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Editorial

Plant Water Use Efficiency for a Sustainable Agricultural Development

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Abstract: The rising shortage of water resources worldwide in crop-producing regions and the need for irrigation optimisation call for sustainable water savings. That is, the allocation of irrigation water will be an ever-increasing source of pressure because of vast agricultural demands under changing climatic conditions. Consequently, irrigation has to be closely linked with water-use efficiency with the aim of boosting productivity and improving food quality, singularly in those regions where problems of water shortages or collection and delivery are widespread. The present Special Issue (SI) contains 19 original contributions addressing water-use efficiency under challenging topic of sustainable irrigation management to meet water scarcity conditions. These papers cover a wide range of subjects, including (i) interaction mineral nutrition and irrigation in horticultural crops, (ii) sustainable irrigation in woody fruit crops, (iii) medicinal plants, (iv) industrial crops, and (v) others devoted to remote sensing techniques and crop water requirements, genotypes for drought tolerance, and agricultural management platform. The studies have been carried out in both field and laboratory surveys, as well as modelling studies, and a wide range of geographic regions are also covered. The collection of these manuscripts presented in this SI updates and provides a relevant knowledge contribution for efficient saving water resources.

Keywords: deficit irrigation; crop-water requirements; smart farming; crop-production functions; food quality; remote sensing; crop physiological response to drought scenarios

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1. Introduction

Water is considered the most vital resource for agricultural development, and under scarcity conditions and climate change, substantial effort must be devoted to introducing measures in improving their sustainable use [1,2]. Various studies have reported the predictably effects of climate change on the agricultural systems [3–5]. Augmenting agricultural water through irrigation systems to complement soil moisture deficit has driven enhanced agricultural productivity in large areas worldwide. The consequences include unintended side effects such as exhaustion of river flow, river basin closure, groundwater reduction, and water pollution [6]. The Green revolution promoted food production but turned out not to be sustainable due to improper management by the agricultural sector.

In many dry climate countries, the dominant form of water is the contained in the soil, i.e., infiltrated rain, and boosting crop production is therefore an issue of water security, which can be achieved only by overcoming the difficulties of rainfall variability exacerbated by climate change. In this line, rainfed agriculture is the most common method of agriculture in developing regions, 80% of the land farmed around the world being rainfed and can cover more than 75% of the needed increase in food production by the year 2025 [7].

Agricultural water management should balance the need for crops with the preservation of a sustainable environment. In this line, water-use efficiency is the main challenge in worldwide farming practices, where water shortages are becoming more frequent. Today, the agricultural sphere is undergoing significant changes regarding irrigation, the implementation of adaptive and water-saving strategies being urgent [8]. Moreover, under climate change conditions, traditional and calculated irrigation at full-water requirements based on crop evapotranspiration (ETC) will probably not be practicable in the medium-long term, requiring alternative strategies to face the current climatic circumstances [9]. In this line, deficit-irrigation could be considered a sustainable option to achieve a balance in irrigated crops in saving water and producing assumable yield losses [10]. That is, deficit-irrigation practices are a tool to mitigate climate change effects, attaining environmental, social, and economic benefits.

In this SI, we tried to collect studies regarding water scarcity as the most limiting factor in agriculture, together with the climate change scenario that promotes a framework of uncertainty and great challenges regarding the sustainability and viability of current agroecosystems. Likewise, this SI provides updates and recent developments in physiological and biochemical perspectives on the response to water deficit in field and greenhouse crops, as well as new tools to assess the crop water status, monitor the continuous soil–plant–atmosphere system, or integrate information systems based on big-data and smart farming tools that reinforce our knowledge to offer an appropriate response to the current challenges for achieve a higher water-use efficiency.

2. Overview of This SI

This SI presents 19 original contributions focused on plant water-use efficiency and aimed to address the challenging topic of sustainable irrigation management to face water scarcity conditions. From a methodological perspective, the contributions involve both field [11–25] and laboratory [26,27] experiments, and modelling [18,28,29] studies. The present SI contains studies at different spatial scales, from the field- to regional-scales. Particularly, the contributions stress five main subjects, including: (i) the interaction of mineral nutrition and irrigation in horticultural crops [11,12,21,27]; (ii) sustainable irrigation in woody fruit crops [15,17,19,22,25,26]; (iii) medicinal plants [14,24]; (iv) industrial crops [23]; and (v) remote sensing techniques and crop water requirements, genotypes for drought tolerance, and agricultural management platform [18,28,29]. In addition, a wide range of geographic regions worldwide are also covered, including Asia [12–14,16,20,24], Australia [23], Brazil [18], the Mediterranean basin [15,17,19,21,22,25,28,29], and Central [11,26] and Western [27] Europe.

Concretely, subject (i) comprises four papers. In general, these works display the impact of interaction fertilization and irrigation on the yield and growth of artichoke (*Helianthus tuberosus* L.) [11], tomato (*Solanum lycopersicum* L.) [12], maize (*Zea mays* L.) [21], and cassava (*Manihot esculenta* Crantz) [27]. These findings illustrate the importance of assessing the effects on crop productivity under various interaction levels of plant nutrients and water doses for proper management strategies, with the aim to reach a sustainable cultivation for a particular environment. According to Bogucka et al. [11], potassium fertilizer applied at rate of 150 kg K_2O ha^{-1} contributed to the greatest increase in the above-ground biomass yield of artichoke, while the irrigation had a significant effect on total tuber and above-ground biomass yields, which increased by 59 and 42%, respectively. On the other hand, the irrigation level based on 80% ET_C and nitrogen (N) incorporation of 15 mM (N_{100}) for soilless tomato production in greenhouses was found to be optimal regarding yield and irrigation water-use efficiency. In the study by Ibrahim et al. [21], it was determined that the potassium silicate (K_2SiO_3) supply, particularly at 2 mM as a foliar spray, may have benefits on maize under limited irrigation supply. These effects were associated with changes at physiological and biochemical levels, including the adjustment of relative water content and osmolytes, the alleviation of oxidative damage and reduction in cell membrane dysfunction, as well as the enhancement of nutrient uptake and regulation of nonenzymatic and enzymatic antioxidant systems. Finally, Wasonga et al. [27] found significant interactions between deficit irrigation and K nutrition, whereby decreasing the irrigation dose to 60% together with 16 mM K resulted in the least reduction in growth and cassava yield. Thus, it seems that deficit irrigation strategies could be used as a tool to develop management practices to improve cassava productivity by means of K fertigation under low moisture field conditions.

Subject (ii), regarding woody fruit trees and water stress induced by deficit irrigation, includes six papers. Millan et al. [15], in a drip-irrigated orchard with early-maturing Japanese plumb (*Prunus salicina* L.) cv. Red Beaut, reported that Ψ_{stem} was found to be the physiological parameter that detected water stress the earliest. Regarding the capacitance probes located closest to the drippers, a drop in the relative soil water content (RSWC) below 0.2 would not be advisable for "non-stress" scheduling in the preharvest period. However, the probes located between the dripper at 0.15 and 0.30 m depth provide information on moderate water stress if the RSWC values falls below 0.2. Severe tree water stress was detected below 0.1 RSWC in capacitance probes located at 60 cm depth from this same position. In vitro culture experiment by Kovalikova et al. [26] revealed that drought stress negatively affects the water content, leaf areas, and chlorophyll content in cherry (*Prunus avium*) and apple (*Malus* × *domestica*) plants. The oxidative status and membrane damage of plants under water deficiency conditions were observed to be important indicators of the stress tolerance mechanism. However, cherries exhibited higher hydrogen peroxide levels compared to apples, whereas their malondialdehyde values were generally lower. The overall findings indicated a wide tolerance range to water deficit among apple and cherry, as well as among cultivars within single plant species. In relation to irrigation strategies, the impact of sustained deficit irrigation (SDI) on parameters related to almond (*Prunus dulcis* L.), including functionality, aroma, and sensory profile of three almond cultivars (Marta, Guara, and Lauranne), was studied by Garcia-Tejero et al. [17]. These authors determined that the SDI strategies allowed the improvement in physical parameters such as unit weight, kernel length, kernel thickness, or color. Higher total phenolic compounds, organic acids, and sugars were found in SDI almonds. Likewise, the highest concentrations of volatile compounds were obtained under SDI, this being a clear advantage in relation to almond flavor. Consequently, a moderate SDI strategy offered relevant improvements in parameters regarding marketability by enhancing the final added value of hydroSOStainable almonds with respect to those cultivated under full irrigation conditions. Similarly, Lipan et al. [19] highlighted that key quality parameters can be used as makers of hydroSOStainable almonds. In addition, these researchers claimed that controlling water stress in almond trees by using deficit irrigation strategies can lead to appropriate yields, improve the product quality, and, accordingly, lead to a final added value. In this context, Gutierrez-Gordillo et al. [22] reported the cultivar effect when a deficit irrigation strategy is being applied because different physiological behaviors with different responses in terms of yield and its components are possible. In this sense, cv. Guara registered the lesser promising results, with significant yield reductions (~14%) when water restrictions around 35% of irrigation requirements (IR) were applied; these are particularly promoted by depletions in the fruit number per tree. Therefore, sustained deficit irrigation at 65% IR (SDI_{65}) was a suitable strategy for cvs. Lauranne and Marta, whereas, for the case of cv. Guara, a more moderate SDI strategy should be selected (such as SDI_{75}). Lastly, Martín-Palomo et al. [25], in a deficit irrigation experiment with table olive (*Olea europea* L.) trees, applied restrictions at 4 and 2 weeks before harvest, irrigation being controlled using the Ψ_{stem}, with a threshold value of -2 MPa, and compared with fully irrigated trees. This water stress did not reduce gas exchange during the deficit period, and the effect on yield was not significant in any of the three-monitoring seasons. In addition, in the high-fruit load season, fruit volume was slightly affected (~10%), but this was not significant at harvest. These findings suggest an early affection of fruit growth with water stress, but with a slow rate of decrease. Thus, a moderate water stress could be useful for the management of deficit irrigation in table olive trees.

The development of aromatic plants under water stress has been described in subject (iii), covering two contributions. In this sense, Kiani et al. [14] evaluated the morphological, phenological, and physiological responses of six *Linum album* accessions under different levels of water deficit treatments (100%, 75%, 50%, and 25% available water) in pot conditions. Accessions UTLA7, UTLA9, and UTLA10 showed a higher seed yield and dry weight of the vegetative part. The maturation process was accelerated in plants under stress conditions, and accession UTLA9 completed its complete growth cycle faster than the other accessions. In addition, the physiological responses of the different accessions did not show the same pattern based on the characteristics studied, and significant differences were observed depending on the trait and accession. Therefore, based on these results, the morphological features (seed yield per plant, plant height, number of inflorescences per plant, shoot, and root dry weight) could be used to select tolerant accessions. On the other hand, Park et al. [24] confirmed that the growth and bioactive compounds of *Crepidiastrum denticulatum*, which is used as a plant-derived raw material for functional food, can be influenced by the water content of the substrate. This study reported that a water content of 45% in the substrate increased the biomass of the shoot and root and increased the phenolic content, antioxidant capacity, and hydroxycinnamic acids content per shoot. These findings are useful for the stable mass production of high-quality *C. denticulatum* in greenhouses or plant factories capable of controlling water content in the root zone.

The subject (iv) includes the industrial crop cultivation. In this line, Braunack et al. [23] with cotton (*Gossypium hirsutum* L.) plantations studied the preformed biodegradable and next-generation sprayable biodegradable polymer membrane (SBPM) formulations, which biodegrade to non-harmful products (water, carbon dioxide, and microbial biomass) and have been introduced as an alternative to plastic mulch films to mitigate plastic pollution. The results showed a higher crop water productivity and crop yield, and increased soil water content with SBPM cover. In addition, this experiment showed that SBPM technology could perform at similar level as oxo-degradable plastic or comparable films under field conditions and, at the same time, provide environmentally sustainable agricultural cropping practices. That is, this innovative technology has shown a high potential even at this early stage of development, indicating that advances in formulation and further testing can lead to significant improvements, and thus increased use in crop production systems.

Lastly, subject (v) includes three contributions in relation to remote sensing and crop water requirements, genotypes for drought tolerance, and agricultural management platform. In this sense, Elnashar et al. [28] reported that the ALESarid-GIS facilitates the selection of suitable crops to improve the estimation of irrigation crop water requirements (CWR) based on crop suitability. In addition, the remote sensing technique and the Surface Energy Balance Algorithms for Land Model (SEBAL) model offer a tool that can be used for estimating the ETa and to support land and water management. The mean daily satellite-based CWR was based on SEBAL ranges between 4.79 and 3.62 mm in Toshka and Abu Simbel areas (Egypt), respectively. This study provides a new approach for coupling Agriculture Land Evaluation System for Arid and Semi-arid regions (ALES-Arid), Ref-ET, and SEBAL models to facilitate the selection of suitable crops and offers an excellent source for predicting CWR in arid environments. In addition, Kamphorst et al. [18] evaluated maize (*Zea mays* L.) genotypes, specifically popcorn inbred lines, under water-stressed (WS) and well-watered (WW) conditions regarding agronomic attributes, root morphology, and leaf “greenness” index (SPAD index), in addition to investigating the viability of indirect selection by canonical correlations (CC) of grain yield (GY) and popping expansion (PE). The WS (-29% less water than WW) significantly affected the GY (-55%) and PE (-28%), increased the brace and crown root density, and more vertically oriented the brace and crown angles. The higher SPAD index was associated with a higher yield, and these measurements were the only ones with no significant genotype × water condition interaction, which may render concomitant selection for WS and WW easier. For associating the corrections of the different traits, CC proved to have better potential than simple correlations. Thus, the evaluation of SPAD index at 29 days after the anthesis showed the best CC, and based on the previous results of SPAD index, may be used regardless of the water condition. Finally, Aguilar Morales et al. [29] developed an agricultural management platform, based on Enterprise Resource Planning (ERP) principles and with the ability to collect geolocated information from different plots related to Protected Designation of Origin (PDO) and Protected Geographical Indication (PGI) wine (*Vitis vinifera* L.) production. The results showed that the end user completes information database, complies with the legal requirements, and obtains benefits derived from the data analysis. Therefore, the platform: (1) solves the lack of agricultural data problem; (2) provides the user with management tools for its agricultural operations; (3) allows the decision maker to obtain geolocated information in real time; and (4) sets out the bases for the future development of agricultural systems based on Big Data.

3. Conclusions

The research studies contained in this SI described several specific processes and their links with environmental irrigation, balancing environmental protection with improved agricultural production. That is, sustainable irrigation must be based on applying uniform and precise amounts of water, based on rational agricultural knowledge of the plant's water needs. It is clear that sustainable water-management practices are essential to boost productivity, promote regional growth, and protect the environment. This entails addressing the potentially negative impacts of water scarcity on food security. Thus, improving water management in agriculture must be based on implementing sustainable irrigation strategies, developing crop modifications that help tolerate water stress, and promoting cooperation among multidisciplinary researchers.

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