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Water in Agriculture: New systems and technologies for irrigation and drainage

Farm Level Optimal Water management: Assistant for Irrigation under Deficit

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Proceedings of the FLOW-AID workshop in Ierapetra (Crete, Greece)

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<td>Alfonso Dominguez</td>
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<td>P7</td>
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<td>Dick Jenkins</td>
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<td>Kazimierz Burek</td>
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<td>P8</td>
<td>GEOMATIONS-GR</td>
<td>Nick Sigrimis (Nick S.)</td>
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<td>Axilleas Anastasiou</td>
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<td>SPAGNOL-IT</td>
<td>Serafino Spagnol (not on picture)</td>
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<tr>
<td>P10</td>
<td>JUST-JO</td>
<td>Jumah Amayreh</td>
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Technical Tour & Ierapetra Conference

The group has left from North Heraklion to reach South. The way was a bit confusing and some time was lost.

16.45 The team has reached Psari Forada where Satellite Internet is supplied and a wireless Greenhouse Network (WGN) is developed and working for 3 years now. The group visited a hydroponic plastic greenhouse where a Macqu hydroponic machine is operating. The grower gave a connectivity demonstration: with his notebook WiFi has had a connection to WGN and with that he was able to login remotely to Macqu server and show a remote management (i.e. sent an irrigation command for greenhouse chamber where the group was and have seen the irrigation started.

Then the group visited a nearby installation where they came in contact with Macqu hydroponics and how irrigation is controlled for soil cultures.

18.00 The group left for Ierapetra about 45 minutes away. The time was late and dark and did not allow visiting the Water Dam as planned in the program.
Ierapetra Greenhouses are supplied with water from a water Dam which is harvesting rain and that is currently empty of rain water and is supplied from seashore fountains with an EC of 2.2 dS/m.

19.00 Convention was at City Hall Melina Merkouri convention center. About 150 attendees were gathered and the group was acquainted with the Ierapetra City Mayor and the Siteia County Vice Mayor (Antinomarchis). The presentations started at 19.30. The event had 2 sessions chaired by Mrs Anna Mihou. All presentation will be bundled by Nick S. and be made available as a dissemination activity. The Program was:

<table>
<thead>
<tr>
<th>TIME</th>
<th>Subject</th>
<th>Speaker</th>
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<tbody>
<tr>
<td>19.30-19.45</td>
<td>Welcome</td>
<td>City Major Mr Mastorakis and Vice County Major</td>
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<tr>
<td>19.45-20.05</td>
<td>1. FLOW-AID- Water Use under deficit 2. <strong>Greenhouses in Holland</strong></td>
<td>Jos Balendonck, PRI Wageningen Frank Kempkes PRI Wageningen</td>
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<td>20.05-20.20</td>
<td>FLOW-AID – New soil moisture sensors for <strong>better water use</strong></td>
<td>Richard Whalley, RRES-UK</td>
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<td>20.20-20.40</td>
<td>Water deficit Irrigation and <strong>Greenhouses in Antalya</strong></td>
<td>Yuksel Tuzel, Ege University - Izmir</td>
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<td>20.40-20.55</td>
<td>Water sources and <strong>Irrigation in Sicily and Almeria</strong></td>
<td>Luca Incroci, University Pisa</td>
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<td>20.55-21.00</td>
<td>BREAK</td>
<td>Migiros G. Prof Geology, AUA</td>
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<tr>
<td>21.00-21.35</td>
<td>New Geohydrologic methods and shoreline water fountains</td>
<td>Karadounias G. Prof Hydraulics – AUA</td>
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<td>21.35-21.55</td>
<td>Water storage banks and complementary measures</td>
<td>Audience</td>
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<td>21.55-22.25</td>
<td>Discussion - Questions</td>
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<td>22.25 –</td>
<td>SUMMARY &amp; Water needs in Ierapetra</td>
<td>Sigrimis N. Prof Mechanics and Automation – AUA</td>
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</table>
Jos Balendonck presenting FLOW-AID (left). Nick Sigrimis translating Eng-Greek.

Yuksel Tuzel, presenting greenhouse production in Turkey.

Participants at 23.00 ended to a Greek Taverna in Ierapetra where they have had the dinner offered by Geomations, until 01.30. Then returned to Creta Maris Hotel in Hersonissos (the flow-aid meeting hosting hotel).
Farm Level Optimal Water management: Assistant for Irrigation under Deficit (FLOW-AID)
J. Balendonck, Wageningen-UR Horticulture

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 feedback, 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

<table>
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<tr>
<th>Participant organisation name</th>
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<tr>
<td>Wageningen University &amp; Research Center</td>
<td>PRI</td>
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<td>Plant Research International</td>
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<td>Rothamsted Research</td>
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<tr>
<td>Lebanese Agricultural Research Institute</td>
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<td>Department of Irrigation and Agro-Meteorology</td>
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<tr>
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<td>Regional Center of Water Research</td>
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<tr>
<td>Ege University Faculty of Agriculture</td>
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<tr>
<td>Dept. of Agric. Structure and Irrigation</td>
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<tr>
<td>University of Pisa</td>
<td>UNIPI</td>
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<td>Dipartimento di Biologia delle Piante Agrarie</td>
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<td>Delta-T Devices Ltd.</td>
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<td>Geomations S.A.</td>
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<td>Spagnol Srl</td>
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<td>Jordan University of Science and Technology</td>
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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).

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 Pistoia (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 assess 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 cooperation 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.
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. It showed that the farmer treatment had the highest crop yield, 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.

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. The coordinator maintains a web-site for the project (www.flow-aid.eu).

In the Annexes a list of dissemination activities and publications can be found.
Water needs in Ierapetra
Sigrimis N. Prof Mechanics and Automation – AUA

“Save water when you have it, to have it”!!!
Geomations has have many links and customers to this island, has helped with conferences in concern with new technologies and water and fertigation strategies and has made major technological contributions, as seen below.

Crete threatened by Desertification
50% of land in Crete and 35% of land in Greece is at high risk of desertification, with dire consequences for the country’s economy and demographic. This is the conclusion was reached by a three-day scientific conference organized by the Agricultural University of Athens in Heraklion, Crete. The conference was part of the “Desire” scientific programme, comprising 28 research institutes and universities from around the world. The findings were judged worrying by those attending the conference, as they emerge from scientific studies of the phenomenon of desertification observed in many areas of the planet. According to the President of the National Committee for Combatting Desertification, Professor of Soil Science Kostas Kosmas, east Crete is considered the area of Greece most at risk of desertification. There are two reasons for this: the warm climate with low rainfall, and human intervention. Today 35% of Greece is at risk of, or partially subject to, desertification, while 49% is at moderate risk of desertification.

Desertification and Agriculture
Farmers may be the first to suffer from desertification, but they are also part of the problem. They contribute to desertification through over-intensive use of land, misuse of irrigation water and wrong water scheduling, over-pumping of groundwater, irrigation with water with a high mineral salt content, use of acidic chemical fertilizers and destruction of vegetation.

1. Ierapetra - Salinity
Region: Greece, Crete, Ierapetra
Crops: Greenhouses (tomatoes, cucumber, peppers, ornamentals, bananas), olive trees.
Cropping sytem: Tomatoes in greenhouses on soil and olive trees for high grade oil.
Irrigation system: pressurized network fed from water Dam.
Water Sources: water Dam, near-shore fountains and underground wells
Background: Expanding horticulture and diminishing water sources
Local problems: Increased pumping produces Salinity in wells and in undersea fountains
Solutions and research targets: Improve Rain Harvest in Dam and Water saving practices

Importance
Ierapetra is located at the eastern part of the island and suffers of the lowest precipitation (300mm) while being of highest horticultural activity. Crete represents 50% of protected crop area of Greece and 50% of the protected area of the island is located in Ierapetra. In recent years Salinity has become a severe problem due to regional water deficit. The reasons are the following:
I. Growers income is reduced and react by
   a. expanding the protected area, which is increasing water consumption
   b. extending the crop time cycle from Sept-April to Sept-July that is they move to higher water demand period.
   c. Olive oil is another source of income and olive tree irrigation is expanding for achieving higher production (although scientifically is proved that olive trees need very little irrigation water (i.e. once a year in late summer) for no yield reduction.
   d. The above reasons have **doubled** water consumption, while

II. Rain Harvest for community Water Dam is not maintained nor improved, and
   a. Rain duct pipes are plugged with soil and this has diminished the flow capacity to the Dam
   b. Climate change has led to abnormal rain conditions (abnormal distribution to more sudden heavy rains which drastically reduces the water capture percentage for the Dam)
   c. Increased water consumption with less water feeding to Dam resulted to “empty” water Dam and the need to **increased pumping**, and

III. Increased pumping has lowered water table and
   a. Wells have salinized
   b. Near-shore fountains (Malavra fountains) are overpumped and led to seawater intrusion, that is Water Dam is fed with pumped water of EC 2.2mmhos or higher.

The above conditions of increased irrigation water demand coupled with less water captured results to **salinity** and risk for desertification and an economic vulnerability of the region with unforeseeable consequences. The establishment of a test site for problem solving solutions with multidialogues and participation of all sharehordels will give the project Fame to problem solving much higher than investment needed. It is of special attention that local friction among different water users (civil and farming) will be resolved due to the respect and trust paid to an EU research project.

**Objectives and tests**

1. Improve rain catchments of water Dam by a **Water Balance Study of the Ierapetra Region**, to be conducted by IMPULSE-MED project, in consultation with expert professors of the Agricultural University of Athens (prof Migiros hydrogeologist, prof Karadounias Ag. Hydraulics and Dams, prof Kosmas desertification) to prove the importance of better rain harvest efficiency “**Save the Water when you have it, to have it**”.

2. Establish Impulse-MED technologies
   a. soil moisture sensors and wireless sensor network,
b. DSS irrigation scheduling,
c. optimized water allocation (olive trees & greenhouses),
d. good governance at catchments level and polices for promoting a more responsible
   and efficient use of irrigation water at farm level with Participatory
To achieve the above a multidialogue approach for participatory planning is possible because
the responsible partner has already an established collaborative effort with
1. Individual Farmers, Groups and Cooperatives
2. The Local Water Management Authority (TOEB)
3. The city major to apply policies for urban and agricultural use.
4. Governmental Water Management Authorities of the Region of Crete.

2. Sithonia (Psari-Forada)- Fertilizer use efficiency

| Region: | Greece, Crete, Sithonia |
| Crops: | Greenhouses (cucumber, bananas), olive trees. |
| Cropping sysyms: | Substrate (pumice) and conventional (on soil) |
| Irrigation system: | pressurized network fed from community wells. |
| Water Sources: | community underground wells |
| Background: | Warm winter, 100% cucumber for exporting, high technology is started. |
| Local problems: | Cost of fertilizers, |

Solutions and research targets: Irrigation DSS for **fertigation scheduling** and water recycle

**Importance**

Saving water is of vital environmental importance but it cannot be viewed separate of
fertilization on high value horticultural crops, which usually are demanding significant amounts
of fertilizers. The method of application, the timing and the amount (fertigation EC) are important
factors for higher Water and Fertilizer Use Efficiency. Growers of Sithonia area young growers
and open to adopt new technologies ad new cropping methods. As shown below, in cooperation
with the responsible partners they have:

1. Developed a wireless greenhouse network for the whole community, that is they have
   covered their community and business area with “network everywhere”.
2. Being in a remote area where wires cannot carry DSL signals the partner has offered, as
   a prize for the eager to “advance to a global village”, satellite Internet connection and
   shift from “digital divide” situation to a “modern city” connectivity.
3. Having a single Internet connection and wireless coverage they have Internet and
   Connectivity inside their houses and their greenhouses. Therefore they can monitor and
   manage their greenhouses from the house or any place around the world (a web camera
   is also installed to bring that remote place on the net).
4. many growers have adopted hydroponics and substrate cultivation and are using most
   recent scientific findings with regards to plant nutrition and watering.

This site is well equipped and growers informed to apply recent technological advances for
water and fertilizer saving.
MACQU technology & Remote Crop Management – Wireless Greenhouse Network in South Crete based on WiFi by Geomations SA

Higher GH technology ready to accept new technologies for water saving in high demand cucumber and need for “water & fertigation decision support”
Objectives and tests
1. Prove advantages of substrate cultivation in water and fertilizer savings with water recycle
2. Prove advantages of DSS in water and fertilizer computed scheduling (lowest possible fertilizer use or maximum water and fertilizer use efficiency)
3. Use this site as Open Farm for nearby City of Ierapetra to promote modern, high water saving methods in greenhouses, like substrate and water recycle, to less technology adopting growers of Ierapetra.

3. Archanes – Vineyards precision irrigation
Region: Greece, Crete, Archanes
Crops: vineyards for wine and table grapes, olive trees.
Cropping systems: Krevatines prune shape
Irrigation system: drip irrigation
Water Sources: underground wells
Background: Improve wine quality and table grapes by balanced precision irrigation
Local problems: Moderate Water shortage and Wine Quality
Solutions and research targets: Irrigation DSS for precision fertigation scheduling

Importance
The Archanes region was known even since the Minoan age for the production of olive oil and high quality wine. Today these two multi annual cultures occupy 96% of the region’s cultivated ground and they are evenly distributed.

The varieties of these cultures are:

<table>
<thead>
<tr>
<th>Culture</th>
<th>Variety</th>
<th>Product</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cultivation of olive trees</td>
<td>Koroneiki</td>
<td>Olive oil</td>
</tr>
<tr>
<td>Vine-growing</td>
<td>Soulta</td>
<td>Grape</td>
</tr>
<tr>
<td></td>
<td>nina</td>
<td>Table Grape</td>
</tr>
<tr>
<td></td>
<td>Kotsifali</td>
<td>Wine</td>
</tr>
<tr>
<td></td>
<td>Mantilari</td>
<td>Wine</td>
</tr>
<tr>
<td></td>
<td>Bilena</td>
<td>Wine</td>
</tr>
<tr>
<td></td>
<td>Razaki</td>
<td>Table Grape</td>
</tr>
</tbody>
</table>

Forms of agriculture
Up to the 60’s Agriculture had an extensional form with absolute respect for the environment. Minimal alterations in the productive process were used. The agriculture that was applied in the 70’s was 100% intensively conventional. Output was high and the rural population prospered economically. However, increased environmental problems were created. In the beginning of the 90’s the application of Biological Agriculture begun.

Today biologically cultivated fields cover about 2% of the entire cultivated extent. Cultures that have been included in the Biological Agriculture have to do with olive and vines. However, environmental issues can’t be ignored for long. At the same time, consumer requirements for safe and healthy foods have increased. The producers’ attitude to Biological Agriculture is beginning to change and thus during the last four years they have chosen an environmental friendlier production method.

The Integrated Production Management (IPM) System has been adopted in the production of table grapes because they were produced by the most intensive way of Conventional Agriculture (big quantities of inputs, fertilizers, water, pesticides).

Wine and olive oil quality is the central issue for Archanes production and a well controlled and knowledgeable system that will irrigate and fertilize at rates permitted by IPM to produce certified products but also to enhance the quality and stability for creating and maintaining a first quality name on wines and olive oil.
The growers' cooperatives of Archanes (President ??) is willing to cooperate with the IMPULSE project to experiment the latest technology application on irrigation scheduling and fertilization. Given the fact that grapes and olive is not of high demand for water, the precision application will be to AVOID over-irrigation and over-fertilization (a common practice of growers to secure quantity) while guarantying desired quantity/quality ratios.

Objectives and tests

1. Prove advantages of WSN and DSS in water and fertilizer computed scheduling (precision farming in wine and grapes quality)
2. Model water needs of vineyards of specific Cretan varieties to weather conditions of Crete.

Disseminate results on water-quality relation for vineyards
Annex 1: LIST OF PUBLICATIONS


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


Annex 2: Reprints of power-point presentations

FLOW-AID- Water Use under deficit, Jos Balendonck, PRI Wageningen

Greenhouses in Holland, Frank Kempkes PRI Wageningen

FLOW-AID – New soil moisture sensors for better water use, Richard Whalley, RRES-UK

Water deficit Irrigation and Greenhouses in Antalya Yuksel Tuzel, Ege University - Izmir

Water sources and Irrigation in Sicily and Almeria, Luca Incrocci, University Pisa
FLOW-AID - Water Use under deficit
Jos Balendonck, PRI Wageningen
Farm Level Optimal Water Management Assistant for Irrigation under Deficit

Jos Balendonck

Irapetra (Crete), November 8, 2008

Contributing countries and target areas

Coordinator:
Wageningen-UR (NL)
2006-2009
Duration: 3 years
Partners: 10
Budget: about 1.7 M€

Test-sites
Partners (Universities/SMEs)
Water management trends

- Over irrigation in cases of high (fresh) water availability
  - Irrigation amounts depend on availability
  - Leaching or run-off of water and nutrients

- Deficit irrigation if water availability and irrigation water quality is low
  - Use of marginal water resources
  - Yield losses and crop damages

Objectives

- Efficient use of available water (SAVE WATER)
- Rational use of nutrients and marginal water resources (SAVE NUTRIENTS)
- Economically and socially accepted farming (EARN MONEY)
  By:
  - Improving current irrigation practices by introducing new tools:
    - Decision Support System for optimal irrigation
    - Sensitive, simple and cheap tools to determine optimal amount and source of water
    - Use in Mediterranean countries
    - for protected and non-protected cultivation
### System Layout

- **Plot 1**
  - Valves
  - Sensors
- **Plot 2**
  - Sensor Node (MOTE)
- **Local Computer**
  - Grower Input
- **Remote Computer**
- **Irrigation Controller**
- **Wireless Network**
- **Decision Support System**
- **Farm Zoning Module**
- **Crop Response Model**
- **Crop Database**
- **Basin Management Weather/Water Forecasting**

### DSS-Irrigation Scheduler

- Farm-level tool
- Day to day planning
- Short-term Water Availability
- Weather Forecasts
- Plant Status (Crop model)
- Set Irrigation Controllers
Crop Response Model for Deficit

- Yield response to
  - Water Quantity (ET-based)
  - Water Quality (Salinity model)

![Diagram showing the equation Y = 100 - B (EC - A)]

Controller and Sensors

- Irrigation – Fertigation
  - Stand-alone operation
  - Parameterized
  - Wired or via GSM-link
- Activation On/Off
  - Timed
  - Sensor controlled
    - Water content, EC,
    - Tensiometer
    - Temperature, Rain gauge
    - Radiation …
  - Model based (f.i. ET)
  - Multiple valves
  - Multiple water sources
Improve Sensor Performance

- Volumetric Water Content
  - Soil/substrate calibrations
- EC
  - WET-sensor, ECHO-probe
  - Pore Water EC calibration
- Porous Matric Sensors
  - New Tensiometer
  - Large range (no air entry at dry end)

Wireless Sensor Network

- Multiple nodes
- Multiple sensors
- Wireless Advantages
  - No cabling
  - Easy installation and handling
- Robustness in field
  - Weather
  - Data Reliability
  - Long Range
  - Solar powered or long battery life time
Turkey

- Region Izmir (Tahtalı Dam)
  - Preservation area
  - Greenhouses permitted
  - Water from wells, but no leaching allowed

- Test-site targets
  - Test-site at local farmer (Cucumber)
  - Irrigation: zero drainage
  - Sensor activated control
  - Monitoring crop yield and quality

Jordan

- Irbid, Jordan Valley
  - Fruit trees, oriental trees, vegetables
  - Very limited water resources
  - Low water use efficiency
  - Poor water management at farm level

- Pilot Project Site
  - Treated Waste Water (2 types)
    - Extended Aeration (1000 m$^3$/day)
    - Rotating biological contactors (600 m$^3$/day)

- Objectives
  - Experiment with soil grown tomatoes
  - Dual water quality irrigation
  - Efficient irrigation scheduling
  - Use of soil moisture sensors (a.o. EC)
  - Technology transfer to farmers
Nursery stock production
Experimental Station CeSpeVi, Pistoia, Tuscany
Container plants (drip/sprinkler)
Farm sizes: 10 - 100 ha
Irrigation unit size: approx. 1200 m²
Deficit (zero-drain)
Dual water irrigation: Cleaned Waste Water and Fresh Water
Greenhouses in Holland
Frank Kempkes PRI Wageningen
Innovative technologies for an efficient use of energy a draft overview
Frank Kempkes, Jos Balendonck, Wageningen UR Greenhouse Horticulture, NL

1. Trends in Horticulture

- increase of production scale/intensity
- Better control of environmental conditions
- Yearround crop production
- Average energy use is high:
  - Italy: 20%, France: 12-22%, Netherlands: 20-25% of production costs
1. Energy efficient greenhouses:

- Three steps:
  - Maximum use of solar energy
  - Reduction of energy use
    - (winter: minimize energy loss)
    - (summer: efficient cooling)
  - Efficient use: unit product per unit energy

To further reduce CO₂ emission:
Replace fossil fuel by other renewable energy sources

Greenhouse construction for higher transmission

- Increasing cover slope (South Europe)
- Minimized construction parts: e.g. no ventilation system: +1.5%
- Wide glass panels
Covering materials: diffuse light

50% diffuse light 5%

- Lower leaf temperature at high radiation
- Better light penetration
- Higher production

Passive cooling: shading or NIR reflection

Shading screens:
- Reduced total radiation
- Reduced PAR
Comparison of different cooling systems
(Based on return on investment)

- Natural Ventilation
- Roof cooling
- Humidification
- (Selective) Shading
- Forced Ventilation
- Pad/fan
- Forced cooling

Example of heat exchanger with plastic ducts for distribution

Phalaenopsis needs cooling for induction to start flowering
Thank You
Forced cooling

Principle: heat exchangers with forced ventilation by fans and air distribution

- Cooling and dehumidification
- Heat pump system (vapour compression or absorption chiller)
- Optional (endothermic system):
  - No ventilation windows
  - Heat storage in summer
  - Use of stored heat in winter

Ventilation: major process in heat transfer

- Ventilation Capacity
  - Area, shape and position of openings

- Conditions
  - Rate of opening
  - Wind speed/direction
  - Temperature difference inside-outside
2. Optimal use of solar energy (materials and construction)

3. Reduction of energy use (summer: Energy efficient cooling)
Example of heat exchanger local distribution
FLOW-AID – New soil moisture sensors for better water use
Richard Whalley, RRES-UK
Workpackage: WP 1, Innovative monitoring tools (dielectric solid-state tensiometer).
Date: 28 October 2008
Participant: RRES (and Delta-T)

The water-filled tensiometer

Typically used between 0 and -90 kPa
New prototype

Field experiment

Irrigated cucumbers in a poly-tunnel near Izmir Turkey
Installing sensors in the field

Using SM160
to control irrigation

Zone 2
Date
Matric potential -kPa
0 20 40 60 80 100 120 140
Water content g/cm³
3 15 20 25 30 35 40 45

Zone 3
Date
Matric potential -kPa
0 20 40 60 80 100 120 140
Water content g/cm³
3 15 20 25 30 35 40 45
Field data

Drought experiment at Woburn
Concluding comments

• Water-filled tensiometers can measure low matric potentials, but even the best of these sensors can fail in drying soil

• Porous matrix sensors are more reliable in dry soils
Water deficit Irrigation and Greenhouses in Antalya
Yuksel Tuzel, Ege University - Izmir
Contents

- Introduction
  Protected cultivation in Turkey
  Milestones
  Distribution of protected cultivation
  Cultivated crops
- Greenhouse technology
- Major problems in irrigation
- Flow-Aid project
- Conclusion
**Introduction**

Total protected cultivation has reached to 49745.6 ha in 2006. Area under low plastic tunnel is 30% (14 854 ha) of the total while the rest (34 891.5 ha) is occupied by greenhouses.

**Milestones**

- Introduction of plastics into agriculture (1960s).
- The rise in oil prices resulting in the increase of heating costs enhanced protected cultivation due to mild climate conditions that makes the production possible under very simple shelters (1970s).
- Technological improvements in plastic covering materials (1980s).
- Governmental subsidy (1990-1995).
- Introduction of high tech greenhouses with soilless culture (1990s).
- Becoming of sustainable production techniques widespread (2000s).
Distribution of protected cultivation

77% of the greenhouses and 92.3% of low plastic tunnels are located at the Mediterranean Region.
Vegetable growing with 96% of the total greenhouse area stands first, ornamental plants (3%) especially cut flowers occupy the second place and these are followed by fruits.
**Greenhouse Technology**

**Low-technology greenhouses:** They have very simple structure with plastic covering, poor climate control and, very often, roof sprinkler irrigation system or simple heaters only to protect the plants against frost damage. Conventional growing methods are used in those small scale greenhouses. Therefore synthetic chemicals are used intensively.

**High-technology greenhouses:**

The investment cost is very high. They are generally built with galvanized iron support structure and glass or PE as covering material. More advanced growing technologies, including hydroponics, are used in those greenhouses. IPP techniques are used and generally EurepGAP/GlobalGAP protocol is followed for certification process. Also they have climate control system (central heating system, forced ventilation, shading, evaporative cooling, etc. humidity control).
Major problems in irrigation

- Water availability,
- Efficient use of water,
- Low water quality,
- Salinity.

Availability of water resources in greenhouse areas

Underground water is used for the irrigation in the greenhouses.

Underground water includes all water that occurs below the earth’s surface, it is derived principally from precipitation that falls upon the earth’s surface and percolates downward under gravity.

Precipitation regimes with increased occurrence of growing season droughts and higher frequencies of extreme rainfall events is typical.
Low efficient use of water

- Irrigation method
  Drip irrigation
- Irrigation programming
  - Visual observations
  - Water field tensiometers & soil moisture sensors
  - Solar radiation sensors in full automated soils culture nutrition systems (Very limited).

Low water quality & Salinity

Irrigation water samples were medium (C2) (22.6%) and high salinity (C3) (73.8%) in Demre Region. Salinity of soil samples was not seasonal difference, but irrigation water samples seem to be problem as regards salinity. Moreover most of irrigation water samples have salinity problem.

Sonmez & Kaplan, 2004
Flow-Aid Project

- No attention to the amount of irrigation water at farmers' level,
- Irrigation water quality and amount is gradually decreasing,
- Requirement sensitive but simple technologies to determine the amount.
- The limitation here is on leaching, in view of possible pollution of the water sources.

The aim of this project is to improve and optimise the irrigation practices, by helping farmers to control water more efficiently.

Treatments

- "Farmer's treatment" (Control) irrigation and fertigation was done according to farmers' decisions.
- "Full irrigation" soil water content was allowed to be depleted to % 20 of available water content of the plant root zone,
- "Deficit 1" soil water content was allowed to be depleted to % 40 of available water content of the plant root zone,
- "Deficit 2" soil water content was allowed to be depleted to % 60 of available water content of the plant root zone.

* irrigated according to the current farmer practice.
** irrigation was controlled by GPIs set to keep different soil moisture thresholds.
### Conclusion

Total amount of water applied in Deficit 1 and Deficit 2 were 43 and 35% lower than full irrigation and also 40 and 31% lower than Farmer’s treatment. It seems that the use of new technology can be easily adapted to the farmer conditions. Additionally, environmental impact due to the excess use of water and fertilizers could be decreased with the proper programs including deficit irrigation.
Water sources and Irrigation in Sicily and Almeria
Luca Incrocci, University Pisa
Greenhouse industry in Sicily (Italy) and in Almeria (Spain)

L. Incrocci

Dipartimento di Biologia delle Piante Agrarie, Università di Pisa (incrocci@agr.unipi.it)

Greenhouse in Spain and Italy
Greenhouse industry in Italy

In Italy there are 25,000 hectares of greenhouses. 7,500 are concentrated in Sicily (Iblea coastal).

Cultivated crop in Sicily....

Five top crops:
1. Tomato (cherry type)
2. Pepper
3. Eggplant
4. Cucumber
5. Squash
Greenhouse industry in Sicily: started in 1960

New greenhouse type
New greenhouse type

Greenhouse constrains in Italy

Labour cost  Scarcity of water  Extra EU countries competition

New technology for increase the production

Soilless culture

More attention to the environment
The total cost is about 30 €/m$^2$
But:
More quality;
More production (18 kg/m$^2$ versus 10-11 Kg/m$^2$ of the soil cherry tomato)
The bigger greenhouses concentration in the world: “Campo de Dalias”

Images of astronauts © NASA 2003
**Tomato and pepper in Almeria**

Pepper (8500 ha of pepper with a 63.5 ton/ha; 0.65 €/kg)

Tomato (8400 ha of tomato with a 96.1 ton/ha; 0.71 €/kg)

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**How to manage the water scarcity**

Collect Rain water as in sicily (rainfall is 700 mm/year)

Reverse-osmosis in Almeria (rainfall is about 250 mm/year)
Reverse osmosis in Almeria area

The “Water industry” in Almeria
The sea water is used to produce pure water (0.60-0.7 €/m³)