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Editorial

Innovation Issues in Water, Agriculture and Food

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Abstract: The main challenge faced by agriculture is to produce enough food for a continued increase in population, however in the context of ever-growing competition for water and land, climate change, droughts and anthropic water scarcity, and less-participatory water governance. Such a context implies innovative issues in agricultural water management and practices, at both the field and the system or the basin scales, mainly in irrigation to cope with water scarcity, environmental friendliness, and rural society welfare. Therefore, this special issue was set to present and discuss recent achievements in water, agriculture, and food nexus at different scales, thus to promote sustainable development of irrigated agriculture and to develop integrated approaches to water and food. Papers cover various domains including: (a) evapotranspiration and crop water use; (b) improving water management in irrigated agriculture, particularly irrigation scheduling; (c) adaptation of agricultural systems to enhance water use and water productivity to face water scarcity and climate change; (d) improving irrigation systems design and management adopting multi-criteria and risk approaches; (e) ensuring sustainable management for anthropic ecosystems favoring safe and high-quality food production, as well as the conservation of natural ecosystems; (f) assessing the impact of water scarcity and, mainly, droughts; (g) conservation of water quality resources, namely by preventing contamination with nitrates; (h) use of modern mapping technologies and remote sensing information; and (i) fostering a participative and inclusive governance of water for food security and population welfare.

Keywords: water-agriculture-food nexus; crop water use and evapotranspiration; irrigation scheduling; design of irrigation systems; simulation models; droughts; irrigation water governance; economic and environmental issues

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1. Introduction

Agriculture's first challenge is to produce enough food for a continued increase in population in a context where the increased demand for food is associated with an ever-growing competition for water and land, climate change and uncertainty, anthropic and droughts water scarcity, poor supply reliability, decline in critical ecosystem services, less-participatory water resources governance, and changing regulatory environments. Facing such a challenging context implies innovative issues in agricultural water management, particularly in the various facets of irrigation to cope with water scarcity, environmental friendliness, and rural society welfare.

Innovation issues in the water-agriculture-food nexus aim at various essential problems and objectives: (a) developing integrated approaches to water and food policies and practices; (b) improving water management in agriculture; (c) adaptation of agricultural systems to enhance water use and water productivity to face water scarcity and climate change; (d) ensuring sustainable management and conservation of natural and anthropic ecosystems favoring high-quality food production; and (e) fostering a participative and inclusive governance of water for food security and population welfare.

These large themes cover a variety of challenges faced by the irrigated agriculture, which represents 16% of the world cropped area, but is expected to produce 44% of world food by 2050 [1,2].

Progresses observed in irrigation support a positive view on future responses to challenges faced by the water-agriculture-food complex as analyzed by Pereira [3]. Crop evapotranspiration processes are progressive and better known with consequent advances in understanding the complexity of climate and in estimating crop water and irrigation requirements. Irrigation scheduling has greatly advanced since knowledge on evapotranspiration and crops water use is improved, computer modeling eases supporting the development of well-focused programs, and modern technologies provide for timely advice to farmers. Remote sensing is progressively revealing its great potential to identify the vegetation water status, assessing crop water requirements and supporting irrigation management decisions. Irrigation systems design at both the farm and system levels is progressing with using various approaches for decision making, namely with combining water and economic performance issues. Progresses in irrigation methods and in canal and pipe conveyance and distribution systems contribute to improved irrigation and delivery schedules with impacts on water saving, yield improvements, and economic and social issues. Participatory governance keeps developing, however slowly, favoring sustainable water use, water productivity, and social welfare. Developments in better and joint approaches to water and fertilizer management are also providing for controlling environmental contamination and reducing greenhouse gas emissions.

This Special Issue is an opportunity to gather different achievements in the domains referred above, thus aimed at the sustainable use of water and other natural resources at different scales, so contributing to promote better development of irrigated agriculture when adopting a variety of well-performing technologies with good consideration of related social and economic environments. The studies presented herein focus on evapotranspiration, crop water requirements and modeling, remote sensing for assessing evapotranspiration, irrigation management for improved productivity and water saving, irrigation methods and systems design, control of soil salinity in irrigation, soil amendments for improved water use, surface water conveyance and distribution systems, participatory water governance, droughts and climate change issues, and environmental impacts of irrigated agriculture with focus on nitrates. Studies largely used innovative information and communication technologies, namely relative to data acquisition, modeling, decision support systems, remote sensing, and mapping.

This book presents the twenty-one selected contributions, consisting of 19 research papers and two revision papers, which were organized in accordance with the spatial scale of the study presented. Three levels were considered: the farm scale, the irrigation system scale, and the basin and regional scale.

2. Innovation Issues at Local Scale

Most research work relative to the local, farm scale is related to innovation on evapotranspiration and crop water requirements. The study by de Bruin and Trigo [4] refers to a new method to estimate reference crop evapotranspiration (ET_o) using products of the European geostationary satellite Meteosat Second Generation (MSG), thus analyzing benefits from computing ET_o with solar radiation data of the Satellite Application Facility on Land Surface Analysis (LSA-SAF). Not only the method allows computing ET_o when ground data on solar radiation are not available but also avoids advection effects. The authors used observations from two quite different sites, one in the Netherlands and the other in Spain. Results are comparable with those computed using the ET_o definition and are therefore appropriate to be used when radiation data are missing, or are of poor quality, or are affected by advection.

Paredes et al. [5] present an innovative approach for the determination of the bermudagrass water requirements in southern Brazil, relating the frequency of cuttings with a density coefficient (K_d) that depends upon the fraction of ground cover and crop height. The basal crop coefficient (K_{cb}) used to estimate crop evapotranspiration (ET_c) with the dual K_c approach is then computed from K_d using the SIMDualKc model. Two seasons of experimentation were used with four different cutting treatments, which provided field data for model calibration and validation. K_{cb} values relative to the various crop growth stages were therefore reported. In addition, results indicated a very high beneficial consumptive water use fraction, mainly when cuttings are not very frequent. The SIMDualKc model proved to be reliable in the evaluation of water saving practices after proper calibration and validation. This was also demonstrated by Zhang et al. [6] when comparing basin irrigation and drip irrigation of a tomato crop in the upper reaches of the Yellow River, China. They concluded that, besides saving irrigation water, drip could speed up the ripening of fruits and shorten the period of crop growth. Considering both water saving and crop yield, drip irrigation using plastic-film mulch was recommended. Moreover, appropriate K_{cb} values relative to the defined crop growth stages are proposed for computing ET_c in the region and to transfer elsewhere after appropriate climate adjustment. Paço et al. [7] confirm the appropriateness of using the SIMDualKc model for ET_c computations and the great importance of irrigation for super intensive olive orchards in an application performed in southern Portugal. Appropriate values for K_{cb} and K_c were determined from the calibration and validation of the model. The authors also concluded that the level of water stress allowed to the crop should be accurately controlled to maximize related benefits, i.e., adopting the so-called eustress. They recommended the use of the SIMDualKc or a similar model to properly schedule irrigation. The papers referred above [5–7] relative to a grass crop, a horticultural crop, and a tree crop all proved the appropriateness of simply computing K_{cb} from the fraction of ground cover and height.

Fuentes-Peñailillo et al. [8] assessed the potential for the use of the two-source Shuttleworth and Wallace (SW) model to compute the intra-orchard spatial variability of the actual ET of olive trees using satellite images and ground-based climate data. The performance of the SW model approach was tested using eddy covariance heat and vapor fluxes measurements performed in Chile. The model separately characterizes evaporation fluxes from the soil and transpiration from the trees and its practical application requires adequate parametrization of both sources of fluxes, the soil and the trees, thus the stomatal resistance and leaf area index of olive orchards under different management practices. Ramos et al. [9] describe the impact of assimilation of leaf area index (LAI) data derived from Landsat 8 imagery on MOHID-Land's simulations of the soil water balance and maize state variables using data collected in southern Portugal. The main conclusion is that the implementation of the MOHID-Land model at the regional scale cannot depend solely on inputs from the LAI data assimilation because estimates may diverge substantially from the reality, thus confirming the need to use a proper data set for calibration.

The study presented by Abrisqueta and Ayars [10] describes how traditionally grapes are fully irrigated in California, while alternative irrigation strategies to reduce applied irrigation water may be necessary in the future. The paper assesses water use and productivity of alternative deficit irrigation schedules with identification of advantages of using sustained deficit irrigation, corresponding to 80% of present growers water use, which provides for water saving and improved yield. Nevertheless, there is little acceptance and implementation of scientific irrigation management by the growers' community. This work demonstrates that simple approaches can be used to facilitate improving irrigation management. The application of technological advances should be investigated particularly in regions where water resources are scarce and agriculture is primarily based on irrigation. In their work, Abi-Saab et al. [11] assessed for two crop seasons the suitability of cloud-based irrigation technologies for durum wheat, a strategic Mediterranean crop of Lebanon. Their study focused on the on-field assessment of a smartphone irrigation scheduling tool—Bluleaf® (Bari, Italy)—with respect to traditional water application practices. A water saving of more than 1000 m^{-3} ha^{-1} (25.7%) was observed for farmers using Bluleaf® with respect to traditional irrigation scheduling.

The study by Miao et al. [12], applied to the Hetao Irrigation System, upper Yellow River basin, China, focuses on upgrading wheat basin irrigation through improved design using multi-criteria analysis to support selection of technical solutions focusing on both water saving and economic returns of the achievable yields. The design considers land parcels characteristics, soil infiltration, hydraulic simulation, precise land leveling, and crop irrigation scheduling, and evaluating solutions through assessing environmental and economic impacts. Alternative solutions refer to basin lengths and inflow rates for both level- and graded-basins under full and deficit irrigation. Better solutions aimed at the upper Yellow River were generally assigned to level-basins.

The application of organic mulches and amendments to the soil is a well-recognized water saving practice. Zhang et al. [13] provided evidence that straw amendments applied to a sloping field of northeastern China reduced water losses by evaporation and increased soil organic matter while decreasing carbon dioxide emissions. In addition, it positively influenced the dynamics of available nitrogen and phosphorous in soil. Therefore, straw amendments not only contributed to improved crop conditions and increased yields but also to control greenhouse gas (GHG) emissions. Furthermore, Zhao et al. [14] show that the applications of organic amendments like farmyard manure and bioorganic fertilizer to a maize crop in the Guanzhong Plain of northwest China improve soil properties and crop roots distribution, controlled soil water depletion, and favored the soil hydrothermal conditions and crop yields.

3. Innovation Issues at Project and Watershed Scale

Agricultural water use at project and watershed scale also drew interest in terms of utilization and conservation of both surface water and groundwater. Quite different approaches were presented. The study by Derardja et al. [15] presents the development of indicators that can help managers and designers to better understand the behavior of pressurized conveyance and distribution networks with respect to the perturbation due to sudden changes in pipe flow rates, namely due to hydrants closure. The indicators refer to pressure variation and associated risk. The study was applied to an on-demand pressurized irrigation project of Capitanata, Southern Italy, and provides a modeling approach for the identification of risky hydrants and potentially affected pipes. Generally, the model contributes to safe water use in collective pressurized systems operating on demand.

An organizational solution for improving the governance of water and land use and, consequently, improving the supply–demand water balance in the Mendoza River basin in Argentina, is described by Solomon-Sirolesi and Farinós-Dasí [16]. A strategic analysis of water organization was performed that produced a strategic map and provided for using the Water Evaluation and Planning (WEAP) model. The application of the organizational and governance model to various scenarios provided for reordering allocations to irrigation water users, so improving farm and irrigation system, which is expected to make it possible to accommodate water demand in 2030 better than at present. Moreover, users' participation is enhanced. Differently, but along the same line of searching for improved irrigation water governance, Playán et al. [17] reviewed the evolution of water governance and societal perception in large irrigation systems in developing countries since the 1980s which included participatory irrigation management, irrigation management transfer, and public-private partnerships or market instruments and, more important, that led to a generalized implementation of water users associations (WUAs). The paper, therefore, reviews recurrent problems and solutions in the governance of irrigated projects in various regions of the world. The authors used a semiquantitative approach to relate solutions to problems in WUAs. The solution vector indicates the adequacy of each solution to a case study WUA. The application of this approach to various case study WUAs demonstrated its potential.

A modified version of the distributed hydrological model Soil and Water Assessment Tool (SWAT) was used by Wei et al. [18] for accurately simulating daily evapotranspiration and crop growth at the hydrological response unit (HRU) scale in an irrigation district of the Hei River basin, China. The parameters of the modified SWAT2009 model were calibrated and validated using data on maize from various HRUs with satisfactory results. The influences of various optimal management practices on the hydrology of agricultural watersheds could, therefore, be effectively assessed using the modified model. Contrasting, but also considering a large irrigation system, Wang et al. [19] reviewed the performance of dry drainage systems (DDS) as an alternative technique for controlling soil salinization. A five-year field observation from 2007 to 2011 was developed in the Hetao Irrigation District, Inner Mongolia.

Results showed that the groundwater table depth in the areas kept fallow quickly responded to the lateral recharge from the surrounding croplands during irrigation events. The groundwater salinity increased in the fallow areas whereas the groundwater electrical conductivity (GEC) just fluctuated in croplands. The water and salt balance showed that excess water moved to the fallow area, roughly four times the one that moved by surface drainage, with near 8 times the corresponding salt. However, the salt transfer slows down after three years and salt starts accumulating in irrigated croplands. Using halophytes in the fallow area may be a solution. DDS may be effective and sustainable in situations where the fallow areas can sustain an upward capillary flux.

4. Innovation Issues at Regional and Country Scale

The Pampa biome characteristic of southern Brazil is a complex ecosystem where the processes of surface–atmosphere interaction are dependent on climate, soil, and vegetation. In this way, the preservation of this biome is essential for the maintenance of biodiversity, animal, and plant species, as well as land use. In their work, Rubert et al. [20] observed the actual ET with eddy covariance measurements over three years and two sites of the Pampa biome, and results showed a strong seasonality, with approximately 65% of the net radiation used for ET. The water availability in the Pampa biome is not a limiting factor for ET, which resulted in a small difference between the reference ET and the actual ET.

Framing integrated policies that improve the efficient use of resources requires understanding the interdependencies in the water–energy–food nexus (WEF) as discussed by Martinez et al. [21]. These authors developed and applied a participatory modeling approach to identify the main interlinkages within the WEF nexus in the region of Andalusia, Spain. Stakeholder involvement in this process is crucial to represent multiple perspectives, ensure political legitimacy, and promote dialogue. Results show that climate change and water availability are key drivers in the WEF nexus in Andalusia. The scenario analysis reveals the interdependencies among nexus sectors that need to be considered to design integrated policies.

At the regional scale, now focusing on water quality problems associated with the agricultural activity, Cordovil et al. [22] present a simplified nitrogen (N) assessment review along the Tagus River basin, which covers a large area of Spain and Portugal in the Iberian Peninsula, mainly relative to agriculture, livestock, and urban activities. Nitrate vulnerable zones comprise approximately one-third of territories in both countries. Differently, sensitive zones are more extended in Spain, attaining 60% of the basin area, against only 30% in Portugal. The authors concluded that the Tagus River basin sustainability can only be guaranteed through reducing load inputs and considering the effective transnational management processes of water flows.

Moreira et al. [23] modeled drought class transitions over a large region using a log-linear approach. Temporal scales of 6 and 12 months were adopted when studying rainfall data for 15 grid points selected over the Prut basin in Romania over a period of 112 years (1902–2014). The modeling also took into account the impact of the North Atlantic Oscillation (NAO), thus exploring the potential influence of this large-scale atmospheric driver on the climate of the Prut region. The authors conclude that the adopted method performs consistently better than the persistence forecast and that it can be part of an early warning system aiming at informing farmers to support them in making their water management decisions.

Finally, returning to the water quality and nitrates issue, Cruz et al. [24] examined the state of surface waters in terms of nitrogen concentrations, its impact on water quality status, and the policy responses across different climatic and management conditions. Portugal and Denmark were chosen as contrasting case studies for the Driver-Pressure-State-Impact-Response (DPSIR) analysis. Results showed a reduction in the levels of N in water bodies which were attributed to the previous, historical implementation of policies aimed at reducing the N losses from land to water in both countries. However, climatic factors such as precipitation play a major role in reducing the N concentration in waters through a dilution effect, namely after infiltrating the soil, so contributing for differences between both countries.

5. Conclusions

The general message emanating from this Special Issue is that consistent progresses are continuously developing that contributes to the sustainability of water use in agriculture and to make available a variety of innovative issues in the water-agriculture-food nexus. This collection of 21 papers emphasizes the importance of understanding the various interdependencies among innovative issues.

It is clear that sets of coherent strategies and solutions need to be applied to mitigate the complexities of overall challenges placed to the sustainable use of water in agriculture and food production. Strategies are different at both the small scale, the field or farm level, and the large operational scale relative to the irrigation district, the river basin, the region, or the country. At a small scale, strategies and solutions are mostly of technological nature, with great importance to be given to the information and communication technologies (ICT), including remote sensing. At the large scale, main strategies refer to governance, to user's participation in water management, and to the ICT required to provide for planning and management decisions. Furthermore, scaling-up innovation remains a challenge. Linkages between the different scales of application are quite important and need to be better investigated. Included are the impact of introduction of innovative management and practices at small scales, with the improved estimation of yields and water use at high spatial resolution, or the impact of the political measures at farm scale and relative to the maintenance of the quality of surface and ground waters. Related knowledge should facilitate the widespread application of technologies and adaptation measures (e.g., agronomic and irrigation practices) aimed at achieving better performance of water use, agricultural production, and relative to the sustainability of water use. Regardless of the spatial scale, modeling is a widespread tool which however requires calibration and validation. The use of models should be framed to adapt easily to obtain data and information, e.g., using the simple crop coefficient approach when modeling crop evapotranspiration, however adopting modern and accurate ET observation instrumentation both at the ground surface and by satellite earth observation.

We hope that this Special Issue will provide for coherent directions of research and support to the scientific community in defining priorities for in the water-agriculture-food nexus research.

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