IRRIGATION CONTROLLERS DRIVEN BY SOLID-SET SPRINKLER AND CROP SIMULATION MODELS

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Abstract: Despite current technological developments and intense capacity building, farmers continue to show wide differences in irrigation water use, even for a given location and crop. Sprinkler irrigation performance is affected by a number of meteors, particularly wind speed. The short-time variability of wind speed requires tactical adjustments of the irrigation schedule. Additionally, energy costs often require consideration of the time evolution of the tariff along the day and among contiguous days. Opportunities have arisen in the last decades which permit to address these challenges through irrigation controllers guided by irrigation and crop simulation models. Among these opportunities: remote control systems installed in collective pressurized irrigation networks; networks of agrometeorological weather stations; and specialized databases for the management of Water Users Associations. In this paper, an irrigation controller configuration based on the use of solid-set sprinkler irrigation and crop simulation models is presented. This controller can develop, update and execute irrigation schedules aiming at maximizing irrigation adequacy and water productivity. Research, development and innovation bottlenecks are assessed to establish agendas leading to the commercial deployment of advanced controllers for solid-set sprinkler irrigation.

Key words: control, scheduling, automation, irrigation systems, water users associations

1. INTRODUCTION

The global demand for agricultural products is increasing in this first decade of the 21st century, responding to factors such as global economic development and population growth. Alexandratos and Bruinsma (2012) predicted that world food demand will increase by 60% by 2050. Irrigated agriculture currently accounts for 40% of global food production (World Water Assessment Programme, 2009), and will take a relevant share of the required additional production. About 60% of the world irrigated area should be modernized in order to match the future world demands (Alexandratos and Bruinsma, 2012). Additionally, the effective irrigated area should be extended by 15%. Agricultural intensification will result in irrigation modernization and expansion projects, increasing the area irrigated with pressurized systems. For instance, in Spain pressurized irrigation systems have increased from 19% to 70% in the last 30 years (MAPA, 1985; MAGRAMA, 2011). Solid-set sprinkler irrigation systems are common in Spain, with0.48 M ha, representing 14% of the irrigated land. Oil and electricity prices are predicted to increase by about 25% and 15%, respectively, in 2035 (IEA, 2012), raising the irrigation costs for pressurized systems requiring pumping stations. These perspectives encourage farmers to invest in water-efficient technologies aiming at maximizing economic return from their investments in irrigation systems.

At the on-farm level, water use remains unsatisfactory. Salvador et al. (2011) analyzed the seasonal irrigation water application patterns of plots located in large irrigation projects of the Ebro valley, north eastern Spain. These authors found average ARIS (Malano and Burton, 2001) values suggesting adequate average irrigation efficiency. However, the standard deviation of the indicator showed very large inter-plot variability. These findings call for a generalized improvement of irrigation scheduling, adjusting water application to crop water requirements and reducing the variability introduced by the human factor. In these days of information technologies, advanced, self-programming irrigation controllers can contribute to this problem, enhancing water productivity in pressurized irrigation regardless of the irrigators' skills. Such irrigation controllers are currently being developed to suit the needs of different pressurized irrigation systems.

Solid-set sprinkler irrigation systems have specific traits which shape-up their control requirements. The entire field is covered by sprinklers located on top of riser pipes, and spaced in triangular or rectangular arrangements. Risers are connected to a network of buried pipelines. In semiarid environments, the water source is typically located far away from the solid-set, and a collective pressurized network is often required for water conveyance. A supply hydrant delivers water to the on-farm network of sprinklers. Solid-sets are typically divided in a number of irrigation blocks which are irrigated in a sequential fashion. This permits to decrease the discharge required to irrigate the field, exploit a large fraction of the time available for irrigation and, hence, reduce the system cost. Irrigation controllers automatically operate the block valves according to a schedule previously programmed by the farmer.

Solid-set irrigation performance heavily depends on meteorological conditions. Wind speed has been shown to reduce irrigation uniformity. In combination with variables such as air temperature, relative humidity and solar radiation, wind speed also determines wind drift and evaporation losses (WDEL). The performance of other sprinkler irrigation systems show slower meteorological dependence. Centre pivots and moving laterals are much less affected by meteorology than solid-sets. Regarding WDEL, in the average conditions of Zaragoza(Spain), Playán et al. (2005) estimated that average day time and night time solid-set losses amount to 15 and 5%, respectively. For irrigation machines, losses amount to 9 and 3% for day and night conditions, respectively. Regarding the wind effect on uniformity, solid-sets are also in worse conditions, since sprinkler overlapping is much more intense in irrigation machines. As a consequence, avoiding periods of unfavorable meteorological conditions is a clear goal for solid-set irrigation controllers. In the difficult meteorology of the central Ebro basin, Faci and Bercero (1991) recommended to stop solid-set irrigation for winds exceeding 2 m s^{-1}. It is not rare to find meteorological stations in the area with long-term yearly wind speed averages exceeding this threshold.

In an attempt to respond to these challenges, Zapata et al. (2009) and Zapata et al. (2013) developed advanced solid-set irrigation controllers based on simulation models. These controllers have been tested in simulated and experimental conditions. Playán et al. (201X) presented an overview of the current opportunities for the adoption of such controllers, outlined designs for controllers located in individual farms and in Water Users Associations (WUAs), and analyzed the current bottlenecks requiring action in the fields of research, development and innovation. This paper presents highlights from the work of Playán et al. (200X), focusing on collective controllers for WUAs.

2. OPPORTUNITIES

Full irrigation automation (from the elaboration of an irrigation schedule to its execution) has been listed in research agendas for a few decades now. However, opportunities have arisen the last decades which have led to practical applications in different irrigation systems and cropping orientations. Key opportunities are listed in the following paragraphs:

<u>Specialized WUA management databases</u>. Playán et al. (2007) analysed the evolution of WUA practices regarding information technologies, and reported on a software application for the daily WUA management. While the use of databases was scarce by the end of the twentieth century, virtually all WUAs in the Ebro valley are today using such tools for water allocation and planning, accessing geographical information systems and filing water orders to their supply canals. WUA management databases contain registers of water users, land tenure, collective network layout, on-farm irrigation structures and crops. These databases permit to automatically produce updated information leading to the establishment of irrigation schedules.

<u>Agrometeorological networks</u>. In the last third of the twentieth century it became clear that real-time agrometeorological data would be required to guide irrigation decision making. The first large-scale network of automated agrometeorological stations was developed in California in 1985 by CIMIS (California Irrigation Management Information System). Its goals included disseminating irrigation requirements and promoting irrigation scheduling. A number of countries followed this example. Such systems and the

resulting databases are currently available in many areas of the world, creating a clear opportunity for irrigation scheduling and control applications.

Computer models for crops and irrigation systems. A new generation of advanced irrigation controllers can build on the success of two parallel research lines on simulation models: sprinkler irrigation and crops. Sprinkler irrigation simulation is often based on the application of ballistics to the drops emitted by a sprinkler (Fukui et al., 1980; Seginer et al., 1991). The output of such models is the spatial distribution of water application within a sprinkler spacing, along with the related performance indicators. Crop modelling has emerged as a useful tool to combine the processes leading to soil water balance, crop growth and crop yield, using mathematical equations implemented in software applications. CropWat (Smith, 1992) is a simple, easy-to-use approach to soil-water-yield modelling. Crop models use irrigation water as one of their inputs, and produce the time evolution of crop water requirements and an estimate of crop yield. The combination of both models has a multiplying effect. Water stress appears at different times in different areas of the sprinkler spacing, and an irrigation event is scheduled when a certain fraction of these points is water stressed (Dechmi et al., 2004a and 2004b).

Communications, including remote control. Pressurized collective networks often install telemetry / remote control (TM/RC) systems operating on mobile phone networks or on dedicated radio connections. The capacities of these systems are quite varied. In some cases, their use is restricted to the conveyance network; very often, hydrants can be remotely operated and their water meter readings automatically registered. The last step in remote control is the integration of the valves controlling irrigation blocks in on-farm systems. This last step is infrequently adopted, but it permits to fully schedule and operate solid-set irrigation from a WUA computer.

Solid-set irrigation systems equipped with on-farm automation devices. Dechmi et al. (2003) published the results of interviews performed in 1998 at La Loma de Quinto WUA, Ebro valley, Spain. This WUA is equipped with solid-sets, center-pivots and linear moves. According to that study, 86% of the farmers did not use any irrigation automation system. In these days, virtually all old and new solid-sets in the Ebro valley have been equipped with automation devices commanded by an irrigation controller. The use of automation devices responds to the progressively high ratio of labour *vs.* automation costs and to the decline in net benefit obtained from field crops (at least till the first decade of this century).

Time slack on network and on-farm design. On-farm sprinkler irrigation systems and collective networks are commonly designed to apply water at a faster rate than irrigation requirements. This results in a certain time slack in irrigation scheduling. Time slack at the on-farm system and at the water inlet is required to optimize irrigation performance. Sprinkler irrigation farmers can select the irrigation periods leading to optimum efficiency (i.e., low wind periods) and/or minimum energy price (if needed) while timely satisfying crop water requirements.

3. A CONTROLLER DESIGN DRIVEN BY SIMULATION MODELS

Current solid-set irrigation controller designs (Fig. 1)are based on the manual elaboration of irrigation schedules. Basic controller set-up data include the number of irrigation blocks and the respective automatic valves. Farmers create a schedule by deciding the irrigation time for each block, the frequency (typically the days of the week when the schedule will be executed) and the starting time of the irrigation sequence. These controllers produce rigid irrigation schedules, which are implemented regardless of meteorology. In specific cases, these controllers may include sensors allowing volume-based irrigation. Some controller models are available in the market permitting to suspend/resume programme execution responding to specific sensors (i.e., wind speed).

Fig. 2 presents a more complex configuration, responding to the goal of governing a solid-set irrigated WUA through its TM/RC system. The system requires the use of one or several computers devoted to irrigation and crop simulations. The WUA structure (land tenure, crops, irrigation equipment…) can be obtained from an on-line connection to the WUA management database. The irrigation controller can in turn feed the management database with the time evolution of water application to the different plots. This controller design can make extensive use of local sensors, taking advantage of the spatial variability of different meteors, and their influence on crop water requirements and solid-set irrigation performance. Irrigation and crop models with different degrees of complexity can be used to support real-time irrigation decision making. Under this controller design, plot irrigation will proceed exploiting moments of low energy costs, suitable meteorological conditions and adequate network pressure. Controlling the irrigation of a whole WUA (or a large part of it) permits to make full use of the abovementioned opportunities. This design can be readily compared to strategy T2 presented and field-experimented by Zapata et al. (2013), which outperformed the rest of studied alternatives. Irrigation proceeds if the estimated Potential Application Efficiency of the low quarter (PAElq) or crop water stress level exceeds given thresholds. Fig. 3 presents pictures of the experiments reported by Zapata et al. (2013) to test strategy T2. Adding water delivery network models to this design could also contribute to reduce energy costs (if needed).

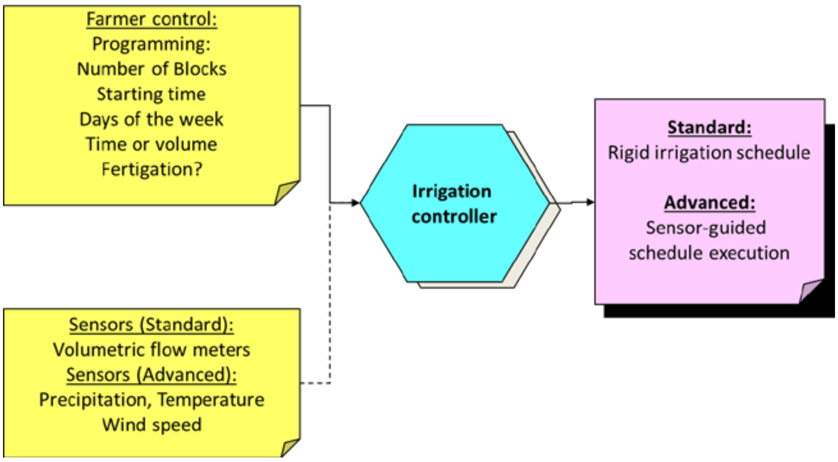

Fig. 1.Schematic representation of a standard irrigation controller.

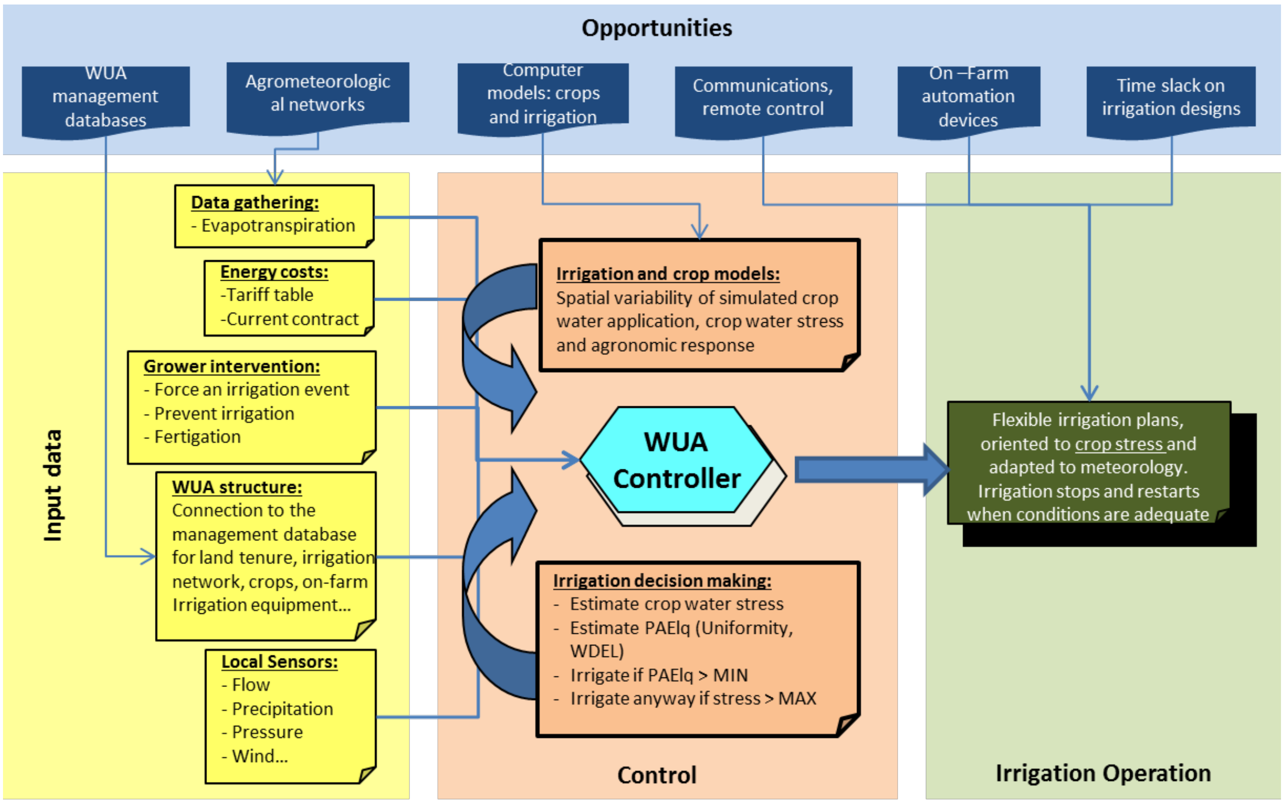

Fig. 2. Schematic representation of a Schematic representation of a WUA solid-set irrigation controller design driven by simulation models.

4. BOTTLENECKS

The following paragraphs describe identified bottlenecks deriving from research, technology and innovation needs, as well as from the required adaptation of farmers and WUAs.

Research needs. Previous works on linking crop and irrigation models indicated that complex crop models resulted in a better prediction of the variability in crop yield (Dechmi et al., 2010). Complex models will permit to explore additional sustainability aspects, such as the interaction between irrigation and agricultural pollution. The use of such models is currently limited by the integration of the computer code. These difficulties were recently signalled by Bergez et al. (2012), when discussing the integration of the STICS crop model in coupled bio-decisional models. The calibration requirements of advanced crop simulation models need to be properly addressed to facilitate controller adoption by users. Ballistic irrigation model results have been shown to depend on the sprinkler manufacturer (Playán et al., 2006). A few sprinkler models have so far been fully calibrated for their use in control applications.

Fig. 3. Experimentation on an irrigation controller based on simulation models: a) automatic irrigation controller in operation; b) harvesting the experimental plots.

Technology needs. Controller manufacturing companies have traditionally focused on their own hardware designs. However, in these days there are a number of alternatives for the controller hardware to be installed at the farm. Open-hardware platforms based on open-software stand as powerful alternatives. The wide commercial offer on TM/RC systems also exploits proprietary developments with very limited intercommunication capacities. The International Standardization Office, through subcommittee ISO/TC23/SC18 "Irrigation Techniques", has created a working group on "Remote monitoring and control technologies". This group aims at releasing a standard on TM/RC systems for irrigation. The completion and application of such a standard is a major requirement for the use of TM/RC systems in WUA controllers.

Innovation needs. The new generation of irrigation controllers will require supporting the offer of related services. Some of these services, like irrigation advising, are already offered in some areas of the world, particularly for cash crops. For WUA controllers, farmers could voluntarily subscribe to the WUA advanced scheduling services. The WUA or a hired services company could offer subscribed farmers a flat rate per volume of water, regardless of the time variations of the electric tariff.

Farmers and WUAs. The current socioeconomic farming context favours the implementation of advanced irrigation controllers: adequate prices for agricultural commodities, high labour and water costs, increasing energy prices and a growing environmental liability. In this context, professional, progressive farmers are required, which are determined to take advantage of research and innovation products. At the WUAs, in addition to bold leadership, irrigation specialists are required which can establish the link to new technologies. Specific policies will be required to favour the development of these services on the account of their agricultural and environmental benefits.

5. CONCLUSIONS

Irrigation controllers for pressurized systems are quickly changing to respond to water, energy and agronomy challenges and to implement new technologies. Opportunities are currently piling-up for the development of solid-set controllers driven by simulation models. A number of technologies have materialized which permit fast-track progress in automating solid-set irrigation control and at the same time progressing in irrigation productivity and sustainability. A design has been presented for a collective controller to be applied to a WUA. This design exploits not only simulation models, but also developments in communications and electronics. Advanced controllers can bridge the irrigation learning curve, and produce relevant improvements respect to manual programming. A number of bottlenecks have been identified in the research, technology and innovation domains. Software/hardware developments, calibration, standardization and demonstration requirements, development of new business models and farmers' expectations, and policy action have been listed as critical points for the deployment of this technology.

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