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Editorial

Editorial—Managing and Planning Water Resources for Irrigation: Smart-Irrigation Systems for Providing Sustainable Agriculture and Maintaining Ecosystem Services

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Abstract: Smart-irrigation systems are a hot topic in irrigation management. Satellite imaging, sensors and controls, communication technologies and irrigation decision models are readily available. The price of the required technology is being reduced year after year, and its implementation in agriculture gives real-time information that allows for more accurate management of water resources. Even so, the adaptation of existing technologies to particular situations that the irrigation management is facing in different agro-environmental contexts is needed. This Special Issue addresses the application of different smart-irrigation technologies in four different research areas: (1) remote sensing-based estimates of crop evapotranspiration, (2) Information and Communication Technologies (ICTs) for smart-irrigation, (3) precision irrigation models and controls, and (4) the price of natural resources. The nine papers presented in this special issue cover a wide range of practical applications, and this editorial summarizes each of them.

Keywords: smart-irrigation practices; soil health; open-source and low-cost monitoring devices; automatic and remote-controlled systems for irrigation; agro-hydrological models; evapotranspiration models and measurements; irrigation with marginal water

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1. Introduction

Smart-irrigation systems provide attractive instruments and methodologies for saving water and improving soil conservation in view of mitigating the impacts of climate change as well as increasing agricultural production. They can avoid over-watering, excessive runoff and soil erosion by scheduling the amount of irrigation according to soil characteristics, crop types, weather conditions and field geometries.

New devices based on open-source and low-cost technologies and apps allow the management of irrigation at field and farm scales through a sustainable water supply system based on actual crop water requirements and accounting for the local variability of soil properties. Tailored irrigation water management approaches oriented towards agro-hydrological models and decision support systems at the farm and district irrigation scales can also maintain reliable and flexible water allocation during dry seasons, preserving water for environmental requirements and decreasing conflicts between water users. Likewise, the use of marginal water resources such as saline or treated wastewater, both from industrial and domestic origin, becomes a source of irrigation in semi-arid and arid regions, where the future of irrigated agriculture is threatened by existing or expected shortages of fresh water, raising concerns of potential hazards to the environment and/or humans. Therefore, smart-irrigation systems that aim to adopt single or combined automation and Information Communication Technologies at the farm/district scale, as well as customized and integrated model approaches at larger scales, would appear to be a farsighted way to promote future resilient irrigation management.

Within this framework, the Special Issue "Managing and Planning Water Resources for Irrigation: Smart-Irrigation Systems for Providing Sustainable Agriculture and Maintaining Ecosystem Services" offers an opportunity to gather studies and multidisciplinary approaches related to advanced technologies and innovative methodologies for irrigation management and soil conservation at different spatial scales, taking into account key issues such as the following:

- New remote and proximal sensing techniques and methodologies for detecting soil hydraulic properties, crop water and nutrient status.
- Innovative laboratory and outdoor experiments for detecting surface and subsurface runoff and soil transport.
- New irrigation methods and techniques for improving the water use efficiency in different crops and environmental contexts, as well as preventing soil degradation such as compaction, loss of soil structure, nutrient degradation, erosion, sedimentation and salinity.
- New agronomic and irrigation management practices to favor soil biodiversity and improve or restore natural ecosystems.
- Systems and methodologies for improving the effectiveness of traditional irrigation methods.
- The role of traditional irrigation methods in maintaining ecosystem and environmental equilibrium.
- Automatic and remote-controlled systems for improving surface, sub-surface, drip and sprinkler irrigation.
- Use of agro-hydrological models and decision support systems to promote better informed decisions on irrigation management and for safe surface water–groundwater interactions.
- Pros and cons of marginal water use in irrigated agriculture.

2. Overview of Contributed Papers

In this Special Issue, nine contributed papers with a very good level of innovation were published. They are subdivided into four macro-categories, as reported in Table 1, and briefly described in this section.

Table 1. Compendium of the works published in the Special Issue "Managing and Planning Water Resources for Irrigation: Smart-Irrigation Systems for Providing Sustainable Agriculture and Maintaining Ecosystem Services". Categories, authors, title and topic are briefly summarized. NDVI: Normalized Difference Vegetation Index; SCADA: supervisory control and data acquisition.

Categories	Author	Title	Research Topic
Remote sensing-based estimates of crop evapotranspiration	Gavilán et al. (2019)	Seasonal Crop Water Balance Using Harmonized Landsat-8 and Sentinel-2 Time Series Data	Integration of satellite NDVI information for assessing evapotranspiration fluxes.
Information and Communication Technologies (ICTs) for smart-irrigation	Bhatti et al. (2019)	Revisiting Telemetry in Pakistan's Indus Basin Irrigation System	Experiences of using Information and Communication Technologies for collecting, in real-time, flow measurements in an irrigation delivery system.
	Zhang and Khachatryan (2019)	Investigating Homeowners' Preferences for Smart-Irrigation Technology Features	Analyzing farmers' attitudes and preferences to use smart-irrigation technologies and support in controlling and addressing farm irrigation.
Precision irrigation models and controls	Mayer et al. (2019)	A Comprehensive Modelling Approach to Assess Water Use Efficiencies of Different Irrigation Management Options in Rice Irrigation Districts of Northern Italy	Modelling traditional irrigated rice field behavior for water-saving purposes and support decision policy.
	Ortuani et al. (2019)	Assessing the Effectiveness of Variable-Rate Drip Irrigation on Water Use Efficiency in a Vineyard in Northern Italy	Addressing variable rate irrigation through the detection of spatial variability of soils in agricultural fields.
	Zhang et al. (2019a)	The Development of a Calculation Model for the Instantaneous Pressure Head of Oscillating Water Flow in a Pipeline	Development of water flow management techniques for improving the anti-clogging of emitters in drip irrigation, water distribution in sprinkler irrigation and reducing energy consumption.
	Solé-Torres et al. (2019)	Assessment of Field Water Uniformity Distribution in a Microirrigation System Using a SCADA System	Testing a supervisory control and data acquisition system for reducing clogging concerns in drip irrigation systems when wastewater is used for irrigation.
	Zhang et al. (2019b)	The Influence of Sinusoidal Oscillating Water Flow on Sprinkler and Impact Kinetic Energy Intensities of Laterally-Moving Sprinkler Irrigation Systems	Development of water flow management techniques for improving the performances of laterally-moving sprinkler irrigation systems in low-pressure conditions.
Price of natural resources	Aydogdu (2019)	Farmers' Attitudes to the Pricing of Natural Resources for Sustainability: GAP-Şanlıurfa Sampling of Turkey	Interaction between water price and farmers' willingness to pay for sustainable natural resources.

3. Remote Sensing-Based Estimates of Crop Evapotranspiration

Aiming at contributing to the efficient use and management of irrigation water, Gavilán et al. (2019) [1] tackle the difficult and important task of estimating evapotranspiration in agricultural irrigated areas. The work explores the feasibility of using satellite-based data to carry out updated seasonal water balances over large areas—an approach that would overcome difficulties in using local measurements of surface energy balance components to extrapolate the conditions over large agricultural areas. Limitations include the heterogeneity, large space-time variability and complexity of the soil–vegetation–atmosphere interactions in agricultural environments. Results of this work are encouraging in relation to the role that the proposed approach might have in improving water management both at plot and water distribution system scales. The authors propose a method based on the integration and harmonization of the Normalized Difference Vegetation Index (NDVI) obtained from Landsat-8 and Sentinel-2 sensors in order to obtain a single NDVI time series as a means to estimate evapotranspiration through specific adjustment equations for each type of crop, which allows one to continuously characterize the demand for water during an irrigation season. The approach aims to take advantage of the characteristics of both products (Landsat-8 and Sentinel-2), and leads to an effective increase in spatial and temporal coverage, improving data availability.

4. Information and Communication Technologies for Smart-Irrigation

In this category, two works were published. Bhatti et al. (2019) [2] describe the experience of installing flow meters in the Indus Basin Irrigation System (IBIS) and their connection in a telemetry system to allow the real-time control of water distribution in the irrigation canals and a continuous recording of water deliveries. Despite this study being focused on the IBIS context, it represents a clear message of how irrigation is still managed in a large part of the world. Unlike agricultural mechanization, which has made huge steps forward in terms of automatic, remote-controlled machineries based on artificial intelligence (e.g., variable rate applications in fertilization, in sowing and in harvesting), irrigation has remained anchored in ancient practices both in terms of methods and management. Through a six-step method based on the definition, assessment, analysis, control, implementation, and improvement of flow measurements in irrigation canals, Bhatti et al. (2019) [2] found the possibility to improve, guide and address water policies in the IBIS district with positive impacts on water distribution efficiencies and managements.

Automatic notifications, mobile controls, integration of irrigation systems at farm and district levels with weather forecast alerts, soil moisture sensors and crop water requirement model tools are the current technologies that farmers perceive as utilities for improving irrigation efficiency. This is discussed in the work of Zhang and Khachatryan (2019) [3]. They found that educating farmers may help to overcome the potential barriers to the adoption of smart-irrigation technologies. All the players in the production chain could, moreover, promote and encourage the use of smart-irrigation technologies through a product certification system which attests to the application of water conservation practices.

5. Precision Irrigation Models and Controls

In this Special Issue, there are five papers published in this category. Mayer et al. (2019) [4] developed an agro-hydrological modelling framework based on three sub-models (one for the agricultural areas, one for the groundwater zone, and one for the channel network) to investigate the water use efficiency in rice areas of northern Italy at the irrigation district scale. Once calibrated for a district of 1000 ha using meteorological, hydrological and land-use data of a four-year period, the model was used to assess four different irrigation management scenarios: (1) wet seeding and continuous flooding until few weeks before harvest (WFL), (2) dry seeding and delayed flooding (DFL), (3) alternate wetting and drying (WDA), and (4) WFL followed by post-harvest winter flooding (WFL-W). Their results suggest that DFL and WDA would lead to a reduction in summer irrigation needs compared to WFL, but also to a postponement of the peak irrigation month to June, which is already characterized by a strong water demand from other crops. Finally, summer irrigation consumption for WFL-W would correspond to WFL, suggesting that the considered winter flooding period ended too early to influence summer crop water needs.

Ortuani et al. (2019) [5] analyzed the performance of a simple drip variable-rate irrigation (VRI) system, designed according to the soil variability in a vineyard of 1 ha located in the Morainic Hills region south of the Garda Lake (Lombardy, Italy), in reducing irrigation water use while maintaining product yield and quality. The mapping of the soil electrical conductivity (EC) was used to identify different management zones and design a drip VRI system. The drip VRI system was characterized by three sectors: two sectors supplied water to different management zones (MZs), while the third sector was used to illustrate the "reference irrigation management" used by the irrigator. Irrigation in the first two sectors was managed firstly according to the different crop irrigation requirements estimated considering the site-specific soil hydraulic properties and successively on the basis of data acquired by soil moisture probes installed in each sector. The results showed a reduction of water use by 18% compared to the "reference" sector without losses in yield and product quality, and a grape's maturation was more homogeneous in time. Therefore, it can be concluded that a relatively simple solution for the implementation of VRI could be designed and implemented in commercial vineyards, showing that precision irrigation techniques are ready to provide tangible results that may be of interest not only for researchers but also for farmers.

Low-pressure drip and sprinkler irrigation systems are of interest because they can decrease costs and energy consumption. However, drip emitters operating at low pressure are more prone to clogging, and sprinklers produce uneven water distribution patterns, making it difficult to ensure the quality of the irrigation. In recent years, oscillating pressure has been used in low-pressure irrigation systems, providing a new way to solve the problems in irrigation. Oscillating pressure increases the flow turbulence in an emitter, which improves the anti-clogging performance of the emitter. The low sinusoidal oscillating pressure can improve the distribution of the sprinkler under low pressure. Zhang et al. (2019a) [6] developed a calculation model for the instantaneous pressure head of oscillating water in a pipeline using a complex function to solve the continuity equation and the momentum equation of a pipeline with a water hammer motion and using the Darcy–Weisbach formula. The model provides a theoretical basis for the application of oscillating water flow in irrigation systems and the design of irrigation pipe networks.

Zhang et al. (2019b) [7] carried out experiments on a laterally-moving sprinkler irrigation system under low-pressure, sinusoidal oscillating water flow. The sprinkler intensity and impact kinetic energy intensity distribution were investigated. In laterally-moving sprinkler irrigation systems, the uniformity of sprinkler intensity and impact kinetic energy intensity should be no less than 85%, and the impact kinetic energy intensity should be no higher than 0.6 W/m^2. In order to meet this standard, the amplitude of sinusoidal oscillating water pressure in laterally-moving sprinkler irrigation systems ranged from 50 kPa to 60 kPa. When the amplitude of sinusoidal oscillating water flow was 50 kPa, the optimal sprinkler spacing was 3.5–4 m; when the amplitude of sinusoidal oscillating water flow was 60 kPa, the optimal sprinkler spacing was 3.5–4.5 m. The results show that within an optimal range of amplitude and nozzle spacing, sinusoidal oscillating water flow significantly improves the combined sprinkler intensity, impact kinetic energy intensity uniformity, and the spraying quality of laterally-moving sprinkler irrigation systems under low pressure conditions.

Solé-Torres et al. (2019) [8] developed a supervisory control and data acquisition (SCADA) system to monitor the pressure and flow across the irrigation laterals in a microirrigation system. The monitored values of pressure and flow allowed distribution uniformity coefficients to be determined, performing an evaluation of the drip irrigation system in real time. Moreover, SCADA will allow the calculation of the flow distribution uniformity coefficient DU_{lq} without the need for annual field measurements, saving labor costs, in spite of its high investment cost. The proposed method presents automation advantages as it indirectly considers all the irrigation emitters, and so DU_{lq} calculation is as affected by emitter clogging as the Merriam and Keller method. In addition, the proposed method also allows subsurface irrigation installations to be evaluated which would be impossible to evaluate without digging out the laterals.

6. Price of Natural Resources

In this category, one contributed paper was published. Aydogdu (2019) [9] explored the attitudes of farmers to pay for natural resources in the case study of GAP-Sanliurfa (Turkey). Data from about 1000 farmers highlighted that 40% of the interviewed farmers showed a positive attitude to pay for natural resources, with a willingness to pay for about 48 USD per hectare. The work of Aydogdu (2019) [9] emphasized that the water price for irrigation purposes, despite the pervasiveness of water pricing in developed countries, is still a source of disagreement regarding the appropriate means by which to price water and the levels of water charges. This is partly due to (i) a lack of tradition, experience, and appropriate institutions to price irrigation water in different countries; (ii) common misconceptions and myths associated with irrigation water pricing; and (iii) a lack of definitions and incorporation of equity criteria. Potential solutions such as the direct involvement of farmers and stakeholders in water planning, the use of improved varieties of seeds to reduce water needs, the change of irrigation methods in specific areas and tailored smart-irrigation practices appear to be some of the rules of thumb to achieve not only decreasing water use but also economic efficiency and sustainability.

7. Conclusions

Managing and planning water resources is known to be a challenging task, involving a high number of variables, uncertainties and risks. Particularly for irrigation purposes, issues related to agriculture sustainability and the maintenance of ecosystems services have triggered the search for smart-irrigation systems, themselves inspiring new approaches and perspectives. Some of the innovative irrigation practices are far from being consolidated; they are instead adapting to the increasing demands associated to diverse natural and socio-economic environments and conditions, facing unprecedented changes.

In the view of the authors of this Editorial, the contributed papers included in this special issue offer updated discussions on the theme of this publication and a sample glance on the many innovative approaches and new concerns related to the general topic. The contributed papers are inspiring works focusing on diverse environments, methodologies and case studies that show the need to deepen our knowledge and share experiences and viewpoints in the continued search for a fair use of water resources among stakeholders, while protecting and conserving the environment and its resources.

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