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FARM LEVEL OPTIMAL WATER MANAGEMENT: ASSISTANT FOR IRRIGATION UNDER DEFICIT (FLOW-AID)

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SUMMARY - FLOW-AID is a 6th Framework European project which started in autumn 2006. The objective is to contribute to the 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 new 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.

Key words: Tensiometer, Wireless, Sensor, Crop, Model, Zoning, Scheduler

RESUME – FLOW-AID est un sixième Cadre projet européen qui a commencé en automne 2006. Il vise à contribuer à la durabilité d'agriculture irriguée dans les situations où il y a une provision d'eau limitée et de la qualité d'eau (l'irrigation de déficit). Il développe et essaie un système de gestion d'irrigation qui peut être utilisé au niveau de ferme dans plusieurs pays méditerranéens. Ce système de gestion d'irrigation intègre les technologies de détecteur innovatrices dans un système de support de décision. Ses objectifs spécifiques sont de fixer et tester des nouveaux innovatrices des techniques de concepts de logiciel simples et abordables pour l'irrigation déficitaire dans des fermes à larges variétés d'installation et des contraintes. Il se fixe sur un tensiomètre sans entretien et les réseaux de détecteur de bas-pouvoir radiographiques. De plus, un système expert pour aider le zonage de ferme et la planification de la récolte. Le système tient compte de la disponibilité d'eau prévue, la quantité et la qualité. Un module de planification d'irrigation, à court terme, alloue de l'eau disponible parmi les terrains individuels. Les concepts développés seront évalués dans quatre sites de teste localisés en Italie, la Turquie, le Liban et la Jordanie. Les sites de teste sont choisis de telle façon qu'ils diffèrent dans le type de contraintes. Les conditions pertinentes sont les structures d'irrigation, les types de cultures, les provisions d'eau locales, la disponibilité d'eau, des sources d'eau (la quantité et la qualité), les buts locaux, et la complexité de la ferme.

Mots clés: Tensiomètre, Radiographie, Détecteur, Culture, Modèle, Zonage, Programmeur

INTRODUCTION

Agriculture is the largest single user of water in nearly every country. In the developing world, water allocated to irrigation is about (or exceeds) 70% of water resources. In view of increased domestic competition for resources and the need of larger agricultural production to ensure food security, such a fraction is unsustainable. Therefore water security can only be warranted by a large increase in agricultural water use efficiency. However, actual crop water requirement is often unknown. Although crop yield is related to water use, farmers often don't know the precise water

requirement of crops. What farmers do know, is that shortage of water results in yield loss, whereas damage is seldom done by over-irrigation. In most cases irrigation costs are a small fraction of total production costs so there is little incentive for farmers to save water. Thus, in practice,, irrigation is often related to the availability of water resources, irrespective of actual water needs.

In many cases water use is limited by the availability of the water. For example, farmers must deal with the constraints due to sharing water within a network. This aspect of water distribution is relevant to constraints imposed on farmers by technology. For example, a rotational schedule with a fixed duration of water delivery to farmers and fixed flow rates restricts what the farmers can do to improve water use efficiency. Further, if used carefully, lower-quality water may alleviate the need for fresh water. However, farmers often do not know the effect of the use of marginal water sources on crop yield. In addition, use of low quality water is usually coupled to high leaching rates, which might lead to pollution of ground water resources.

This paper describes an ongoing project that aims to contribute to sustainability of irrigated agriculture by developing, testing and optimizing in relevant conditions, 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 project goals are to improve and optimise deficit irrigation practices, by helping farmers to control irrigation systems more efficiently. In addition, it will develop a tool for (annual) farm zoning and crop planning. The system may serve as an assistant for communication with higher level water management systems at basin scale. If used by most farmers it allows for longer term estimate of the water needs at basin level and, the other way around, it optimises water use at farm level within the constraints of water availability within the basin. By testing and calibrating the new system in various conditions of basin management and constraints, it will help to ensure that the environmental and economic performance of irrigation systems is improved. This project integrates innovative sensor technologies into a decision support system for irrigation management, taking into consideration relevant factors in a number of South European and third country partners around the Mediterranean.

FLOW-AID started in autumn 2006, and is a three year, 6th Framework European project, submitted for the priority Global Change and Ecosystems. It contributes to the thematic priority of developing new engineering irrigation infrastructures, management approaches, research and demonstration activities, since it aims at integrating innovative sensor technologies, and measurement devices, within appropriate decision support systems. It takes into consideration various economic, environmental and technical factors, in particular those of South European and third countries in the Mediterranean basin. The project is performed by a number of European universities and research institutes from the Netherlands, United Kingdom, Spain, Italy and Turkey and two third partner countries Lebanon and Jordan. Three small and medium enterprises (SMEs) will adapt the general concepts to the local situation, and will build prototypes, which will be installed at four test-sites. The SME involvement will ensure that the results will be implemented in a short time into adequate and appropriate products for the end-user irrigation market (Fig. 1).

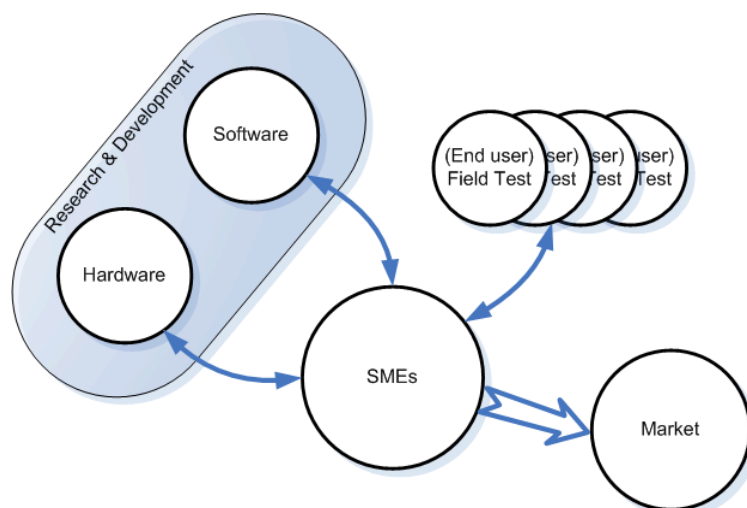


Fig. 1. The general approach of the FLOW-AID project.

The research plan for the project is split up into three parts: (i) hardware development; (ii) software development; and (iii) field testing, as shown in Figure 2.

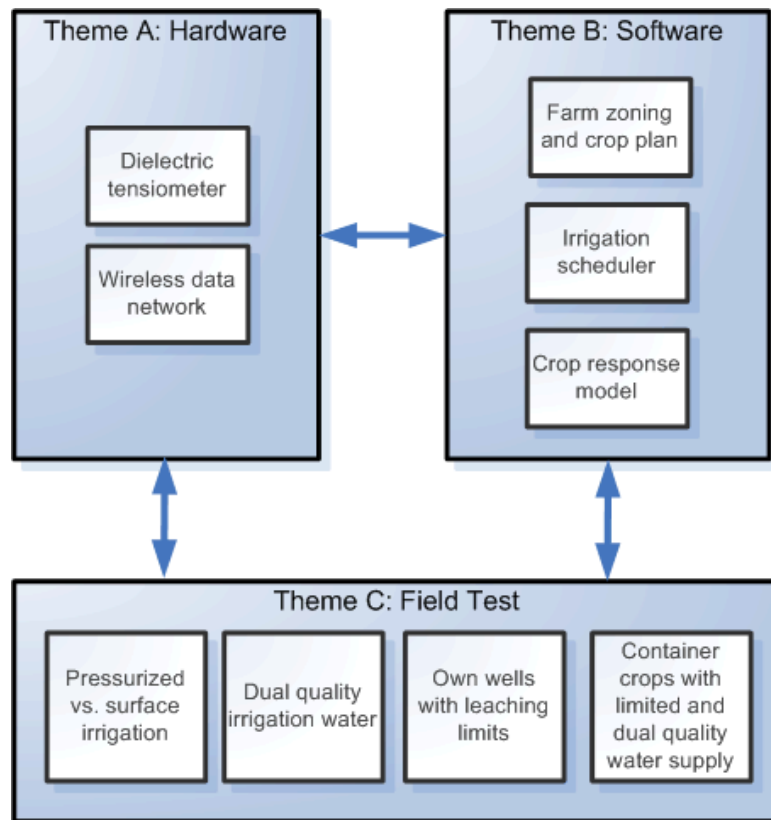


Fig. 2. Schematic overview of the work packages involved in the FLOW-AID project.

The objectives can be described more specifically as follows: (i) development and test of new and innovative, but simple and affordable sensor technology (hardware) for irrigation under deficit conditions, that can be used at farm level in a large variety of set-ups and constraints, particularly a dielectric solid-state tensiometer, and wireless low-power data networks; (ii) development of a water management decision support system (software) that contains an off-line/long-term expert system to assist in farm zoning and crop planning, in view of expected water availability, amount and quality, with link to basin management; a crop response model that can be incorporated into the irrigation scheduler; and an on-line/short-term irrigation scheduling module that allocates available water(s) among several plots and schedules irrigation for each one, with link to basin management; (iii) calibration of the tools in view of relevant factors at four test-sites in various market conditions, with different irrigation structures, crop types, local water supplies and constraints, and adaptation of 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 Lebanon, Jordan, Turkey and Italy. The individual tasks will be described in the following paragraph.

MATERIALS AND METHODS

Irrigation Controller (hardware)

The irrigation controller monitors in each farm plot all relevant weather and soil parameters such as soil moisture (available amount of water in soil), soil water matric potential (extractability of water from soil by plant roots), soil temperature and electrical conductivity (water quality), and activates an irrigation or fertigation event through valves. It performs a local scheduling task, which can be downloaded or parameterised from the central irrigation scheduler, and runs this task autonomously until it is reprogrammed. Each plot has an individual irrigation controller and sensors and valves are

added to this controller as needed by the application. To cover a wide distance, each controller communicates with the central computer by using a wireless network (radio transmitters or GSM-modems). The network can make use of a hopping principle to relay data to the central computer by using other controllers as a repeater. The irrigation controllers must be rugged, have low maintenance cost, affordable investment, low energy use, no wiring in the field, easy installation and reprogramming, widespread application and a wide range of sensor choices. The irrigation controller can control one or more valves in such a way that it steers the amount of water to be given and possibly also the choice between one or more water sources of multiple water quality (a well, a reservoir, reuse of water, irrigation network etc.).

The system makes, where possible, use of equipment that is already available from the market, and research and development is performed upon those components that are not available like a dielectric tensiometer and the protocols for low-power wireless communication. Furthermore the embedded software for the irrigation controllers will be developed in such a way that it can accommodate the newly developed scheduling tasks. Figure 3 gives a schematic overview of the system.

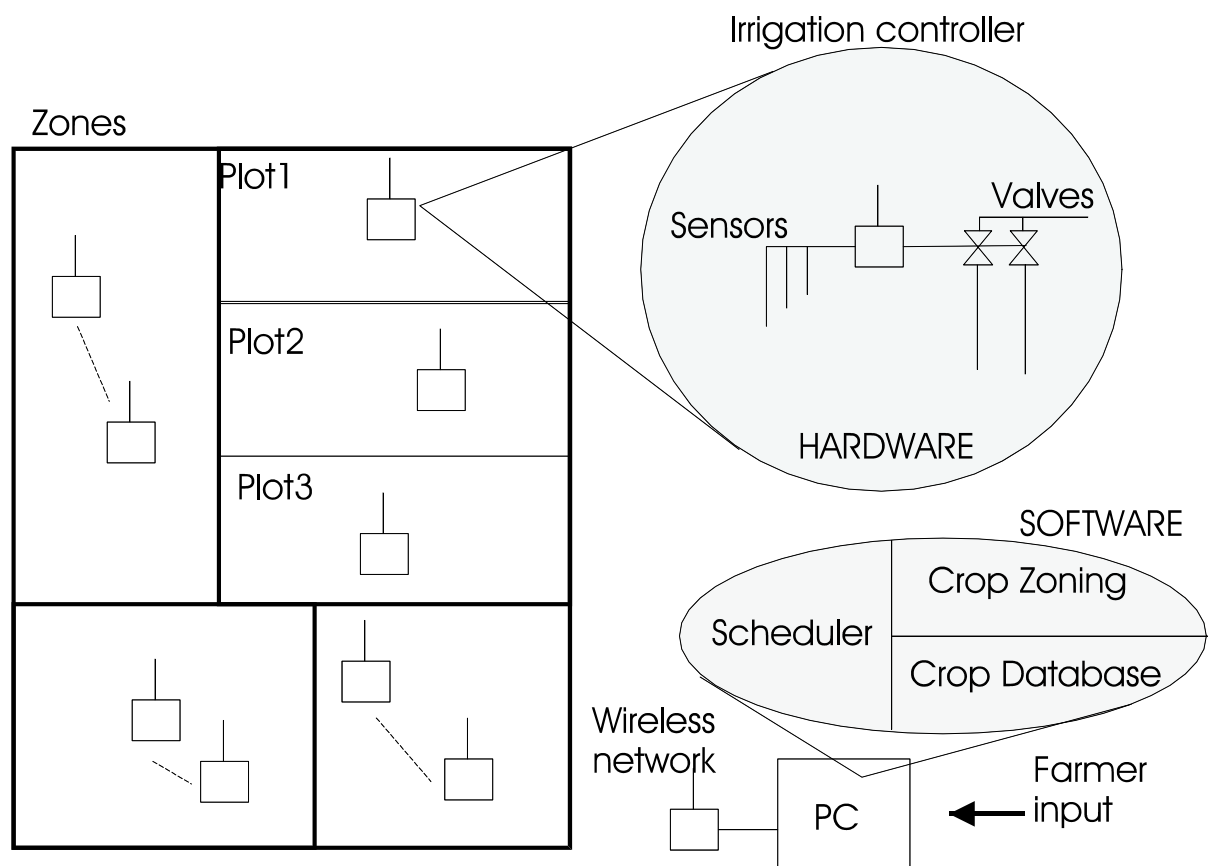


Fig. 3. Water management system for farm level irrigation under deficit irrigation (FLOW-AID).

Dielectric Tensiometer

With respect to estimating crop water need, over the past few years there have been significant shifts in perceptions within the irrigation industry. It is now widely accepted that soil moisture sensors may offer an effective measure of plant conditions for irrigation. This is a significant departure from the widespread scepticism born of earlier experiences with gypsum blocks. For instance, the Irrigation Association in the US is now actively promoting intelligent irrigation and intelligent controllers, SWAT as they refer to it. Sensors that use the dielectric properties of moist soil to measure soil water content are now widely available and, in many cases, have replaced the neutron probe as the instrument of first choice. This is largely due to safety considerations and the ease of logging offered by most

dielectric sensors. The most effective approaches to soil management, however, require measurement of the matric potential of soil water. Unfortunately, advances in technology to measure matric potential for water management as for instance proposed by Balendonck et al. (1998) have been modest compared with those for soil water content.

Two strategies have typically been followed to measure the matric potential of pore water. In the first approach, the matric potential is measured directly in a water reservoir that is connected hydraulically to the soil by a porous filter. In order to yield reliable results, both reservoir and porous filter must remain saturated throughout the period of measurement. To this end, devices that employ this technique (water-filled tensiometers) are typically fitted with ceramic filters with small air entry potentials in order to prevent desaturation when subjected to negative potentials. However, conventional water-filled tensiometers typically only work over the limited range of 0 to -85 kPa and require regular maintenance if long-term measurements are to be obtained (Or, 2001; Mullins, 2001).

Recent research into saturation techniques and tensiometer design has led to the development of a new class of high capacity tensiometer in which the magnitude of measurable suction is limited only to the air entry potential of the porous ceramic filter and the tensile strength of water (e.g. Ridley & Burland, 1999; Tarantino & Mongiovi, 2001; Take & Bolton, 2003). Although these devices can work successfully down to matric potentials as small as -2 MPa, their widespread use has been limited by the present lack of a commercially-available device and by the technical experience needed for the saturation and measurement processes.

The limited range of conventional water-filled tensiometers has led to the development of a second strategy for the measurement of matric potential, the porous-matrix sensor (e.g. Or & Wraith, 1999; Whalley et al., 2001). In contrast to the first approach, the porous ceramic is chosen so that it will readily alter its degree of saturation to maintain equilibrium with the soil water. If the water retention characteristic of the porous matrix is known, measurement of the water content of the ceramic will allow the matric potential of the soil water to be estimated indirectly. Originally, these sensors used plaster of Paris as the porous matrix and electrical resistance measurements of matrix were calibrated against matric potential (Bourget et al., 1958). Such sensors are now commercially-available and are best suited to dry soils (matric potential < -500 kPa), where they work well because hysteresis in the sensor is small at these matric potentials. Recently, they have been modified by increasing the pore size of the porous matrix, to obtain a sensor that will work at matric potentials between 0 and -200 kPa.

However, in making this adaptation, the sensor has become unreliable as the calibration varies when the same sensor is repeatedly calibrated in the same soil (Spaans & Baker, 1992). Whalley et al. (2001) analysed this adapted design and concluded that it will never work well because (i) performance in wet soils is likely to be a function of the soil rather than the sensor and (ii) even in drier soils, hysteresis is not taken into account in the calibration. However, Whalley et al. (2001) showed how to take hysteresis into account in the calibration of a ceramic-based porous-matrix sensor between matric potentials of 0 and -60 kPa. Recently Whalley et al. (2006a) have designed dielectric tensiometer that work over a much wider range of matric potentials.

In this work more reliable models for hysteresis were developed and the sensors have been used successfully to moisture soil drying by the roots of wheat (Whalley et al. 2006b). Thus the state of the art is: (i) the design for the dielectric tensiometer has been determined; and (ii) suitable models to calculate matric potential from the sensor output have been tested, which is described in full by Whalley et al. (2001, 2006). What needs to be done is to understand how this technology can be used for irrigation in a practical sense, more specifically: (i) How these sensors should be installed in the field to guarantee their most reliable function; (ii) How essential it is to apply the full hysteresis model to determine matric potential when porous matrix sensors are used in an irrigation control context; and (iii) How porous matrix sensors compare with other soil moisture sensors in a practical sense.

Wireless communication

For optimal and precision real-time sensor activated irrigation control, a large number of sensors are needed that are spread out on each plot of the farm. The cost for use and maintenance of pre-installed wiring between irrigation controllers and sensors is a large bottleneck. Further, for plot-based

individual irrigation control one needs to have sensors and controllers installed in the field at each plot or at least at every (group) of sprinklers or drippers. These controllers perform an irrigation schedule which must be set and reprogrammed individually on a regular basis. Since many controllers are needed, labour costs will force farmers to use automatic updating of his controllers. The use of wireless sensor networks (Kim, 2006; Baggio, 2005.) is a good way of overcoming all of these problems, but then power management and data-communication reliability is a problem under outdoor agricultural conditions.

Some companies in the United States and Australia are already offering wireless radio-communication equipment for irrigation management. However, there are still problems associated with this trend. Each company uses its own communication and programming protocol, equipment is still expensive and uses a lot of electric power to overcome the variable damping of electro-magnetic waves in crops (Goense, 2005). The use of solar power instead of batteries is sometimes not useful due to blocking of the sun by high crops. Therefore battery operated equipment is still favourable and thus reliable communication protocols and equipment are needed that can work at very low-power.

Decision Support System (software)

The decision support system (DSS) will help the farmer to optimise the scheduling tasks for the irrigation controllers in each plot. That is, the farmer will obtain the optimal planning of the use of the water per plot (crop distribution, irrigation scheduling, etc.), in agreement with the characteristics of his farm (area, availability of machinery, water availability, etc.), their production costs and preferences, incorporated like restrictions in the model. First of all the system can assist the farmer with farm zoning by dividing his farm into zones and each zone into manageable plots, to plan his crop planting all this with respect to the long term (months or even years) expectation of the water availability in terms of amount, quality and timing. This information comes in general from what the farmer already knows or what he is told by the local water authority. It can be entered into a PC manually. This results into a file containing all relevant plant and soil data, named the "crop plan".

Further it consists of an irrigation scheduler that optimises the water scheduling for each plot, based upon the actual weather and available water on a short term basis (f.i. weekly or daily, in terms of amount and quality) and the crop plan. To evaluate the potential crop yield — and so the economic profit with respect to the used amount of water and specific water quality — the irrigation scheduler and farm zoning and crop planning tool make use of a crop response model. This crop response model is a library containing all relevant data for a number of crops and soil type the farmer uses or intends to use.

As a result, the irrigation scheduler chooses a specific irrigation program out of a database of predefined programs, calculates the settings of parameters for it, and downloads this set into the irrigation controllers for each individual plot. The irrigation controllers will ensure that the optimal amount of water per plot is allocated according to real-time available data. Even if there is a failure in the system, this will ensure that individual plots can operate autonomously, or can even be set by hand, if needed. The irrigation scheduler DSS is run on a day-to-day basis and checks whether new conditions give need to reprogramming the individual controllers. The DSS does not need to be installed on the farm, but can be web-based as well, or rely on some modules that are web-based.

Crop planning and farm zoning tool

Work from Ortega et al. (2004) has resulted in the model MOPECO (economic optimization model of irrigation management) that is a tool to analyze the surroundings, where the decisions, about the production plan to be implemented in the farm must be taken. The model has three components: (i) *Computing Modulus I*, which gives seasonal net irrigation requirements for each crop and different years in analyzed climatic series. With this modulus, an initial estimation of the effect of irrigation management on crop yield is made, considering net irrigation depths. The methodology for irrigation scheduling is based on FAO recommendations (Doorenbos and Pruitt, 1977), using a simplified hydraulic balance (Pereira and Allen, 1999); (ii) *Modulus II*, which employs the normal function to calculate water distribution for the irrigation system used on a plot, modelled by Christiansen's Uniformity Coefficient, using the deficit coefficient (Anyoji and Wu, 1994; de Juan et al., 1996; Ortega

et al., 2004). This modulus implements the distribution function of irrigation water on the plot, as well as the production function with respect to irrigation water (Stewart et al., 1977; de Juan et al., 1996; Ortega et al., 2004), determining the gross margin function for each crop and different irrigation depths, or what is equivalent, relative evapo-transpiration. It uses economic data (continuous function of productive costs as a function of relative evapo-transpiration, costs of the application of the irrigation water, commercial price of products and by-products, etc.); and (iii) *Modulus III*, which proposes the crop alternative that provides maximum gross margin, taking as a basis the gross margin function that has been determined. These are the optimum crop alternatives for each year in the climatic series, which must fulfil some restrictions imposed by the process (available resources, area, etc.). This optimization problem, where multiple variables intervene and the search area is quite broad, is solved by means of evolutionary computation techniques (Ortega, 2004). This modulus permits to analyse, in a concrete crop alternative, irrigation depths of each crop which drive to the maximum gross margin of that productive plan as a whole, to optimize, in an economic form, the available irrigation water.

There are many factors involved in the correct use of irrigation water and the most important are local factors (climatic variability, soil, irrigation system, production costs, etc). The project intends to develop a tool that must be readily usable in climatic and economic conditions quite different from the ones prevailing in the relatively mild and advanced region where it was developed, it is essential therefore to test and calibrate such a management tool for application in such diverse conditions as foreseen in the field tests of this project.

Irrigation scheduler

The irrigation scheduler uses the crop plan as a constraint for the allocation of available water to the several plots on the farm. It will optimise the irrigation schedule based on the short-term availability of water (amount, quality, time, and source type), available weather data (possibly incorporating weather forecasts) and distributed information about the local water status (hydraulic pressure, water content, electrical conductivity and temperature) of the soil root zone. Optimal supplemental irrigation in view of possible rainfall will be determined through the ICARDA method (Oweis, 2005).

The scheduler makes use of this information obtained for every plot and crop, and it optimises the schedule plan by using a standardised knowledge database about crop response to drought and salinity, at different crop stages. In general it has to deal with deficit conditions and marginal water sources. At each instant it will run a "look-ahead" (long time horizon) water risk assessment, taking into consideration the recommendations of the off-line crop planning and farm zoning tool, in order to decide about the foretime of the optimizing scheduler, as well as to issue warnings of taking early (agronomic) measures whenever drought risks are identified. In addition, it gives advice on irrigation management as for instance to use desalinisation equipment, to control a fertigation device (on/off) or to use alternative sources (network, local well or storage).

The scheduler allocates available water of multiple sources (with different qualities and costs), with the purpose of maximising return in the sense of crop yield and quality (Stanghellini et al., 2003), under constraints of limited amount of resources; sub-optimal qualities; and limitations on leaching, although not necessarily all aspects need to be implemented at a farm. It selects the water source to use for each zone (or plot) and the time (frequency) and amount to irrigate. The result is an individual "schedule program" for each zone, which will be downloaded into the irrigation controllers automatically or in a manual way. For instance this DSS-tool could be used by a central agency to instruct farmers to set their individual controllers. Farmers, not having a PC, could then be informed by sending a simple text message to set the controllers manually.

Crop response model

Drought and salinization of water resources are the main constraints to agriculture and horticulture in many regions all over the world, particularly in the Mediterranean basin. Therefore, the application of modern (micro) irrigation systems together with smart scheduling of water distribution are essential to improve crop water use efficiency as well as to limit the environmental impact that is typically associated with the agrochemicals contained in runoff-drainage water.

Much experimental work has been done on the response of many important agricultural and horticultural crops to drought and salinity, which basically are both responsible for an impairment of plant water relations and the related physiological effects such as reduced expansion growth and leaf carbon assimilation provoke primarily by stomatal closure (Munns, 2002). Although not all the underlying biological mechanisms have been clarified, in many crop plants the influence of water stress has been established rather well in terms of yield and produce quality as well. Moreover, some practices have been developed to mitigate the negative effects of water or salt stress (e.g. Sanchez and Silvertooth, 1996; Heuvelink et al., 2003).

Modelling crop response to drought and salinity is a difficult task, since many factors related to climate, soil type, growing techniques and plant genotype determine how yield and product quality are affected by water stress induced by deficit or saline water irrigation. Furthermore, it is known, that the parameters of the salinity/drought response curve are affected by factors such as prevailing humidity, so that there is always some uncertainty in transferring results to other climatic conditions. In addition, it is known that different varieties of the same genus can have quite different response, which obviously limits the usefulness of a compilation of responses. Nevertheless, some mathematical models have been developed and they will be used in the DSS designed to predict the gross effect of reduced water supply (not cultivation in the absence of irrigation) or increasing salinity in the root zone on crop yield and economic profit.

An example of these models is provided by Adiku et al. (2001), who developed and tested under greenhouse conditions the effect of water and salinity stress on the growth and seed yield of bean. Mass and Hoffman's (1977) and Van Genuchten (1983) report two simple mathematical models for the response of crop to salinity stress. The first has the following form: $Y = 100 - B(EC-A)$, where Y is the relative yield, A is the threshold, that is the maximum salinity (saturated-paste soil extract, or irrigation water) without yield reduction, and the slope B is the percentage yield decrease per unit increase in salinity above the threshold. The second model has the following form: $Y = 100 / [1 + (EC/EC50)^P]$, where EC50 is the value of EC which reduces yield to 50% of maximum yield and P is an empirical constant. The models are relatively simple and useful to interpret experimental data. In many cases and for most practical purposes, there is little difference between the two approaches, but the Maas-Hoffman's equation model has become a sort of benchmark in the assessment of crop yield response to salinity. Heuvelink et al. (2003) reported a simulation study of the effect of salinity stress on the yield and fruit quality of greenhouse tomato, which used Maas-Hoffman's model and considered the effect of salt stress on stomatal resistance and leaf area index, which is a useful approach to quantify the effect of water stress on crop performance under intensive cropping conditions.

FIELD TESTING

There are many factors involved in the correct use of irrigation water and the most important are local factors (climatic variability, soil, irrigation system, production costs, etc). Therefore, it is very important that the integrated FLOW-AID system (both the on-line and off-line tools) is calibrated, during field tests under a broad range of conditions. For this purpose farm irrigation trials will be set-up at research centres in Jordan, Lebanon, Turkey and Italy. The first step these test-sites will take is to build the site in close co-operation with the SMEs, based on available and existing technologies. The next step is to implement the newly developed concepts into the test-sites, adapt them to the local constraints and to test these concepts in co-operation with the research institutes and SMEs. Each test-site has one of the following particular constraining conditions: (i) pressurized versus surface irrigation network; (ii) dual water quality irrigation networks; (iii) own wells with leaching limitations; and (iv) container crops with limited and dual water supply, which will be described in the following paragraphs.

Pressurized versus surface irrigation

This test will be done in pilot irrigation farms within the Litani river irrigation district of South Bekaa in Lebanon, in close cooperation with both the Litany River Authority (LRA) – Department of Rural Development (DRD) and the Association of Irrigation Water Users in South Bekaa Scheme (AIWUSBS). The test-site is situated on the eastern side of Litany River, also called the Left Bank. Of

the 6700 ha command area; only 2000 ha are served by pressurized pipelines, that allow the use of modern water application devices such as sprinklers and tricklers, while in the remaining 4700 ha, furrow irrigation and other traditional surface irrigation methods are still in use by many farmers.

Aim of this test is to evaluate how the technological level of the irrigation method affects the performance of the irrigation system. In particular, the ability of the system to manage deficit irrigation under water constraints will be evaluated. A limited set of pilots will be selected, to represent a broad range of irrigation conditions necessary to evaluate in practice water management options and their feasibility from both technical and socio-economic points of view. In the selected irrigation farms, field experiments will be carried out aiming at studying the effects of regulated deficit irrigation using drip and sprinkler irrigation methods, on growth, yield and water use efficiency of the cultivated crops (fruit trees and vegetables).

Dual water quality irrigation

This test will be performed in Jordan, where treated wastewater is commonly used for irrigation. The test site is within the highland area where vegetables (tomato, cucumber, pepper, lettuce, potato, squash, cabbage, cauliflower) and fruit trees (olives, and grape) are the main crops grown by farmers. The irrigation system is mainly drip irrigation. The main sources of irrigation water are ground water with different qualities and reclaimed wastewater. Scarcity and quality of irrigation water are major constraints to agricultural development in the region. Farmers receiving poor quality water are complaining, for the yield reduction with negative impact on soil and crop quality parameters. Water and nutrient use efficiency, plant growth and the yield quantity and quality are strongly influenced by management of irrigation water and in particular by the irrigation scheduling.

The main purpose of the test is to evaluate the performance of the system when fresh water is available only in limited amount, the rest of water needs being fulfilled by poor quality water. Subject of the test will be both the evaluation of soil humidity and EC sensors and the performance of the DSS in managing the dual sources. Several tools such as water markers and tensiometers, class A pan evaporation and neutron probe are used for monitoring soil moisture and determination of the water balance and appropriate irrigation scheduling. However, these tools are costly and not easy to be used by the farmers. Therefore, the main objective of this field test is to evaluate the performance and precision of affordable and easy to use soil sensors for monitoring soil moisture, salinity and other parameters that can be used to optimize irrigation management at the farm level. This will lead to developing an irrigation strategy that takes into the account quality and quantity parameters in order to make low-quality water more acceptable to farmers and, ultimately to maintain sustainable development in the semi-arid areas of Jordan.

Own wells with leaching limitations

This field test will happen in Turkey, in the catchment of the Tahtali dam, which provides 30% of the drinking water for the city of Izmir, the third largest city in Turkey. The growing rate of population increase within the city centre and in rural areas surrounding the city brings with it problems of infrastructure and mainly water supply. Within the preservation area of the Tahtalı Dam, greenhouse production is an important agricultural activity. Cucumber production ranks in the first place followed by lettuce and cut flowers. Cucumber production is realized in spring and summer months. The production is realized under prevailing climatic conditions in very simple structures; therefore, problems are more frequent and complicated.

Irrigation water is provided from the wells and drip irrigation is used by the growers. Although there are restrictions in respect to irrigation, fertilization and pesticide use, this is not well controlled yet. Therefore, decision for the amount of irrigation water is according to the visual observations and experience of grower resulting in excess use of water that could cause environmental impact in the region. The limitation here is on leaching, in view of possible pollution of the water sources. Therefore, the DSS will be programmed to minimise the amount or chemical content of drain water.

Container crops with limited and dual water supply

This field test will be set-up in Tuscany, which is the first Italian region for nursery stock production for garden and ornamental plants and contributes for more than 30% to the Italian gross income of this horticultural sector. Nursery industry is mostly concentrated in the Ombrone valley around the town of Pistoia, where the cultivation of ornamental plants, from small seedlings to large trees, initiated nearly one century ago and some 2,000 plant nurseries have been settled. Most nurseries are family-managed with size smaller than 3 ha. Large firms, with more than 20 ha represent 5% and cover 30% of the total area.

Recent local research (IDRI; www.cespevi.it/idri), concluded that the water use efficiency of nursery crops could be improved significantly by means of: (i) improved irrigation scheduling, that the cultivation of many different species on the same plot makes difficult; and (ii) the application of closed-loop (recycling drainage water) growing systems, also to prevent environmental pollution caused by the leaching of agrochemicals (fertilisers, weed-control agents, pesticides). In order to reduce the consumption of ground water resources for irrigation use, a project supported by public authorities has been initiated to supply local nurseries with treated domestic wastewater, which is of poor quality due to its relatively high salinity for the application to ornamental production. This source of water may represent a valuable help during peak water demand in summer. In this period ground water may be reduced by seasonal drought that may be quite severe as in summer of 2003, when nearly four months without rain caused serious economical damages to local nurseries.

Field tests will be conducted from spring to early-autumn (the typical irrigation season) in an experimental plot recently set up at the experimental station in Pistoia (Centro Sperimentale per il Vivaismo). The crop performance will be evaluated in terms of plant growth, water and fertiliser use efficiency, and environmental impact (water and nutrient runoff). Special attention will be paid to closed growing systems, since this technology is expected to expand in the next future, and actually it does, owing to water shortage and public concern about environmental issues. A large fraction of nurseries have at least a part of the farm as container crops, so that there is the additional advantage here of testing and calibrating the crop plan module, and the EC sensors as well as the wireless sensor networks.

DISCUSSION AND CONCLUSIONS

This paper described the goals and the research plan of a specific targeted European 6th Framework project aiming at optimal water management at farm level under deficit conditions. So far no concrete results have been reported since the project started in October 2006. This paper is meant to share the research plan with irrigation scientists to be able to discuss the plan and to adapt the upcoming research and experiments to the latest knowledge available in water management.

The FLOW-AID system will be developed and tested by the responsibility of the project team which will consult local stakeholders to help and advice on local and regional situations. Members of local stakeholder boards are farmers and managers of the water services involved in the test sites, representatives of the local water authorities, leading local farmers and extension services from each region. This will ensure that the project will provide appropriate technology to assist with improved management of water at the farm level and a good communication with water management at the basin level.

This project gives local farmers tools to operate irrigation in such a way that they can manage deficit conditions. The tool will help to (i) increase economic efficiency of application under deficit and (ii) decrease pressure on water resources by stimulating exploitation of marginal water for irrigation. By using these tools farmers learn how to cope with less water, or more expensive water in future. Having these new technology tools available, it is easier for future research to evaluate the feasibility of new economic strategies and incentives for water pricing.

The proposed project is targeted directly at sustainable management of scarce regional water resources that are presently being wastefully applied to agricultural production. As such, the project will provide a tool to help combat the effects of climate change. The project also addresses the key priorities identified by the European Union in the provision of robust engineering irrigation

infrastructures and management approaches. In particular, the research activities proposed here focus on developing a directly applicable, cost-effective tool for improving use efficiency of irrigation water. Such a tool will result from the combination of individual technological steps into a package suitable for exploitation by farmers and managers of water services, with due account for the socio-economical context. The utility of the approach is to provide a tested hardware system that can be driven by flexible decision support software.

By focusing two of the four field tests to successful application of poor quality water, this project aims to decreasing pressure on fresh water resources, particularly in the socio-economic and institutional arrangements and different types of stakeholders of Mediterranean countries. The European Water Framework Directive recognises in various places that the principle of “full cost recovery” may not be fully applicable in the near future, in particular where established practices prevent “full cost” pricing of water services. The communication on pricing policies (European Commission, 2000) points out that “Clearly, pricing is not the sole instrument that can (and will) solve water resources problems”. Indeed, presently policies are often simply a limit on water use (deficit irrigation) or on leaching. However, the results of this project may even go towards making it more affordable for third partner countries to meet the European Water Framework Directive.

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REFERENCES

- Adiku, S. G. K., Renger, M., Wessolek, G., Facklam, M. and Hecht-Bucholtz, C. (2001). Simulation of the dry matter production and seed yield of common beans under varying soil water and salinity conditions. *Agricultural Water Management*, 47(1): 55-68.
- Anyoji H., Wu I.O. (1994). Normal distribution water application for drip irrigation schedules. *Trans. Asae*, 37: 159-164.
- Baggio, A. (2005). Wireless sensor networks in precision agriculture, In on-line Proc. of the *Workshop on Real-World Wireless Sensor Networks 2005*, Stockholm.
- Balendonck, J., Kuyper, M.C. and Hilhorst, M.A. (1998). WATERMAN, a water management method for non-closed crop production. In *Proc. AgEng98*, Oslo.
- Bourget, S.J., Elrick, D.E. and Tanner, C.B. (1958). Electrical resistance units for moisture measurements: their moisture hysteresis, uniformity and sensitivity. *Soil Science*, 86: 298-304.
- De Juan, J.A., Tarjuelo, J.M., Valiente, M., García, P. (1996). Model for optimal cropping patterns within the farm based on crop water production functions and irrigation uniformity. I: Development of a decision model. *Agricultural Water Management* 31: 115-143.
- Doorenbos J., Pruitt W.O. (1977). Crop water requirements. *Irrigation and drain*, 24. FAO, Rome.
- European Commission (2000). Pricing policies for enhancing the sustainability of water resources COM (2000)477, http://ec.europa.eu/environment/docum/00477_en.htm.
- Heuvelink, E.P., Bakker, M. and Stanghellini, C. (2003). Salinity effects on fruit yield in vegetable crops: a simulation study. *Acta Hort. (ISHS)*, 609:133-140.
- Kim, Y., Evans, R.G., Iversen, W.M., Pierce, F.J. (2006). Instrumentation and control for wireless sensor network for automated irrigation. *ASABE paper No. 061105*. St. Joseph, Mi (USA): ASABE.
- Maas, E.V., Hoffman, G.J. (1977). Crop salt tolerance: current assessment. *Journal of Irrigation and Drainage Division*, 103:115-134.

- Mullins, C.E. (2001). Matric potential. In: *Soil and Environmental Analysis*, Smith, K.A. and Mullins C.E. (eds). Marcel Dekker, New York, pp. 65–93.
- Munns, R. (2002). Comparative physiology of salt and water stress. *Plant, Cell Environ.*, 25:239-250.
- Or, D. (2001). Who invented the tensiometer? *Soil Science Society of America Journal*, 65: 1–3.
- Or, D. and Wraith, J.M. (1999). A new soil matric potential sensor based on time domain reflectometry. *Water Resources Research*, 35: 3399–3407.
- Ortega Álvarez, J. F., Juan Valero, J.A. de, Tarjuelo, J. M., Martín-Benito and López Mata, E., (2004). MOPECO: an economic optimization model for irrigation water management. *Journal Irrigation Science*, ISSN 0342-7188, Springer, Berlin/Heidelberg, pp. 1432-1319.
- Oweis, T. (2005). The role of water harvesting and supplemental irrigation in coping with water. In: *Drought and water crises: science, technology, and management issues*, Wilhite, D.A. (ed), Boca Raton: Taylor and Francis, 2005, pp. 191–213.
- Pereira, L.S., Allen, R.G. (1999). Crop water requirements. In: *CIGR Handbook of Agricultural Engineering. Volume I: Land and Water Engineering*, Van Lier, N.H., Pereira, L.S., Steiner, F.R. (eds), ASAE and CIGR, St. Joseph, Mi (USA).
- Ridley, A.M. and Burland, J.B. (1999). Use of tensile strength of water for direct measurement of high soil suction: discussion. *Canadian Geotechnical Journal*, 36: 178–180.
- Sanchez, C.A. and Silvertooth, J.C. (1996). Managing saline and sodic soils for producing horticultural crops. *Horttechnology*, 6: 99-106.
- Spaans, E.J.A. and Baker, J.M. (1992). Calibration of Watermark soil-moisture sensors for soil matric potential and temperature. *Plant and Soil*, 143: 213–217.
- Stanghellini, C., Kempkes, F., Heuvelink, E., Bonasia, A. and Karas, A. (2003). Water and nutrient uptake of sweet pepper and tomato as (un) affected by watering regime and salinity. *Acta Hort. (ISHS)*, 614: 591-597.
- Stewart, J.I., Hagan, R.M., Pruitt, W.O., Kanks, R.J., Riley, J.P., Danilson, R.E., Franklin, W.T., Jackson, E.B. (1977). Optimizing crop production through control of water and salinity levels. *Utah Water Res. Lab. Pwrg*, 151-1. Utah (USA).
- Take, W.A. and Bolton, M.D. (2003). Tensiometer saturation and the reliable measurement of soil suction. *Géotechnique*, 53: 159–172.
- Tarantino, A. and Mongiovi, L. (2001). Experimental procedures and cavitation mechanisms in tensiometer measurements. *Geotechnical and Geological Engineering*, 19: 189–210.
- Thelen, J., Goense, D., Langendoen, K. (2005). Radio wave propagation in potato fields. In *First Workshop on Wireless Network Measurements* (co-located with WiOpt2005), Riva del Garda, Italy.
- Van Genuchten, M.T. 1983. *Analysis of crop salt-tolerance data: model description and user's manual*. USDA-ARS-USSI, Research Report, 120.
- Whalley, W.R., Watts, C.W., Hilhorst, M.A., Bird, N.R.A., Balendonck, J. and Longstaff, D.J. (2001). The design of porous material sensors to measure matric potential of water in soil. *European Journal of Soil Science*, 52: 511–519.
- Whalley, W.R., Clark, L.J., Take, W.A, Bird, N.R.A., Leech, P.K., Cope, R.E. and Watts C.W. (2006a) A porous-matrix sensor to measure the matric potential of soil water in the field. *European Journal of Soil Science* (In Press).
- Whalley, W.R., Clark, L.J., Gowing, D.J.G., Cope, R.E., Lodge, R.J. and Leeds-Harrison P.B. (2006b). Does soil strength play a role in wheat yield losses caused by soil drying? *Plant and Soil* 280: 279-290.