS but its application demands extra skills, especially due to soil variability. It is advisible to adapt the DSS so that it automatically checks sensor calibration and fine-tunes set-points. Farmers are interested to use sensors and a DSS, even for just monitoring soil water dynamics, but there is a demand for more accurate and cheaper sensors.

Recommendations

Growers are advised to give more frequently water and nutrients with smaller doses, matching more closely the crop demand over time, preferably by using an automated system, which can save a lot of work. SMS-activated IS is a tool that can help farmers to manage DI in a controlled way under severe conditions of water availability and quality. Industry may use the FLOW-AID concept and should focus on accurate, low-cost sensor and controller technology and a robust DSS capable to serve a broad diversity of cropping systems and constraints.

Conclusions

SMS-activated DI scheduling may significantly enhance water use efficiency and reduce or prevent leaching. In our case studies and compared to common grower practices, it saved water from 19% up to 69% while maintaining acceptable yields (-6% to +17%) and crop quality. Large DI depths may influence crop quality and yield severely, but it is possible to achieve acceptable crop quality and yield at moderate DI-depths. RW or saline water sources can be used under DI regimes, but continuous EC-monitroing with e.g. WET-sensors is adviced to prevent crop losses. An optimized fertigation strategy matching crop demands is a pre-requisite to maintain sustainability, especially when RW or saline water is used. The DSS works well, and to ensure a fail-safe operation in growers practice, an automatic fault detection and warning system must be implemented.

ACKNOWLEDGEMENTS

The FLOW-AID system (www.flow-aid.eu) was developed through a close partnership between research institutes, universities and SME's; mainly funded by the European Union under the contract 036958 in the 6th Framework Programme. We further thank all (un-mentioned) national funds that contributed to this work and the companies GEOMATIONS s.a. (Greece), Spagnol Automation (Italy) and Delta-T Devices Ltd (UK) for their contributions to the experiments and the supply and adaptations of the software, sensors and fertigation equipment.

Glossary of Terms

CIMISe	California Irrigation Management Information System equation
DI	Deficit Irrigation
DSS	Decision Support System
EC, EC_p	Electrical Conductivity, Pore Water EC
ET	Evapo-Transpiration
ε	Dielectric permittivity
FC	Field Capacity
FW	Fresh Water
IC	Irrigation Controllers
IS	Irrigation Scheduling
K_c	crop coefficient
MAD	Management Allowable Depletion factor
PC	Personal Computer
PMe	Penman–Monteith equation
RW	Reclaimed Wastewater, also used for treated waste water
SMS	soil moisture sensor
WET	Sensor for Water, EC and Temperature sensor (introduced by Delta-T-Devices Ltd, UK)
WUE	Water Use Efficiency

References

Allen, R.G.; Pereira, L.S.; Raes, D.; Smith, M., 1999. Crop Evapotranspiration. Guidelines for Computing Crop Water Requirements. Food and Agriculture Organization of the United Stations (FAO), Irrig. Drain. Paper 56, Rome, Italy, 14 January 1999, http://www.fao.org/docrep/X0490E/X0490E00.htm.

Anastasiou, A., Savvas, D., Pasgianos, G., Sigrimis, N., Stangellini, C. and Kempkes, F.L.K. 2009. Decision Support for Optimzed Irrigation scheduling. Acta Hort. (ISHS) 807:253-258. http://www.actahort.org/books/807/807_33.htm.

Balendonck, J., C. Stanghellini, J. Hemming, F. Kempkes, B. v. Tuijl. Farm Level Optimal Water management: Assistant for Irrigation under Deficit (FLOW-AID). ISHS Symposium on Protected Cultivation for Mild Winter Climates, Izmir, 2008.

Chazbeck, A. 2008. Les effets du stress hydrique sur la croissance, la production, et l'efficience d'utilisation d'eau de l'aubergine (Solanum melongena L.,). B.Sc. Thesis. Holly Spirit Univ., Facultuy of Agricultural Sciences, Jounieh, Lebanon, 54 pages.

Dominguez, A., E. Lopez-Mata, A. de Juan, A. Artigao, J.M. Targuelo, 2008. Deficit Irrigation under Water Stress and Salinity Conditions. The Use of the MOPECO Model. CIGR Int. Conf. of Agr. Eng., Conbea, Brazil Aug. 31 – Sept. 4, 2008.

Food and Agriculture Organization of the United Nations (FAO). 2000. Deficit irrigation practices. Water Rep.. 22, Rome, Italy. 6 January 09. <http://www.fao.org/docrep/004/Y3655E/y3655e13.htm#m>

Food and Agriculture Organization of the United Nations (FAO). 2002. Crops and Drops - Making the best use of water for agriculture. Rome, Italy. 26 pg. 6 January 09. http://www.fao.org/docrep/005/Y3918E/y3918e00.htm

Geerts, S. and D. Raes (2009). "Deficit irrigation as an on-farm strategy to maximize crop water productivity in dry areas." Agricultural Water Management 96(9): 1275-1284.

Hilhorst M.A. 2000. A Pore Water Conductivity Sensor. Soil Sci. Soc. Am. J. 2000, 64, 1922–1925.

Incrocci L., Incrocci G.,. Pardossi A., Lock G., Nicholl C., Balendonck J., 2009. The Calibration of WET-Sensor for Volumetric Water Content and Pore Water Electrical Conductivity in different Horticultural Substrates. Int. ISHS Symp. "Strategies towards Sustainability of Protected Cultivation in Mild Winter Climate", Antalya, 7-10 April 2008. Acta Hort.(ISHS) 807:289-294.

Incrocci, L., P. Marzialetti, G. Incrocci, Balendonck J., S. Spagnol and A. Pardossi, 2010. The Application of the WET Sensor for the Management of Reclaimed Wastewater Irrigation in Container-Grown Ornamentals (*Prunus lauroceraus* L.). 3rd Int. Symp. on Soil Water Measurement Using Capacitance, Impedance and TDT, Murcia, Spain, April 7–9, 2010.

Incrocci L., Pardossi A., 2009. Crop Stress Response Database version 1.2, 2 December 2009, available from: http://www.flow-aid.wur.nl/UK/Activities/Crop+Response+Model/

Meron, M., Hallel, R., Bravdo, B. and Wallach, R. 2001. Tensiometer Actuated Automatic Micro Irrigation of Apples. Acta Hort. (ISHS) 562:63-69.

Pardossi A., Incrocci I., Incrocci G., Marzialetti P. (2009a). What limits and how to improve Water and Nutrient Efficiency in Outdoor Container Cultivation of Ornamental Nursery Stocks. Int. Symp. "Soilless Culture & Hydroponics", Lima, Peru, 25-28 August 2008. Acta Horticulturae (ISHS) 843: 73-80.

Pardossi A., Incrocci l., Incrocci G., Malorgio F., Battista P., Bacci L., Rapi B., Marzialetti P., Hemming J., Balendonck J. (2009b). Root Zone Sensors for Irrigation Management in Intensive Agriculture. Sensors 9, 2809-2835. Available at http://www.mdpi.com/1424-8220/9/4/2809

Rousan, L. M., M. J. Rusan and J. Amayreh. 2008. Irrigation with Treated Wastewater under Full and Deficit Soil Moisture Conditions. Eds: Hashem Al-Mattarneh, Lariyah Mohd Sidek and Mohd Zamri Yusoff: Proceeding of the International Conference on Construction and Building Technology (ICCBT): Innovations in Water Resources and Environmental Engineering. Kuala Lumpur, Malaysia. (38): 405-416.

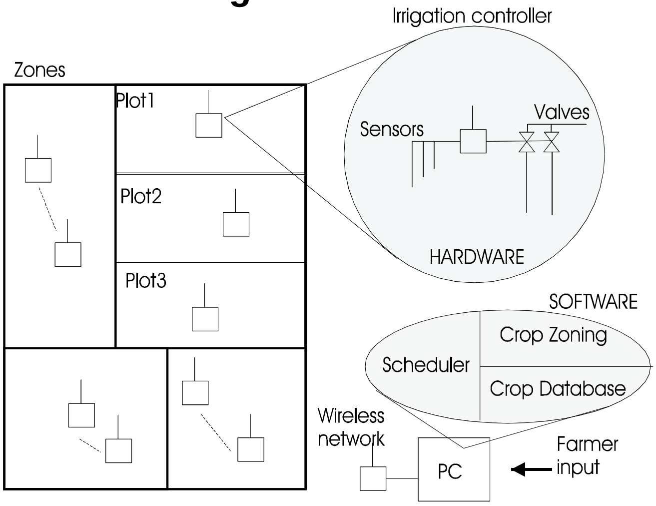
Pruitt, W.O. and J. Doorenbos, 1977. Empirical calibration, a requisite for evaporation formulae based on daily or longer mean climatic data. ICID Conf. Evapotranspiration, Budapest, Hungary, May 26-28, 1977.

Saliba, R. 2009. Monitoring the effects of soil water deficit on eggplants 'Solanum melongena L.' using the smart irrigation controller GP1. B. Sc. Thesis. Lebanese University, Faculty of Agricultural and Veterinary, Beirut, Lebanon, 71 pages.

Tuzel, I.H., Y. Tüzel, M.K Meriç, G.B. Oztekin, R. Whalley, G. Lock, 2009. Response of cucumber to deficit irrigation. Acta Hort. 807:259-264. Available at http://www.mdpi.com/1424-8220/9/4/2809.

Whalley, W. R., G. Lock, M. Jenkins, Tony Peloe, K. Burek, J. Balendonck, W. A. Take, İ.H. Tuzel and Y.Tuzel, 2009. Measurement of Low Matric Potentials with Porous Matrix Sensors and Water-Filled Tensiometers. Soil Sci. Soc. Am. J.: Vol. 73: No.:6, Nov.-Dec. 2009.

Tables and figures



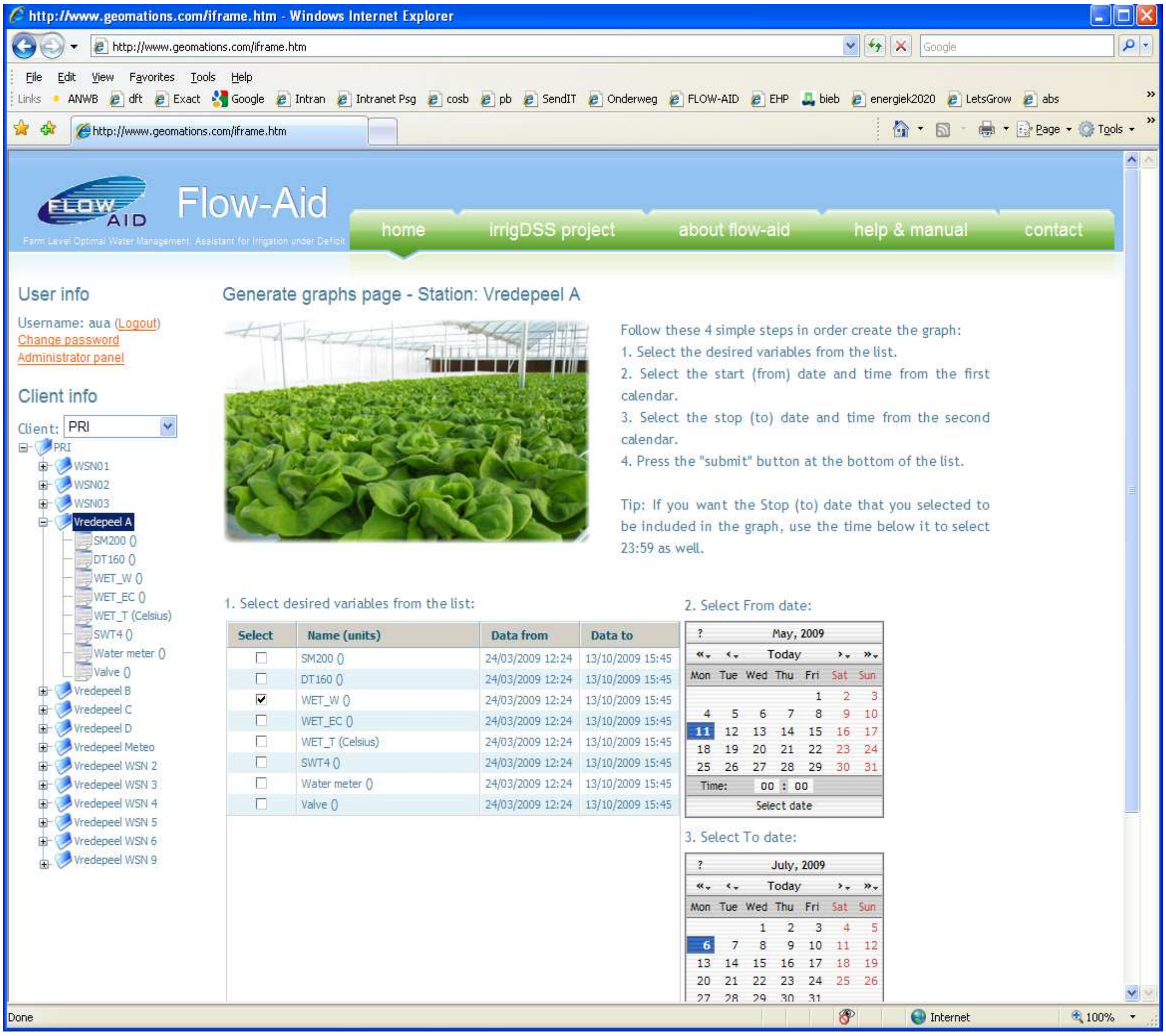
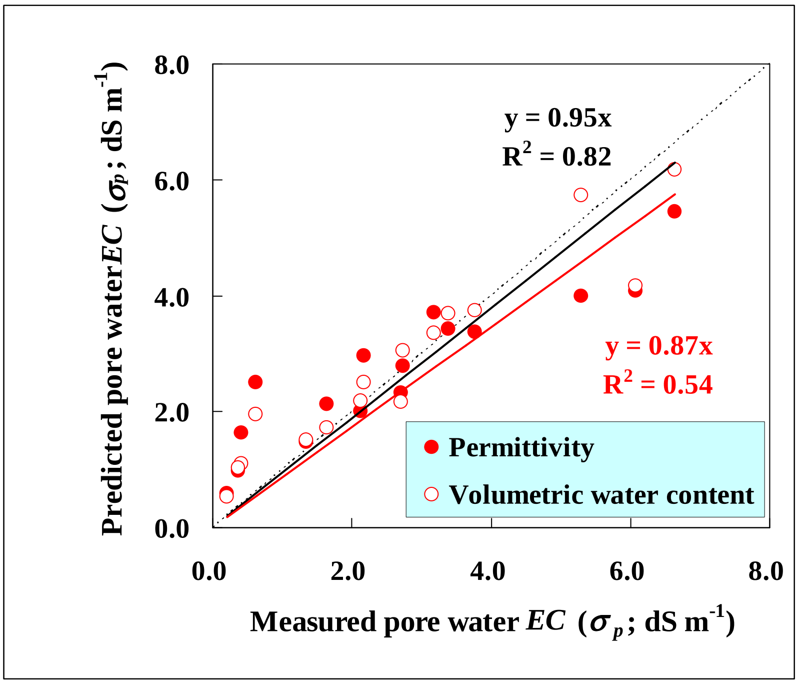


Figure 1 – *From above left to right under: Schematic representation of the FLOW-AID concept; a web-based DSS tool, a platform for data exchange and presentation (Geomations S.A., Greece); a WET-sensor (Delta-T-Devices, UK) and a 5TE (Decagon, US) to measure water content, EC and temperature (Dutch case study); fertigation unit (Spagnol Automation, Italy) installed for the Turkish case study; a wireless sensor network (eKo,Crossbow, US) and irrigation controller (GP1, Delta-T Devices, UK) installed just after planting Iceberg lettuce (Dutch case study).*



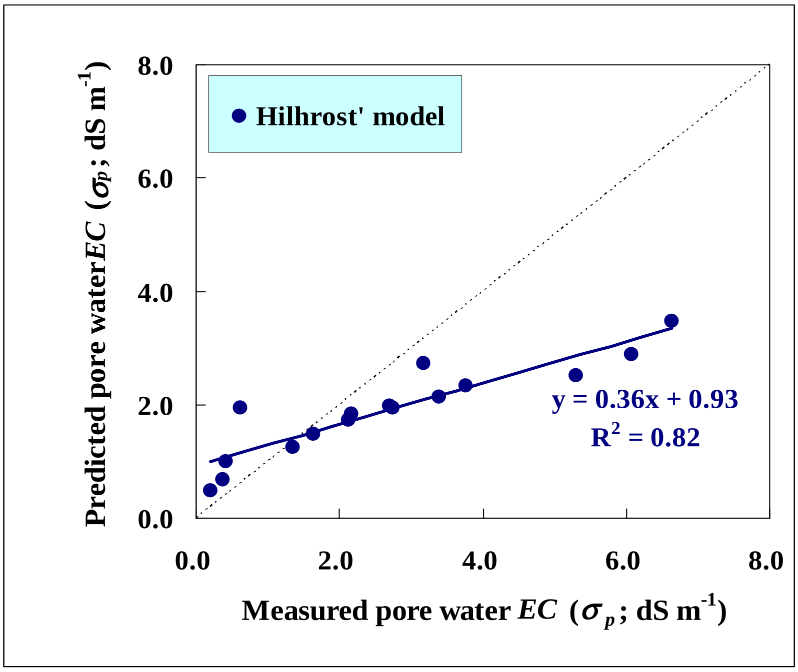


Figure 2 – *Results of a WET-sensor calibration for pore water EC in a peat-pumice mixture for container-grown ornamentals in the Italian case study (Incrocci et al., 2009) compared to calibration using Hilhorst (2000).*

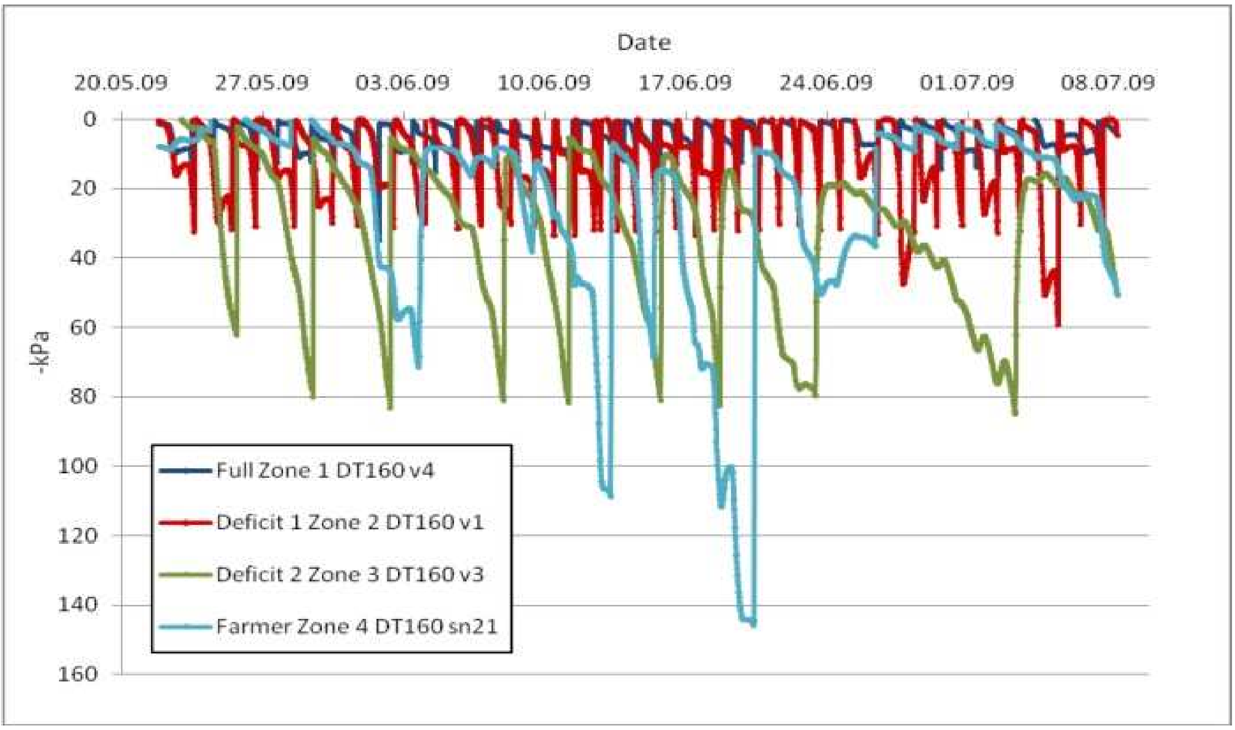
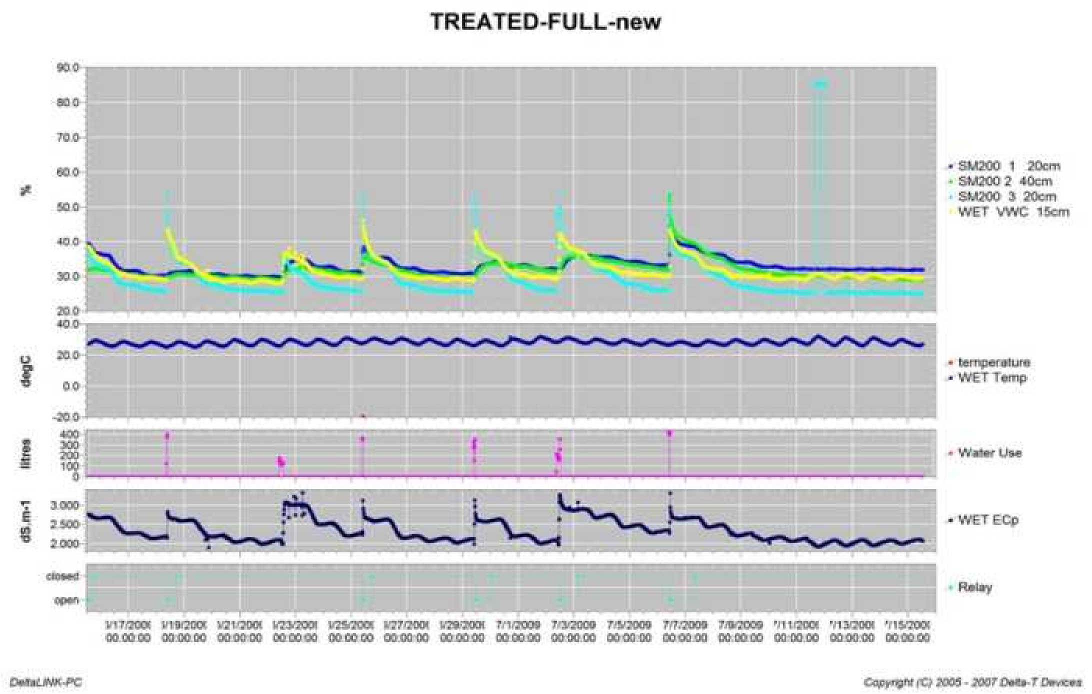


Figure 3 – *Dielectric tensiometer (DT160, Delta-T-Devices, UK) used in Turkey case study on cucumber, shown while wetted prior during installation (left). Readings with the DT160 for several deficit treatments.*

Figure 4 – *Results from the Jordan Case Study. Left picture: Tomato grown with fresh water under Full Irrigation (left-side) and Deficit Irrigation (right-sight). Right picture: Crop damage due to blossom rot in the deficit treatment.*



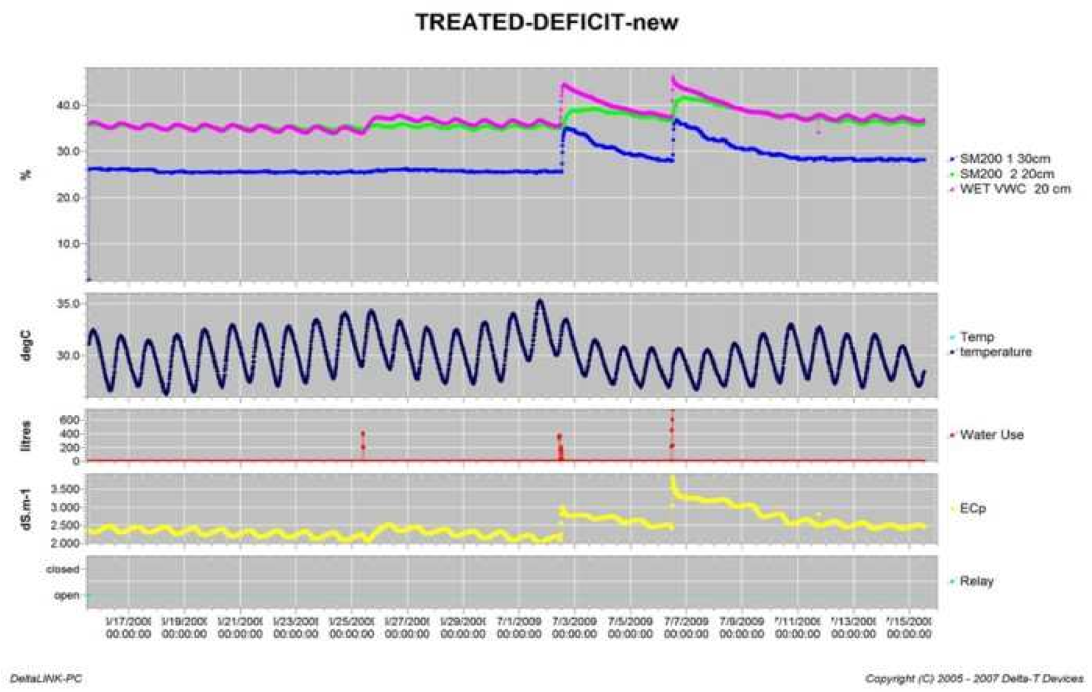


Figure 5 – Results from the Jordan case study. Sensor readings of SM200 and WET-sensor for treatment with treated wastewater, for Full Irrigation (left) and Deficit Irrigation (right). Pore Water EC (EC_p) values obtained from WET-sensor by using the Hilhorst equation (Hilhorst, 2000).

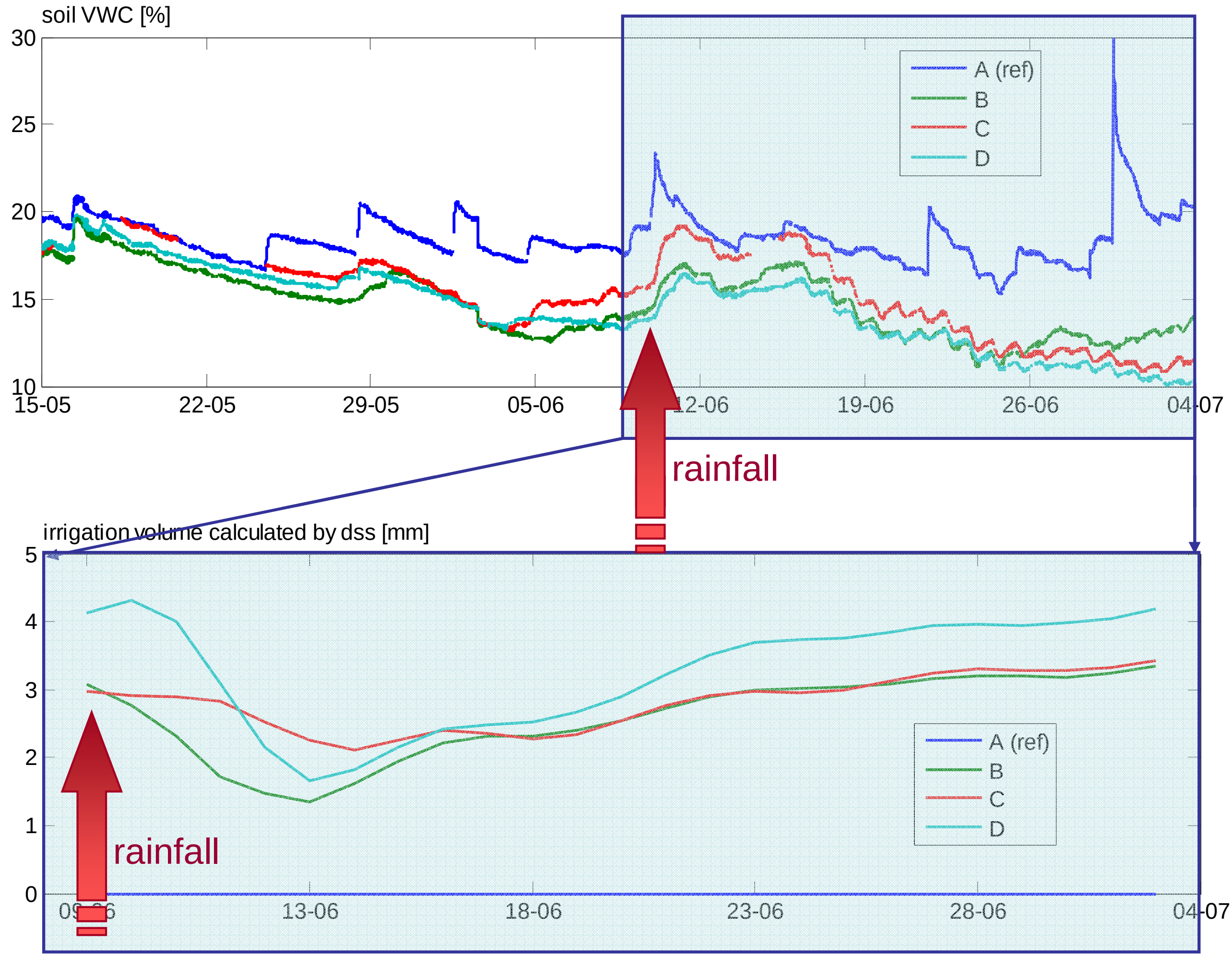


Figure 6 – Dutch case study on rain-fed Iceberg lettuce, example on DSS functionality. Above: Volumetric Water Content for all 4 treatments, and the blue line refers to the farmer treatment. Below: Calculated irrigation dose. After rainfall the dose is decreased and then slowly increased again.

Table 1 – Case study results with obtained Water Use Efficiencies(WUE) and Water Savings Indices.

Case Study	*Strategy* (MAD%, dose)	*Marketable Crop Yield* (kg/m^2)	*Water Use* (mm)	*Drainage* (mm)	*Ratio Fresh to Total Water* (%)	*Fresh Marketable WUE* (kg/m^3)	*Water Saving Index*[8] (%)
Ornamentals[8]	Farmer (Timer)	-	540 (n=3)	237	100	-	0 [1]
	ET-Model	-	410 (n=1)	94	100	-	24
	SMS (WET+TM) [2]	-	379 (n=3)	84	100	-	**30**
	WET (GW+RW) [2]	-	413 (n=2)	119	66	-	24
Cucumber	Farmer	25.4	717 (n=5)	92.4	100	35.4	0 [1]
	Deficit 1 (20/100%)	29.0	683 (n=5)	10.3	100	42.4	17
	Deficit 2 (40/100%)	23.8	545 (n=5)	0	100	43.7	**19**
	Deficit 3 (60/100%)	21.2	495 (n=5)	0	100	42.7	17
Tomato	Full 1	1.8	425 (n=2)	-	100	6.1	0 [1]
	Full 2	2.3	410 (n=2)	-	0 [3]	7.0	13
	Deficit 1	1.6	275 (n=2)	-	100	7.0	13
	Deficit 2	1.6	275 (n=2)	-	0 [3]	8.1	**25**
Egg plant	Full (30/100%)	3.4	94.6 (n=1) [6]	-	100	35.7	0 [1]
	Deficit 1 (30/75%)	3.9	71.0 (n=1) [6]	-	100	54.4	**35**
	Deficit 2 (30/50%)	2.0	47.3 (n=1) [6]	-	100	41.3	14
	Deficit 3 (30/25%)	1.3	23.7 (n=1) [6]	-	100	23.7	-51
Lettuce	Farmer	4.1	186 (n=1)	-	50.5 [4]	22.2	0 [1]
	Deficit 1 (35/-[7])	4.2	67.6 (n=1)	-	59.2 [5]	62.5	64
	Deficit 2 (35/-[7])	4.7	69.6 (n=1)	-	60.3 [5]	68.0	67
	Deficit 3 (35/-[7])	4.8	65.6 (n=1)	-	57.9 [5]	72.6	**69**

Values not obtained or available; [1]Reference treatments; [2]WET = WET-sensor, TM = Tensiometer, GW = Ground Water, RW = Reclaimed Wastewater; [3]RW; [4]Including 92 mm rain water; [5]Including about 30% of 92 mm rain leaked through the foil coverage (estimate); [6]Water use calculated based upon an ET-model; [7]Dose variable and computed with DSS, [8]Refers to a multi-crop irrigation scheme with four different ornamental species; [8]Maximum Water Saving Index printed in bold type characters.

PLAN FOR USING AND DISSEMINATING KNOWLEDGE

The role for the test-sites will be the organisation of all kinds of dissemination actions such as conferences, workshops and seminars for farmers (by each site partner together with the SME particularly involved at the site). All scientific partners will focus on the publication of their research results through papers for periodicals, conferences and local farmer magazines.

In the Annexes a list of dissemination activities and publications can be found. The coordinator maintains a web-site for the project (www.flow-aid.eu).

The Flow-Aid Team

Picture taken during the 4th FLOW-AID meeting in Izmir-Turkey, 3-4 April 2008, visiting the Turkeys test-site in Yeniköy-Menderes. *From left to right in the front: Farmer's family, Nick Sigrimis, Cecilia Stanghellini, Jos Balendonck, Dimitrios Savas, Jochen Hemming, Paolo Marzialetti, Alberto Pardossi, Hakkı Tüzel. From left to right in the back: Farmer's son, Richard Whalley, Dick Jenkins, Yüksel Tüzel, George Pasgianos, Frank Kempkes, Jose Tarjuelo, Tony Peloe, Jumah Amayreh. Other participants: Alfonso Dominguez, Fadi Karam, Munir Rusan, Laith Rousan, Kaz Burek, Luca Incrocci, Giorgio Incrocci.*

Annex 1: Overview table of dissemination activities

Date	Type	Type of audience	Countries	Size of audience	Partners involved
16/11/2006	Conference, publication	General public	Italy (Bologna)	100	UNIPI
01/12/2006	Seminar at Pistoia test-site	Attended by local actors both agriculture and politics	Italy (Pistoia)	50	PRI, UNIPI, CESPEVI
18/01/2007	Conference, publication	General public	Italy (Milan)	100	UNIPI
19/01/2007	FLOW-AID: Een assistent voor deficit irrigatie.	Article in: Tuinbouw Onder Glas, Februari 2007 (NL)	NL	>1000	PRI
01/02/2007	Leaflet on FLOW-AID	Public domain handout	NL, International	100	PRI
01/02/2007	Journal article EJSS, Febr. 2007,58,18-25	Public	International	>1000	RRES
14/02/2007	Conference presentation	Public	Italy	150	PRI
22/06/2007	Conference	General public	Italy (Mola di Bari)	50	UNIPI
02/08/2007	Farmer meeting	Turkish farmers, Agric. Engineers, Officials of Min. of Agric. & Municipality	Izmir, Turkey	20	EUFA, RRES
3-5/09/2007	Training days	Technicians, farmers, and WUAs	Lebanon	25	LARI
3-5/09/2007	Training	Agricultural and Bio system engineering students	Jordan	12	JUST
4-6/09/2007	Conference	Local scientific researchers	Spain(Albacete)	50	UCLM
13/09/2007	Conference	General public	Italy (Padova)	50	UNIPI
01/10/2007	Growers magazine: Tuinbouw Onder Glas	Growers	NL	>1000	PRI
05/10/2007	Scientific conference (Greensys2007)	Scientists in the area of horticulture engineering	International	350	PRI
2007	Press release(press/radio/TV)	General public	Jordan Mass Media	About 1.5 Million	JUST
2007	Media briefing	Graduate and Under graduate Students at JUST,	North part of Jordan	75	JUST
2007	Demonstrations	Farmers Leaders	North Jordan	8	JUST
01/02/2008	Article, growers magazine: Tuinbouw Onder Glas, Februari 2008 (NL)	Growers	Netherlands	1000	PRI
05/04/2008	Poster at conference ISHS SPCMWC2008	Agricultural scientists	Antalya, Turkey	200	UNIPI
7-10 April 2008	International Symposium	Research	35 countries	135	EUFA
6-11/04/2008	Special session on FLOW-AID project at the Conference in Antalya (Turkey), 4 presentations	Scientists in the area of hortucultureal engineering	International, Antalya, Turkey	200	PRI, EUFA, Geomations, UNIPI,
29/05/2008	Farmer meeting	Farmers and local authorities	Turkey	50	EUFA
03/06/2008	Seminar	Academic staff and students	Turkey	25	EUFA
05/06/2008	Presentation at Open Day on irrigation technology	Local farmers and technicians, general public	Pistoia, Cespevi, Italy	50	UNIPI
25/06/2008	Scientific conference (AgEng 2008)	Scientists in the area of agricultural engineering	International	150	PRI, UNIPI, RRES, EUFA, DELTA-T
25/6/2008	Scientific conference (AgEng 2008)	Scientists in the area of agricultural engineering	International	150	GEOMATIONS, PRI
26/06/2008	Presentation at Conference: XXVI CONGRESO NACIONAL DE RIEGOS	Scientists	Huesca, Spain	100	UCLM
07/08/2008	Flow-Aid article in: RRA Newsletter - December 2008	General public	UK		RRES
22-24/08/2008	Conference/Symposium	General public	Lima (Peru)	130	UNIPI

	presentation				
04/09/2008	CIGR - International Conference of Agricultural Engineering - presentation	Scientists	Brazil	>100	UCLM
07/10/2008	Scientific meeting	Experts in soil watermeasurement	US	40	RRES, DELTAT,PRI
14/09/2008	International ISHS Symposium, paper	General public	Italy (Bologna)	50	UNIPI
10/10/2008	Seminar Presentation	General public	Italy (Pisa)	30	Cespevi
21/10/2008	Poster presentation at Research Station Bleiswijk	Agricultural Attachees	Netherlands	60	PRI
23/10/2008	Seminar	General public	Italy (Battipaglia, Salerno)	50	UNIPI
2008	Press release(press/radio/TV)	General public	Jordan Mass Media	About 2.0 Million	JUST
2008	Media briefing	Graduate and Under graduate Students at JUST,	North part of Jordan	125	JUST
2008	Training	Agricultural and Bio system engineering students	Jordan	8	JUST
2008	Demonstrations	Farmers Leaders	North Jordan	10	JUST
07/11/2008	Irrigation workshop with 6 presentations	Farmers and local authorities and water board	Ierapetra, Crete	100	GEOMATIONS, RRES, PRI, EUFA

Annex 2: LIST OF PUBLICATIONS

The reprints (pdf-formats) of the following publications related to the FLOW-AID project are kept on the projects web-portal.

Anastasiou A.; Savvas, D.; G. Pasgianos, C. Stangellini, F. Kempkes, N.Sigrimis, 2008. DECISION SUPPORT FOR OPTIMISED IRRIGATION SCHEDULING, ISHS Symposium on Protected Cultivation for Mild Winter Climates, Antalya, 2008. To be printed in Conference Proceedings.

Anastasiou A.; Savvas, D.; G. Pasgianos, N.Sigrimis, 2008. “Wireless Sensors Networks And Decision Support For Irrigation Scheduling” International Conference on Agricultural Engineering (AgEng2008), Hersonissos, Crete, 23-25 June 2008. Conf. Proc. CD-ROM .

Balendonck, J. C. Stanghellini, J. Hemming, 2007. FARM LEVEL OPTIMAL WATER MANAGEMENT: ASSISTANT FOR IRRIGATION UNDER DEFICIT, Int. Conf. on Water Saving in Mediterranean Agriculture & Future Research Needs, 14-17 Febr. 2007, Bari (Italy).

Balendonck, J., 2007. FLOW-AID: Een assistent voor deficit irrigatie, Tuinbouw Onder Glas, Februari 2007 (NL), 19-1-2007.

Balendonck, J., 2007. Leaflet: Flow-AID, Plant Research International, Wageningen (2007), 1-2-2007.

Balendonck, J., 2007. FLOW-AID, EEN WATERGEEF HULP BIJ GEBREK AAN GOED EN VOLDOENDE GIETWATER, Tuinbouw Onder Glas (NL), 1-10-2007.

Balendonck, J., C. Stanghellini, J. Hemming, F. Kempkes and B.A.J. van Tuijl, 2008. Farm Level Optimal Water management: Assistant for Irrigation under Deficit (FLOW-AID), ISHS Symposium on Strategies Towards Sustainability of Protected Cultivation in Mild Winter Climate, Antalya, Turkey. To be printed in Conference Proceedings.

Balendonck, J., J. Hemming, B.A.J. van Tuijl, A. Pardossi, L. Incrocci, P. Marzialetti, 2008. Sensors and Wireless Sensor Networks for Irrigation Management under Deficit Conditions (FLOW-AID), International Conference on Agricultural Engineering (AgEng2008), Hersonissos, Crete, 23-25 June 2008. Conf. Proc. CD-ROM ref. OP-1985 (1130087), Editor: George Papadakis et al., Published by: Vougas Associates Ltd. 29, Sinopis Street, 115 27, Athens, Greece (www.vougas.gr), 2008, p.19.

Balendonck, J. I. Hakki Tuzel, Yuksel Tuzel, Kamil Meric, Golgen Oztekin, 2009. Introducing techniques to save water. FlowerTECH 2009, vol. 12/no.3, pp 18-19.

Balendonck, J., Hakki Tuzel, Yuksel Tuzel, 2009. Water saving tools for horticulture, Fruit & Veg Tech 9 no.2, pp. 27-28.

Balendonck, J, A. Pardossi, H. Tuzel, Y. Tuzel, M. Rusan, F. Karam, 2009. FLOW-AID, a farm level tool for irrigation management under deficit conditions: Preliminary case study results. STRIVER conference: Integrated Water resource Management in Theory and Practise, Conference Proceedings, Brussels, 28-29 May, 2009. p. 64/69.

Balendonck, J, 2009. FLOW-AID, a farm level tool for irrigation management under deficit conditions: Preliminary case study results. Presentation at the STRIVER conference: Integrated Water resource Management in Theory and Practise, Brussels, 28-29 May, 2009.

Balendonck, J, 2009. Assistance for Irrigation under Deficit, International Workshop on “Innovative irrigation technologies for greenhouse vegetables”, Menderes-Izmir (Turkey), 23 June 2009 (presentation at workshop)

Balendonck, J. 2009. Flow-aid, an assistant for deficit irrigation : international workshop on "innovative irrigation technologies for container-grown ornamentals", Centro Sperimentale Vivaismo, Pistoia (Italy), 10 July 2009.

Balendonck, J. et. Al, 2009. Farm Level Optimal Water management: Assistant for Irrigation under Deficit: Proceeding Final Workshop/ Info-day PLEIADes and FLOW-AID, Albacete (Spain), 11 November 2009. Editors: J. Balendonck, A. Osann.

Balendonck, J. 2009. Farm level Optimal Water Management: Assistant for Irrigation under Deficit (FLOW-AID), Leaflet: II Spanish and Dutch Innovation Water Event, Leeuwarden, 3 dec 2009 (NL) .

Balendonck, J., J. Hemming, F. Kempkes, Alberto Pardossi, Luca Incrocci, 2010. "Ervaringen met sensoren voor vochtgehalte en EC bij vollegronds tuinbouw en containerteelten", Presentatie op themadag "Watergift pot- en containerteelt", Boskoop(NL), 26 Februari 2010. (Presentation at workshop)

Balendonck, J.; A. Pardossi, H. Tuzel, Y. Tuzel, M. Rusan, F. Karam, D. Jenkins. FLOW-AID, a deficit irrigation management system using sensor activated control: results of five case studies. Third International Symposium on Soil Water Measurement Using Capacitance, Impedance and TDT, Murcia, Spain, April, 7–9, 2010.

De Juan, J.A.; Domínguez, A.; Tarjuelo, J.M.; Córcoles, J.I.; Ortega, J.F. EFFECT OF THE TYPE OF EMITTER AND HEIGHT ABOVE THE SOIL ON ONION (Allium cepa L.) CROP. XVII World Congress of the International Commission of Agricultural Engineering. June 13-17 2010. Québec (Canada) (accepted).

Domínguez, A.1, López-Mata, E., Tarjuelo, J.M., de Juan, J.A., 2007. Adaptación del modelo MOPECO para estimar la evolución diaria de la biomasa y del índice de área foliar. V Congreso Nacional y I Congreso Ibérico de Agroingeniería. September 4-6 2007. Albacete (Spain).

Domínguez, A., López-Mata, E., De Juan, J.A., Artigao, A., Tarjuelo, J.M., 2008. DEFICIT IRRIGATION UNDER WATER STRESS AND SALINITY CONDITIONS. THE USE OF MOPECO MODEL. CIGR - International Conference of Agricultural Engineering. August 31 – September 4 2008. Iguazu (Brazil).

Domínguez A, de Juan JA, Tarjuelo JM, Ballesteros R, López-Mata E., 2009. COMBINED EFFECT OF DEFICIT IRRIGATION AND IRRIGATION UNIFORMITY. 12th Inter Regional Conference, November 9-11 2009. Marrakech (Morocco).

Dominquez, A. et. Al, 2009. COMBINED EFFECT OF CONTROLLED IRRIGATION AND UNIFORMITY. This paper describes the coefficient of uniformity module and has been sent to European Journal of Agronomy.

Dominquez, A. et. Al, 2009. CONTROLLED IRRIGATION UNDER WATER STRESS AND SALINITY CONDITIONS. This paper describes the salinity module and has been sent to Irrigation Science.

DOMÍNGUEZ, A., KARAM, F., DE JUAN, J.A., TARJUELO, J.M., 2010. Controlled irrigation under water stress and salinity conditions. Agricultural Water Management. (Under construction. The paper is based in Deliverable 16).

Dominquez, A. et. Al, 2009. AN ECONOMIC OPTIMIZATION MODEL FOR IRRIGATION WATER MANAGEMENT. UPDATED VERSION. This paper describes the model as a whole, delighting the innovations of the last two years (optimizer, coefficient of uniformity module, salinity module, controlled deficit irrigation and risk analysis). This paper has been sent to Agricultural Water Management.

Domínguez A., de Juan J.A., López-Mata E., Tarjuelo J.M. CALIBRATION OF IRRIGATION SCHEDULE MODULE OF MOPECO MODEL THROUGH SOIL MOISTURE AND ELECTRICAL CONDUCTIVITY SENSORS. The Third International Symposium On Soil Water Measurement Using Capacitance, Impedance and Time Domain Transmission. April 7-9 2010. Murcia (Spain).

Domínguez, A.; de Juan, J.A.; Tarjuelo, J.M.; Ballesteros, R.; López-Mata, E. MOPECO-Risk: AN ECONOMIC OPTIMIZATION MODEL FOR IRRIGATION WATER MANAGEMENT. XVII World Congress of the International Commission of Agricultural Engineering. June 13-17 2010. Québec (Canada) (accepted).

DOMÍNGUEZ, A., DE JUAN, J.A., MARTINEZ-ROMERO, A., TARJUELO, J.M., 2010. Effect of climate change on irrigated semiarid agriculture. Regional Environmental Change (Under revision).

DOMÍNGUEZ, A., KARAM, F., DE JUAN, J.A., TARJUELO, J.M., 2010. Controlled irrigation under water stress and salinity conditions. Agricultural Water Management. (Under construction. The paper is based in Deliverable 16).

DOMÍNGUEZ, A., TARJUELO, J.M., DE JUAN, J.A., BALLESTEROS, R., LÓPEZ-MATA, E. 2010. The use of on-line models in the Advisory Irrigation Service of Castilla-La Mancha (Spain). Environmental Modelling and Software. (Under construction. The paper is based in Deliverable 56).

Haan, J. de, K. van Wijk, J. Balendonck, J. Wilms, 2009. Sensoren en fertigatie in ijssla. Presentatie voor slatelers bijeenkomst 20 aug. 2009, LTO-groeiservice, Zeeland (NL, N.Br.)

Haan, J. de, J. Balendonck, 2009. Beregenen met sensoren, in: “Gewas nieuwsbrief Sla”, Groeiservice, juni 2009.

Hemming, J., Kempkes, F.L.K. ; Balendonck, J. 2009. Wireless sensor systems for irrigation management in container grown crops : international workshop on "Innovative irrigation technologies for container-grown ornamentals", Centro Sperimentale Vivaismo, Pistoia (Italy), 10 July 2009.

Hemming, J. E.A. van Os, J. Balendonck, 2009. Intelligent bewässern im Gartenbau: Forschungstrends in den Niederlanden. Tagungsband, p. 81-87.

Incrocci L., Pardossi A.. 2007. La subirrigazione in vaso a ciclo chiuso effettuata con acque di scarsa qualità. Atti della Giornata di Studio su “I Sistemi di Allevamento in Vaso con Subirrigazione a Ciclo Chiuso per le Produzioni di Serra”, Mola di Bari, 12 maggio 2006. Aracne Editrice srl, Roma. Technical articles: PDF AVAILABLE

Incrocci L., Pardossi A.. 2007. La tecnica della subirrigazione in serra: problematiche inerenti l'uso di acque saline in colture ortofloricole. Atti del Convegno su “I Sistemi di Allevamento in Vaso con Subirrigazione a Ciclo Chiuso per le Produzioni”. Il Floricoltore 3, 34-28. Technical articles: PDF AVAILABLE

Incrocci L., Pardossi A., 2007. La tecnica della subirrigazione in serra: problematiche inerenti l'uso di acque saline in colture ortofloricole. Atti del Convegno su “I Sistemi di Allevamento in Vaso con Subirrigazione a Ciclo Chiuso per le Produzioni”, Bologna, 16 novembre 2006. Il Floricoltore 3, 34-28. UNIPI_WP9_doc01.pdf

Incrocci L., Massa D., Carmassi G., Maggini R., Bibbiani C., Pardossi A. (2008). SIMULHYDRO, a simple tool for predicting water use and water use efficiency in tomato soilless closed-loop cultivations. Acta Horticulturae (Greensys 2007), in press.

Incrocci, L., Incrocci, G., Pardossi, A., Lock, G., Nicholl, C. and Balendock, J (2008) “The calibration of WET sensor for volumetric water content and pore water electrical conductivity in different horticultural substrates”. Acta Horticulture, in press. (UNIPI_WP9_2Y_doc01.pdf)

Incrocci L., “La tecnica della subirrigazione in serra: problematiche inerenti l'uso di acque saline in colture ortofloricole [The use of the subirrigation in greenhouse: problems related to the cultivation of vegetable crops using saline water]”. Giornata di studio: “Coltivare senza suolo a ciclo chiuso: subirrigazione e irrigazione a goccia”[The soilless closed-systems: the subirrigation and drip irrigation techniques]. Battipaglia, (Sa, Italy), 23 Oct 2008. (Incrocci Battipaglia_23_10_08_ppt.pdf).

Incrocci L., “Un’analisi dell’uso dell’acqua nel vivaismo ornamentale e possibili strategie per una maggiore efficienza dell’irrigazione e della fertilizzazione”. Seminario tecnico: " “La razionalizzazione dell’irrigazione e della fertilizzazione nel settore vivaistico”, Pistoia, 5 June 2008. (UNIPI_WP9_2Y_ppt03.pdf)

Incrocci L. (coauthor: S. Spagnol), “Dual water irrigation of container-grown ornamentals”. International workshop on “Innovative irrigation technologies for container-grown ornamentals”, Pistoia, 10 July 2009 (Incrocci Pistoia_10_07_09 _ppt.pdf).

Incrocci I., Incrocci G., Pulizzi R., Malorgio F., Pardossi A., Spagnol S., M Marzialetti P. 2009. Più efficienza all’irrigazione con i sensori dielettrici. L’Informatore Agrario 40, 39-41 (Technical article: Incrocci dielectic sensors IF_09.pdf).

Incrocci I., Incrocci G., Pulizzi R., Malorgio F., Pardossi A., Spagnol S., M Marzialetti P., 2009. Per un’irrigazione sostenibile. Colture Protette 11, 48-51 (Technical article: Incrocci dielectric sensors CP 11_09.pdf).

Incrocci L. was a teacher on an advanced course on “The greenhouse and its climate management” held in Sicily (Italy) from 23 to 25 November 2009. The course was organized by the Agricultural Extension Service of the Sicily region (Italy). During this advanced course, the CSR database as useful tool for obtaining information on evapotranspiration requirement and salt-tolerance of some greenhouse crops was presented to the participants (about 40 people). (Incrocci Comiso course_24_11_09_ppt.pdf).

Incrocci L. (coauthor: S. Spagnol), “Dual water irrigation of container-grown ornamentals”. International workshop on “Innovative irrigation technologies for container-grown ornamentals”, Pistoia, 10 July 2009. (handouts attached as pdf file)

Incrocci L., “La gestione irrigua delle colture ortive in funzione dell’umidità del terreno”. [Root zone sensor for irrigation management in vegetable crops]. Seminar on “Criteri di gestione degli impianti e degli interventi irrigui per il risparmio idrico”, Alberese (Grosseto), 16 Jul 2009. (handouts attached as pdf file)

Incrocci, R. Cianfarra, C. Giangiulio, A. Pardossi (Eds.). 2009). Irrigazione e concimazione delle colture ornamentali in contenitore. Edizioni ARSAA, Regione Abruzzo. 63 pp. Textbook: PDF AVAILABLE

Incrocci I., Incrocci G., Pulizzi R., Malorgio F., Pardossi A., Spagnol S., M Marzialetti P. 2009. Più efficienza all’irrigazione con i sensori dielettrici. L’Informatore Agrario 40, 39-41. Technical article: PDF AVAILABLE

Incrocci I., Incrocci G., Pulizzi R., Malorgio F., Pardossi A., Spagnol S., M Marzialetti P., 2009. Per un’irrigazione sostenibile. Colture Protette 11, 48-51. Technical article

Incrocci , L.; Incrocci, G.; Lock, G.; Nicholl, C.; Pardossi, A.; Balendonck, J. 2009. The calibration of WET-sensor for volumetric water content and pore water electrical conductivity in different horticultural substrates. Acta Horticulturae (ISHS) 807, 289-294. PDF AVAILABLE

Incrocci, L., “Il monitoraggio radicale per il controllo dell’irrigazione e della fertilizzazione nelle colture florovivaistiche”. [Root zone sensor for irrigation management in ornamental crops]. Workshop on “Colture florovivaistiche: tecnologie ed informatica per la gestione sostenibile dell’irrigazione e della nutrizione”, Villanova (Pescara) 27 Oct 2009. (handouts attached as pdf file)

Incrocci L., Marzialetti P., Incrocci L., Balendonck J., Spagnol S. and Pardossi A. The Application of the WET Sensor for the Management of Reclaimed Wastewater Irrigation in Container-Grown Ornamentals (Prunus laurocerasus L.)Third International Symposium on Soil Water Measurement Using Capacitance, Impedance and TDT, Murcia, Spain, April, 7–9, 2010.

Incrocci L., Spagnol S., Incrocci G., Marzialetti P., Pardossi A. Root zone sensor for irrigation scheduling in outdoor container cultivation of ornamental nursery stocks. In litteris

Incrocci L., Spagnol S., Incrocci G., Marzialetti P., Pardossi A. Crop evapotranspiration model fors scheduling irrigation in outdoor container cultivation of ornamental nursery stocks. In litteris

Incrocci L., Spagnol S., Incrocci G., Marzialetti P., Balendonck J., Pardossi A. WET sensor for managing dual water irrigation in outdoor container cultivation of ornamental nursery stocks. In litteris

Incrocci L., Spagnol S., Incrocci G., Marzialetti P., Pardossi A. Root zone sensor for irrigation scheduling in outdoor container cultivation of ornamental nursery stocks (In litteris)

Incrocci L., Spagnol S., Incrocci G., Marzialetti P., Pardossi A. Crop evapotranspiration model fors scheduling irrigation in outdoor container cultivation of ornamental nursery stocks. (In litteris)

Incrocci L., Spagnol S., Incrocci G., Marzialetti P., Balendonck J., Pardossi A. WET sensor for managing dual water irrigation in outdoor container cultivation of ornamental nursery stocks. (In litteris)

Kirkels, M., Balendonck, J. 2008. Wageningen op zoek naar de ideale vochtsensor, Tuinbouw Onder Glas, Februari 2008 (NL).

La Fata S., Incrocci L., Malorgio F., Pardossi A., Battista P., Rapi B., Bacci L. 2009. The influence of irrigation method on pot geranium (Pelargonium peltatum L.) grown with saline water (2008). . International ISHS Symposium “Strategies towards Sustainability of

Protected Cultivation in Mild Winter Climate”, Antalya, 7-10 aprile 2008. Acta Horticulturae (ISHS) 807, 283-288. PDF AVAILABLE

López-Mata, E., Domínguez, A., Tarjuelo, J.M., Artigao, A., De Juan, J.A., 2008. SISTEMA DE AYUDA A LA TOMA DE DECISIONES VIA ON-LINE APLICADO A LOS SERVICIOS DE ASESORAMIENTO DE RIEGO, XXVI Congreso Nacional de Riegos AERYD, June 24-26 2008. Huesca (Spain).

López-Mata, E. Tarjuelo, J.M., de Juan, J.A., Ballesteros, R.,Domínguez, A. EFFECT OF THE IRRIGATION UNIFORMITY ON THE ECONOMIC EFFICIENCY OF A CROP. VI International Symposium on Irrigation of Horticultural Crops. November 2-6 2009. Viña del Mar (Chile).

López-Mata, E., Tarjuelo, J.M., de Juan, J.A., Artigao, A., Ballesteros, R. Domínguez, A. EFECTO COMBINADO DEL RIEGO DEFICITARIO Y LA UNIFORMIDAD DE RIEGO. XXVII Congreso Nacional de Riegos AERYD. Asociación Española de Riegos y Drenajes. June 16-17 2009. Murcia (Spain).

LÓPEZ-MATA, E., TARJUELO, J.M., DE JUAN, J.A., BALLESTEROS, R., DOMÍNGUEZ, A. 2010. Efecto combinado del riego deficitario y la uniformidad de riego. Agricultura (Accepted).

LÓPEZ-MATA, E., TARJUELO, J.M., DE JUAN, J.A., BALLESTEROS, R., DOMÍNGUEZ, A. 2010. Effect of irrigation uniformity on the profitability of crops. Agricultural Water Management. (Under revision).

López-Mata, E., Domínguez, A., Tarjuelo, J.M., Artigao, A., De Juan, J.A. SISTEMA DE AYUDA A LA TOMA DE DECISIONES VIA ON-LINE APLICADO A LOS SERVICIOS DE ASESORAMIENTO DE RIEGO. XXVI Congreso Nacional de Riegos AERYD, June 24-26 2008. Huesca (Spain).

Marzialetti P., “L'irrigazione delle colture vivaistiche: situazione attuale e prospettive”. Seminario tecnico: “La razionalizzazione dell’irrigazione della fertilizzazione nel settore vivaistico”, Pistoia, 5 June 2008. (UNIPI_WP9_2Y_ppt02.pdf)

Marzialetti P., “Cambiamenti climatici ed impatto sulle colture vivaistiche. L’uso dell’agrometeorologia nel pilotaggio dell’irrigazione nel vivaismo ornamentale: esperienze e problematiche”. Seminario: “Applicazioni dei dati agrometeoclimatici nel settore ortoflorovivaistico, in relazione ai cambiamenti climatici”, Pisa (Italy), 10 Oct 2008. (UNIPI_WP9_2Y_ppt06.pdf).

Marzialetti P., L., “Il monitoraggio radicale per il controllo dell’irrigazione e della fertilizzazione nelle colture florovivaistiche”. “Monitoring root zone condition for the management of irrigation and fertilisation in ornamental crops”. Workshop on “Tecnologie ed informatica per la gestione sostenibile dell’irrigazione e della nutrizione” Villanova (Pescara) 27 Oct 2009. (handouts attached as pdf file)

Marzialetti P., Incrocci L., Pardossi A. 2009. Attività di ricerca svolta nel 2008 dal Centro nel settore della gestione dell’irrigazione. Notiziario Ce.Spe.Vi. 165, Nov.-Dic, 4-10. Technical articles: PDF AVAILABLE

Marzialetti P., Pardossi A., Incrocci L.. 2009. Risparmio idrico: una ricerca del 2008 sulla gestione intelligente dell’irrigazione. Linea Verde 34 (3), 32-36. Technical articles: PDF AVAILABLE

Pardossi A., Incrocci L. , Marzialetti P., Bibbiani C. (2007). I substrati e la coltivazione delle piante in contenitore. Atti del Convegno CIEC “Substrati di coltivazione: sviluppi qualitativi, tecnici, legislativi e commerciali”, Milano, 18-19 gennaio 2007. Fertilitas Agrorum, in press. UNIPI_WP9_doc01.pdf

Pardossi A, “I substrati e la coltivazione delle piante in contenitore”. Convegno CIEC “Substrati di coltivazione: sviluppi qualitativi, tecnici, legislativi e commerciali”. Milano, 18 gennaio 2007.

Pardossi A., “Modellizzazione del bilancio idrico e minerale di colture idroponiche a ciclo chiuso”. Giornata di Studio su "La coltivazione degli ortaggi con sistemi di coltivazione senza suolo". 22 giugno 2007, Mola di Bari (BA).

Pardossi A., "Economia della tecnica di coltivazione a ciclo chiuso: punti di forza e di debolezza.. Convegno "Strategie per il florovivaismo ecocompatibili", Padova, 13 Sep 2007.
Pardossi A.. 2008. Acqua irrigua e qualità dei prodotti agricoli. Atti del 2° Congresso nazionale "Qualità del Suolo, Alimenti e Salute", Bari 22-24 ottobre 2008. Biologi Italiani, 34 (9), 97-100. Technical article
Pardossi A., "What limits and how to improve water use efficiency in outdoor container cultivation of ornamental nursery stocks". International Symposium ISHS on Soilless Cultures and Hydroponics", Lima (Peru), 24-28 august 2008. (UNIPI_WP9_2Y_ppt04.pdf)
Pardossi A., "The influence of fertigation strategies on water and nutrient efficiency of tomato grown in closed soilless culture with saline water. International Symposium on "Strategies Toward Sustainability of protected cultivation in mild winter climate.", Antalya, 6-11 Apr. 2008. UNIPI_WP4_2Y_ppt01.pdf
Pardossi A., "The calibration of WET sensor for volumetric water content and pore water electrical conductivity in different horticultural substrates". International ISHS Symposium on "Strategies Toward Sustainability of protected cultivation in mild winter climate", Antalya, 6-11 Apr. 2008.(UNIPI_WP9_2Y_ppt01.pdf)
Pardossi A. "Traditional and new approaches to irrigation scheduling in vegetable crops", International ESA Workshop on "Improvement of nitrogen and water use efficiency: interest of assessment tools in vegetable crops", Bologna, 16 September 2008. (UNIPI_WP4_ppt05.pdf)
Pardossi, A., Incrocci, L., Incrocci, G., Marzialetti, P. and Tognoni (2009). What limits and how to improve water use efficiency in outdoor container cultivation of ornamental nursery stocks". Acta Horticulture, in press. (UNIPI_WP9_2Y_doc02.pdf).
Pardossi, A., Incrocci, L., Massa, D., Carmassi, G. and R. Maggini, 2009. The influence of fertigation strategies on water and nutrient efficiency of tomato grown in closed soilless culture with saline water". Acta Hort. 807:445-450 (Pardossi_Acta_Hort_807.pdf).
Pardossi A., "Metodi innovativi nella gestione dell'irrigazione: sistemi chiusi e sistemi senza drenaggio". [Innovative approach to irrigation management: closed and zero-runoff system] Seminar, Pescara, 26 March 2009. (handouts attached as pdf file)
Alberto Pardossi, Luca Incrocci, Giorgio Incrocci, Fernando Malorgio, Piero Battista, Laura Bacci, Bernardo Rapi, Paolo Marzialetti, Jochen Hemming and Jos Balendonck, 2009. Root Zone Sensors for Irrigation Management in Intensive Agriculture. Sensors 2009, 9, 2809-2835; doi:10.3390/s90402809, ISSN 1424-8220, www.mdpi.com/journal/sensors. 21 April 2009.
Pardossi A., Estimating plant transpiration for irrigation scheduling in greenhouse crops. International Workshop on "Innovative irrigation technologies for greenhouse vegetables", Menderes, Izmir (Turkey), 23 June 2009. (handouts attached as pdf file)
Pardossi A., "La gestione irrigua delle colture ortive in funzione dell'umidità del terreno". [Root zone sensor for irrigation management in vegetable crops]. Seminar on "Criteri di gestione degli impianti e degli interventi irrigui per il risparmio idrico", Cesia (Arezzo), 2 July 2009. (handouts attached as pdf file)
Pardossi A., Incrocci L., Marzialetti P., 2009. Proceedings of the International Workshop on Innovative irrigation Technologies for Container-grown Ornamentals. Pistoia, 10 July 2009. (Summaries and handouts). Proceedings: PDF AVAILABLE (ITALIAN AND ENGLISH)
Pardossi A., "La qualità dell'acqua e la gestione della risorsa" [Water quality and how to manage it]. Acta of the "II National Congress on soil and environment quality and health", held in Bari from 22 to 24 October 2009.
Pardossi A., "Strategie per la riduzione dell'impatto ambientale nel florovivaismo". [Strategies for mitigating environmental impact of ornamental crops]. Workshop on "Colture florovivaistiche: tecnologie ed informatica per la gestione sostenibile dell'irrigazione e della nutrizione", Villanova (Pescara) 27 Oct 2009. (handouts attached as pdf file)
Pardossi A., Incrocci L. Traditional and new approaches to irrigation scheduling in vegetable crops. PDF AVAILABLE (Submitted)

Rousan, L. M., M. J. Rusan and J. Amayreh. 2008. Irrigation with Treated Wastewater under Full and Deficit Soil Moisture Conditions. Eds: Hashem Al-Mattarneh, Lariyah Mohd Sidek and Mohd Zamri Yusoff: Proceeding of the International Conference on Construction and Building Technology (ICCBT): Innovations in Water Resources and Environmental Engineering. Kuala Lumpur, Malaysia. (38): 405-416.

Sigrimis, N., Y. Tuzel, F. Kempkes, J. Balendonck, R.; L. Incrocci, W.R. Whalley, 2008. Proceedings Irrigation workshop, Ierapetra, Crete, 7-11-2008.

Stanghellini, C., 2006. Il valore dell'acqua nel vivaismo: prima il prezzo o la qualità? (Value of water in plant nursery: what comes first, water price of water quality?). Public seminar at Pistoia test-site, attended by local actors (both agriculture and politics), Dec 1st, 2006.

Os, E.A. van, J. Balendonck, E. Beerling, 2009. Protected and non-protected horticulture: improving water use efficiency in soil and soilless cultivation. Leaflet: II Spanish and Dutch Innovation Water Event, Leeuwarden, 3 dec 2009 (NL)

Tuijl, B. van, E. van Henten, J. Hemming, 2007. Wireless Sensor Networks, GreenSys 2007, Napels, 5-10-2007. To be published in ISHS proceedings.

Tuzel İ. H. Tuzel, Y., Meriç K, Öztekin G., Whalley, R, Lock, G., 2008. REPONSE OF CUCUMBER TO DEFICIT IRRIGATION, ISHS Symposium on Protected Cultivation for Mild Winter Climates, Antalya, 2008. Presentation.

Tüzel, I.H., Tüzel, Y., Öztekin, G.B., Meriç, M.K., Whalley, R., Lock, G., 2009. Response of Cucumber to Deficit Irrigation. Acta Hort. 807:259-264.

Verstegen, S. (J. Balendonck, J. de Haan, F Kempkes, J. Wilms, K. van Wijk), 2009. IJsbergsla aan het infuus. Groenten en Fruit, no.29, 17 juli 2009 (NL).

Whalley, W.R., L.J. Clark, W.A. Take, N.R. Bird, P.K. Leech, R.E. Cope & C.W. Watts, 2007. A Porous Matrix Sensor to measure the matric potential of soil water in the field, European Journal of Soil Science, February 2007, 58, 18-25 (Pre-existing Knowledge).

Whalley, R.W., 2008. Farm Level Optimal Water Management: Assistant for Irrigation under Deficit, RRA Newsletter - February 2008, 7-8-2008.

W.R. Whalley, G. Lock, M. Jenkins, T. Peloe, K Burek, J. Balendonck, W. A. Take, İ.H. Tuzel and Y.Tuzel, 2009. Measurement of Low Matric Potentials with Porous Matrix Sensors and Water-Filled Tensiometers. Soil Science Society America Journal, Volume 73: Number 6, Nov.-Dec 2009.

W. R. Whalley, M Goodchild, M. Jenkins, Tony Peloe and K Burek, J. Balendonck, İ.H. Tuzel and Y.Tuzel, 2010. Soil-based sensors and irrigation scheduling. Presentation at the Lancaster Environmental Centre, Irrigation Day, Lancaster (UK), march 18, 2010.

Wijk, C.A.P. van; Wilms, J.A.M.; Haan, J.J. de; Balendonck, J. , 2009. Sensoren en fertigatie in ijssla. Wageningen UR, 2009 Telersbijeenkomst, Vredepeel, 2 juli 2009