# EIP-AGRI Focus Group

## Water & agriculture: adaptive strategies at farm level

MINIPAPER: Tools for improving irrigation scheduling: present and future perspectives.

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**a) Introduction**

***Irrigation management***

Irrigation management comprises all agricultural practices aimed at controlling the amount and timing of water application to cultivated crops, to meet crop needs and maximise their productive performances, especially during the most critical stages of crop development, while trying to preserve water sources.

EU agriculture is highly heterogeneous in terms of irrigation approaches, in fact, depending on the crop cultivated, the environment and the infrastructures available locally, EU farmers apply a broad range of different irrigation techniques: from the most water demanding, like flooding, to the most water saving like drip and subsurface irrigation. Similarly, the adoption of rational decision making approaches for irrigation scheduling is highly heterogeneous and in many farms irrigation is still carried out only based on the grower's experience, with a high extent of incertitude and inefficiency, both on the amount and on the timing of water supply. Such incertitude may often cause over-irrigation with negative consequences on both water use efficiency (WUE) and potential leaching of pollutants, while on the other hand, under-irrigation may have strong negative consequences for the crop productive performances.

**b) Identification and description of the main problem related to the topic.**

***Climate change/water scarcity / Need to improve water use efficiency***

Due to climate change and future resource limitations, the security of the EU food supply, in a society with increasing population, is under threat. Several phenomena are expected to occur, like increased heat and water stress conditions; reduced water availability; competition of water use with other human activities, with the risk to reduce yields and quality of agricultural products.

Agriculture is central in meeting this challenge because the production of food and other agricultural products takes 70% of the freshwater withdrawals from rivers and groundwater, while irrigation needs are expected to increase up to 20-30% by 2030 (Doll et al., 2002).

With agriculture striving to increase yields while relying on water resources that are gradually diminishing, the need to increase WUE becomes progressively more crucial and must become the goal for all the actors playing along the agricultural chain. In this regard, significant improvements can be achieved through the adoption of improved, more rational irrigation scheduling approaches, allowing EU farmers to increase the WUE of their crops. Supplying water only when and where the crops need it, will reduce the amount of water used while preventing irrigation-induced environmental problems such as salinity, soil erosion, leaching of nutrients and pesticides into groundwater. Also it will directly affect WUE by increasing the yield per unit of water applied.

**c) Description of the existing best practices** and possible solutions to solve the problem.

A sustainable, improved irrigation scheduling requires a sound basis for decision making as the crop water needs vary with soil type, crop species and phenological stage, weather, irrigation system and various other management factors. A series of best practices regarding irrigation scheduling are already available and can be used by EU farmers to improve the sustainability of their water use, like sensors for monitoring crop (or soil) water status, online services for irrigation scheduling and regulated deficit irrigation protocols. Other approaches are available but need further improvements before they can be applied on a larger scale, such as precision irrigation and remote sensing techniques. A short description of some of the technologies already available is reported here, with the aim to provide an overview of the potentialities to improve WUE while facing the challenge of water scarcity.

ON-LINE SERVICES/MODELS FOR IRRIGATION SCHEDULING

Crop water use varies depending on many cultural and environmental factors. Basing on physiological and environmental studies, special models have been developed to estimate the water balance of different crops as a response to changes in the environmental conditions, so that irrigation needs can be quantified as the difference between the water inputs and the water losses to/from the soil-plant system (FAO66, 2012).

In several cases these models have been implemented on web platforms capable to provide custom-tailored advices to growers on the irrigation needs of their crops. These services can go from the simple estimation of the crop evapotranspiration (ETc) in a specific location, to the delivery of specific irrigation recommendations, to the advanced quantification of the plant water needs based on  on site-specific data collection with soil and (sometimes) plant sensors.

Usually, to access these services, growers need to register and fill in data concerning their cultivation and environment. The main inputs required are species, phenological stage, GPS coordinates, acreage, soil features, crop management, irrigation system used etc. Weather data can be automatically collected from a network of weather stations available on the area, while soil maps with specific features of the farm soils can be downscaled by the system and serve as inputs to estimate the soil water content. Further information on crop set up (i.e. plant density etc.), management and phenological stage allows the system to calculate the crop water balance (water available in the soil minus water losses via crop evapotranspiration) and estimate crop water needs. A warning message can suggest to the farmer the timing and amounts of the next irrigation.

In the EU, there are several successful examples of online services to support irrigation scheduling:

In the Emilia Romagna region (Italy), the Consorzio per il Canale Emiliano-Romagnolo (CER) has developed "IRRIFRAME": an expert system for irrigation scheduling that since 1995 (formerly IRRINET) provides growers with free irrigation advices for a wide set of water demanding crops (**www.irriframe.it**). Currently the system is included in the frame of the regional action plan for rural development of the Emilia Romagna region and it is available and adopted at national scale.

In Spain, the "Istituto Valenciano de Investigaciones Agrarias" has developed "RiegosIvia" (**www.riegos.ivia.es**) an online service where growers can access in real time the weather data and $Et_0$ coming from a network of weather stations located in the region. Also, custom-tailored advices for irrigation scheduling are provided to registered users.

Furthermore, the "Centro de Edafologia y Biologia Aplicada del Segura" (CEBAS-CSIC) of Murcia, has developed "OPIRIS" an online precise irrigation-scheduling algorithm based on the combined interpretation of soil, plant-based and weather sensors (**www.opiris.eu**). Growers  can choose among different levels of service, from the simple monitoring of the ETc for a specific crop on a specific location (free access) to custom-tailored feedbacks on the actual time and amount of irrigation required by their crop. For this latter service, growers are required to install soil and plant-based sensors in the farm with the need of some initial affordable investment, while sensors installation and irrigation management is facilitated by the availability of professional support from the service providers.

Several other web-based services are available online, providing advices for irrigation scheduling in different EU agricultural regions.

These online approaches to manage irrigation have several advantages: they are easily accessible, user-friendly and economically affordable (some of them can even be free of charge). Also, they provide a rational approach to irrigation scheduling, which is based on actual inputs data (mainly weather data) and validated models. All this results in a significant WUE increase, in the reduction of water losses and of pollution-related problems.

However, while on one hand these systems may help saving water and improving WUE, on the other hand, many of them are supposed to work in conditions of unlimited water supply (when irrigation water is available "on demand")and may  be not very helpful in the presence of water shortages (i.e. when the farmer cannot follow the advices due to water scarcity, or the water provided by the irrigation system is available "on turn"). Moreover, several models use to implement the online services for irrigation scheduling assuming the FAO reported Kc for the calculation of the water balance, with possible over-estimations of the calculated ETc.

In this perspective, some of these models already foresee alternative Kc or the application of regulated deficit irrigation (RDI) protocols, which allow sub-optimal levels of water supply at specific phenological stages.

*REGULATED DEFICIT IRRIGATION*

When the available water is insufficient for crop requirements, irrigation can be reduced during the whole growth period (deficit irrigation) or only in those phenological periods in which yield is relatively less sensitive to soil water deficits (regulated deficit irrigation - RDI). This last option was developed in the 1980s as a strategy to reduce vegetative growth of vigorous trees and to save water (Behboudian and Mills, 1997). Many experiments, recently reviewed by Naor (2006) and Fereres and Soriano (2007), have shown that, by applying the most appropriate RDI strategy, it is possible to reduce water applications and plant transpiration by approximately 10-20% without any yield loss in the short-term. However, the long-term effects of irrigation using RDI strategies are still fairly unknown.

The usefulness of RDI practices is strongly dependent upon avoiding water stress during the critical phenological stages, when marketable yield is particularly sensitive to water stress. For example, in fruit , a clear separation between vegetative and fruit growth phases is often needed (Hueso and Cuevas, 2008) to guarantee that fruit growth will not be reduced by water restrictions.
For instance, in citrus trees, under Mediterranean climate, the first phase of fruit growth after the June fruit drop is probably the most appropriate period for applying water restrictions (González-Altozano and Castel, 1999). Citrus trees appear to have compensatory growth following alleviation of water deficit (Cohen and Goell, 1988). To take advantage of this mechanism, it is necessary that recovery of optimum water status occurs well before harvest. The intensity of autumn rainfalls and the irrigation regime have a crucial importance for the rapid recovery of tree water status.

In stone fruit trees, the pit hardening phase has been identified as an appropriate period for RDI. During this period, fruit growth is minimal and therefore generally not affected by drought, while shoot growth can be reduced (Chalmers *et al.*, 1981). However, in early maturing cultivars, this phase is very short, enabling only small water savings. In these cultivars, there is a long post-harvest period which is more suitable for the reduced irrigation (Johnson *et al.,* 1994). However, caution is required to prevent negative effects of after harvest drought on flower bud development (Johnson and Handley, 2000).
In most cases, the final effects of water stress on crop performance seem to be very dependent on several orchard, environmental and tree characteristics. These aspects are currently limiting the widespread adoption of this promising technique for dealing with water scarcity in the expected scenario of global change.
However, while RDI is possible in fruit trees and vines because these species have periods of growth when yield is not sensitive to an ET deficit, the possibilities to apply RDI to vegetable crops are limited. In fact, most of these crops do not show clearly defined stages, during which deficit irrigation can be applied without affecting yield. Generally, in many vegetable crops, there is a linear relationship between yield and ET, and any reduction in ET will linearly affect yield and farmer income (Fereres *et al.,* 2003). Additionally, vegetable crops are generally shallow rooted and rapidly experience effects of irrigation at less than potential $ET_c$ (Stanley and Maynard, 1990). Finally, the success of RDI technique depend on the pedologic condition and mainly on the total available water (TAW) in the soil profile (which in turn is a function of the soil texture and depth): the higher the TAW the more effective the resulting RDI (Katerji et al., 2010).

On the other hand, there is some interest in the use of deficit irrigation with both vegetable and fruit crops to increase the quality of the production. Deficit irrigation during fruit production, particularly during ripening can enhance fruit quality by increasing the soluble solids content in the fruit of species such as tomato and melon (Fabeiro *et al.,* 2002; Shock *et al.,* 2007).

<u>PRECISION IRRIGATION</u>
Precision irrigation can be considered the new approach on irrigation management. Therefore the new challenge and the new opportunity. Traditionally, it is defined as the site-specific application of precise amounts of water at precise time across the farm (Smith and Ballie, 2009). In the same plot, water amounts may vary according to soil and canopy characteristics, in order to obtain a final uniform production with the minimum impact on the environment. Although there is disagreement in literature about the correct definition of precision irrigation, on a wider perspective, it can be defined as all innovative technologies aiming at optimizing water use efficiency based on a wide range of information inputs from the farm. The adoption of precision irrigation is thus related to the availability of several new technologies that include the soil mapping (at the farm scale) and the monitoring of crop water status. From this information, homogeneous areas are identified, for which the site specific timing and amount of irrigation water are specified.

Factors like soil and crop features, field management, and topography represent the most important inputs fore decision-making and planning. The correct collection of these inputs and the drawing of a map describing the field variability for the different features represents the first bottleneck for the adoption of precision irrigation technologies. Inputs collection can occur through classical soil sampling, proximal sensing technologies, or using more new and complex approaches as remote sensing.

*REMOTE SENSING: a very useful tool for precision irrigation*

Remote sensing is defined as a group of techniques for collecting images or other forms of data about a target, from measurements made at a distance. Data are then cross-checked, processed and analysed, and act as inputs for making decisions and providing irrigation recommendations.

The most common types of remote sensing used in agriculture can be divided into four main categories of resolution, including spatial, spectral, radiometric, and temporal resolutions. In spatial resolution, information can be collected to identify physical traits in crops, such as size, relative distance and proximity patterns, height, width and diameter of plants, crop damage from pest infestation, weather, and more. Spectral resolution can collect information based on the whole spectre (hyperspectral imaging) or on certain frequency ranges. Thermal images obtained through the use of infrared sensors are of particular interest for the application of precision irrigation as they can allow to detect situation of upcoming (or already existent) drought stress in a cultivated crop. Also, NDVI sensors can provide feedbacks on the area occupied and the physiological status of the vegetation.

The "Precierieg" (**www.precirieg.eu**) and "Telerieg" (**www.telerieg.eu**) projects funded by the EU interregional south-west programme, have recently come up with a successful example for improving irrigation scheduling at regional scale. The system integrates thermal images from remote sensing to actual soil moisture data from a network of soil sensors placed on the monitored area, which act as reference points, thus allowing to provide precise feedbacks on upcoming drought stresses on a large area.

Data collection through remote sensing is currently used both on annual and perennial crops although the application of precision irrigation technologies to both systems is still under development. In fact, while on annual crops precision irrigation is working already on methods and equipment and good results have been achieved, the application of site-specific irrigation to perennial crops is still at an embryonic stage mostly due to difficulties and cost issues in the variable application of water across the orchard.

The variable rate water application in central pivot irrigation systems is one of the most successful examples of the adoption of precision irrigation to annual crop productions. With this technology, traditional centre-pivot and lateral-sprinkler irrigators are modified so to allow variable-rate irrigation through the control of each individual sprinkler. This allows to provide different amounts of water depending on the field variability of the soil and crop. With the help of GPS, software automatically controls valves on the sprinklers so that water can be varied and optimised along the length of the irrigation pipe.

As a new area, precision irrigation is now being studied and discussed worldwide and its success depends on sharing experiences and achievements, thus allowing to have a realistic approach.

**d) Identification** of the gaps in terms of **further research needs** (list) and **practical solutions** which require a project on the ground

Despite most of the irrigation strategies hereby reported help growers to improve their WUE and their productive performances through an optimisation of the amount and time of water supply, most of them, like the on-line services currently available are not suited in conditions of serious water scarcity. Scheduling of irrigation is possible only if water is available "on demand" for the farmer. Where water is distributed "on turn" by the irrigation schemes, farmers cannot schedule the time for irrigation according to rational criteria. Also, these systems often rely on the estimation of the crop water balance without taking into account the real plant water needs. Research is needed in this regard to improve RDI strategies to further case-studies and to broaden the number of species, environments and soils where they can be applied. Furthermore, the high heterogeneity in the physiology of the different agricultural systems and crops, indicate the need of further studies to validate and fine tune the application of online services, RDI protocols and precision irrigation approaches to a broader range of different species and agricultural systems.



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Also, most of these strategies may appear too difficult to be adopted for a large number of growers as the use of web platforms, sensors (i.e. for monitoring soil moisture), high technology systems (i.e. for precision irrigation and remote sensing) are envisaged, and the support of professional technical experts, capable to assist the grower with the correct application of the different methodologies may be required. The propensity to adopt innovation is a key trait for a grower, and failing to understand the need to customize solutions to the preferences (technologies, technical assistance, impact on current practices, etc.) may hinder the adoption of novel technologies. Dissemination and training actions over EU are needed to encourage the use of these systems to the highest amount of farmers.

### *Ideas for innovative projects addressing the problem*

PLANT-BASED irrigation

Traditional irrigation scheduling approaches rely on keeping optimal amounts of water in the soil, thus allowing plants to operate at their maximum potential performances during the whole season. However, several plants are able to activate efficient adaptation strategies to drought stress, being able to work efficiently even under conditions of sub-optimal water availability. This highly performing conditions can also lead to better crop quality at harvest.

This opens new opportunities for researchers to develop innovative irrigation scheduling approaches, based on maintaining the plant to their maximum limits of stress tolerance, without negatively affecting productivity. However, this is possible only through the precise monitoring of plant water status and productive performances. Plant water status can be assessed through different plant-based parameters such as stem water potential, sap flow, stem and/or fruit diameter variations, although the monitoring of these parameters requires the installation of sensors and data-loggers systems. In this regards, research should help improving the adoptability of these decision support systems (DSS) making them more universally applicable, user-friendly, and economically affordable.

INTEGRATED DSS

Also, as plant water relations and productivity are strongly related to many other management factors like plant density, nutrient application, crop load (for horticultural species) and pest management, improved and integrated DSS capable to include these factors should be developed. The basic understanding of the complex relationships between all these factors should allow researchers to develop new management approaches and DSS capable of improving and optimizing all inputs to the cultivation, with the aim to achieve the maximum economical and environmental sustainability and to help the grower in a more inclusive way. These DSS could also take advantage of other existing technologies, for example through the integration of precise and reliable weather forecast data into their models. This would significantly improve the decision making process, thus allowing growers to modulate their agronomic inputs (irrigation, but also nutrition and pest management) not just basing on the actual crop status, but also on the forecast (and prevention) of upcoming potential stresses.

EFFICIENT KNOWLEDGE TRANFER AND TRAINING

Clearly, one of the main bottlenecks for the application of the existing technologies to improve WUE in EU agricultural systems is the difficulty to disseminate correct information and provide proper training to all EU farmers and consultants. Projects and actions at different levels of the EU agricultural chain are needed to improve growers awareness on water limitation problems, while enabling them to adopt improved, more efficient irrigation strategies.

## *CONCLUSIONS*

Nowadays, the application of innovative technologies for irrigation scheduling still faces many difficulties. However, people are progressively becoming more aware of the environment-related problems, and of the need to improve production sustainability and the efficient use of the natural resources, mainly water. In the next few years, this may reflect on a shift in the consumers' behaviour, being available to prefer the products that were produced on a more efficiently and environmental friendly way. Also, it is important that governments emphasize the use of methods and techniques that will affect less the future generation. By this, it means giving financial support both to farmers, and organizations that develop and test them, and also through public



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awareness on this area. Like someone once mentioned, we are just passing by on this Earth, so let's try to leave it better than when we started the journey.

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