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Editorial

Refining Irrigation Strategies in Horticultural Production

Arturo Alvino [1] and Maria Isabel Freire Ribeiro Ferreira [2,*]

[1] Department of Agricultural, Environmental and Food Sciences (DAEFS), University of Molise, Via De Sanctis, 86100 Campobasso, Italy; alvino@unimol.it
[2] Instituto Superior de Agronomia, DCEB and LEAF, Universidade de Lisboa, Tapada da Ajuda, 1349-017 Lisboa, Portugal
* Correspondence: isabelferreira@isa.ulisboa.pt

Water, energy and food security are crucial for a sustainable long-term economy. Irrigated agriculture plays a crucial role in all of the key factors. Irrigated crops are the only ones to guarantee safe food production throughout the year. On the other hand, they require high inputs of water and energy (fertilizers, pesticides, fuel, etc.). Irrigated agriculture is in a constant and growing competition with other productive civilian and industrial sectors.

It is more necessary than ever to understand the links between water scarcity, food production, food security, and environmental sustainability, especially in a changing world and in the context of global warming. The excessive removal of ground water often imposes coping with salinity. Expected climate-change effects on humidity and temperature as well as on precipitation patterns will most likely increase water scarcity in many areas of the world, with a consequent drastic reduction in the productive potential of agricultural and natural ecosystems. In many agro-ecosystems, high-input productive agriculture will possibly be replaced by dryland farming, with a consequent marginalization of agriculture and different cropping systems characterized by lower productivity, income, and employment levels. Since agriculture accounts for approximately 70% of global water withdrawals, studies must be encouraged to find solutions in the various fields of science and technology.

This Special Issue (SI) was planned with a structure to consider a large range of aspects on irrigation of horticultural crops, under current and future conditions. The SI collects some scientific contributions on sustainability of irrigated agriculture by improving water-use efficiency (WUE) of horticultural crops, e.g., through a better estimation of their evapotranspiration and an improved irrigation scheduling. It presents a picture of current and future technologies for identifying bottlenecks and constraints, providing solutions that can turn out to be fruitful or inconclusive, depending on whether the transfer of research knowledge to farmers and technical advisors is effective or not.

The SI gathers one research paper [1], eight reviews [2–9], and one concept paper [10]. The editorial novelty has met considerable success among researchers, with a total number of 370 (Scopus) citations up to the past year. We wish that it may help a reader to better understand the complexity of irrigation management, which has the aim of maximizing yield quality and quantity while respecting the environment.

Irrigation is complex because it links soil, plant and atmospheric issues that must be understood, monitored and quantified, albeit managed as a continuum, as well as technical, logistic, and social constraints. The old questions on how much, when and how to irrigate remain the same. This SI focuses mostly on answers to when and how much, with one contribution that considers genetic improvements of plants used.

Woody plants are the biggest challenge in dealing with water use, due to their uneven and developed aerial and root systems and the consequent limitations on use of some of the many measuring techniques. Three contributions deal especially with woody plants in relation to irrigation scheduling [1,4,10]. Fernández [4] describes plant-based irrigation scheduling approaches, mainly from an eco-physiological perspective, while Ferreira [10]

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shows the necessity of complementing the water-balance-based approach with the use of water stress indicators, mainly when scheduling irrigation in woody, deficit irrigated crops. Blanco-Cipollone et al. [1] focus on isohydricity implications in relation to plant water potential indicators commonly used, with two contrasting case studies (vine and plum orchards).

Four papers [2,3,5,7] especially highlight innovative technologies for improving horticultural yields in relation to water applications. Incrocci et al. [3] deal with decision-support systems based on crop monitoring techniques for improving efficiency of fertigation. Cahan and Johnson [7] describe an irrigation advisory tool to help farmers determine and meet crop water needs of annual crops. Alvino and Marino [2] present applications of remote sensing for managing irrigation and water resources for meeting the current and future challenges of agricultural water resource management. Ruggiero et al. [5] point out the role of molecular genetics in identifying and characterizing genes that play an important role in increasing WUE and drought tolerance.

With respect to soil and water quality, Cameira and Mota [9] give a significant contribution to our comprehension of the most common mitigation strategies in horticultural production systems related to diffuse pollution, mainly in soils in relation to nitrogen, while Machado and Serralheiro [6] analyze management practices and plant tolerance with respect to salinity. The best irrigation practices have in mind that environmental protection goes hand in hand with maximum and stable agricultural production.

Concerning changes in the future, the paper from Snyder [8] gives a particular view of the climate change effects on evapotranspiration. A clear distinction is necessary between evapotranspiration rates per se (ET), irrigation requirements per unit area, maintaining crops and their cycles and practices, and water demand for irrigation on larger scales. The scientific studies on the possible changes caused by climate change on water requirements consider differently the unknowns in processes and feedbacks. Models do not lead to unequivocal considerations on changes of freshwater requirements; very likely instead will be changes of cultural systems from irrigated to rainfed. Snyder's model previews lack of significant changes in ET for the following effects (i) increase in canopy resistance of C_3 plants caused by atmospheric CO_2 increase; (ii) increase in air vapor content as the air temperature rises; and (iii) slight decreases in K_c, in particular for taller, rougher canopies (e.g., vines). The topic needs careful attention to the space scale and the assumptions considered with climate change models and feedback effects on plant water use, including changes in vegetative cycles and on WUE. Furthermore, policies can impact changes on infrastructure and land use, in a manner quite difficult to predict.

Below, our summary of the scientific contributions. In order to describe and categorize the contributions of the papers, herewith a list of keywords for all 10 papers published (alphabetical order): Anisohydric and isohydric behavior, Crop coefficients, Crop salt tolerance, Crop Water Status, Crop yield, CWSI, Drought tolerance, Evapotranspiration, Fertigation, Irrigation scheduling, Mitigation practices, Modeling, Molecular genetics, Orchard crops, Platforms, Precision irrigation, Remote sensing, Sensors, Soil salinization, Stress coefficients, Vegetation Indexes, Water and nutrient management, Water uptake, Water Use Efficiency.

1. Plant Water Status Indicators for Irrigation Scheduling Associated with Iso- and Anisohydric Behavior: Vine and Plum Trees. Blanco-Cipollone, F., Lourenço, S., Silvestre, J., Conceição, N., Moñino, M.J., Vivas, A., and Ferreira, M.I., Spain and Portugal

Under the environmental conditions considered, both vine and plum behaved as anisohydric or isohydric. After presenting the two contrasting examples, authors confirm, from a literature search, that in cases of isohydric behavior, most likely Ψ_{pd} (predawn leaf water potential) has been generally preferred to Ψ_{st} (stem water potential) as a plant stress indicator, being the safer choice also in cases of uncertainty, while the latter can be recommended and is often used in cases of anisohydric behavior but is not advisable for isohydric. In fact, there has been a tendency to obtain a better performance using stem diameter variations (SDV) and derived indexes with anisohydric than with isohydric behavior, which is consistent with the above. It is important to stress that the validity of these indicators depends not only on isohydric versus anisohydric behavior, but also on the stress level to which plants are subjected.

2. Remote Sensing for Irrigation of Horticultural Crops. Alvino, A., and Marino, S., Unimol, Italy

The study by Marino and Alvino contributes in providing the latest trends related to different applications of remote sensing that could potentially be utilized in monitoring soil- and crop-water status for irrigation purposes. Particularly, the study reveals gaps in various models utilized by researchers, including the amount of water to supply for different irrigation strategies (maximization of yield or WUE), and a connection between crop-water status versus crop yield. The review describes the role of remote sensing with respect to crop-water status, its surface energy balance, the relationship between surface temperature and remotely sensed vegetation indices, and WUE and evapotranspiration. The review is limited to field-key studies, and presents applications of remote sensing for managing irrigation and water resources for meeting the current and future challenges of agricultural water resources management. The review is organized into the following main sections: (1) Sensors and platforms applied to irrigation studies; (2) Remote-sensing approaches for precision irrigation for estimating crop water status, evapotranspiration, infrared thermography, and soil and crop characteristics. Authors underline the limits of RS that may answer the question of "when to apply water", not how much water is needed. The irrigation requirements remain to be estimated by other methods.

3. New Trends in the Fertigation Management of Irrigated Vegetable Crops. Incrocci, L., Massa, D., and Pardossi, A., UniPI, Italy

The study reveals some innovative and modern approaches regarding optimal nutrient management of vegetable crops cultivated under fertigation regimes and provide ways on plant, root zone and decision-support systems based on crop monitoring techniques for vegetable crops. The authors focus on optimal nutrient management of fertigated crops, which will guarantee high incomes to growers only under optimal management techniques that interact with the fertilization process. Among the several tools analyzed by authors, decision support systems (DSS) based on simulation models and soil testing approaches are the most common. The main bottleneck comes from an easy and effective transfer of research knowledge to farmers and technical advisors.

4. Plant-Based Methods for Irrigation Scheduling of Woody Crops. Fernández, J.E., IRNAS, CSIC, Spain

The review considers classical and advanced plant-based measurements on water status, automated or not automated. The author refers the traditional so-called physiological measurements (leaf-water potential, photosynthesis, sap flow, stem diameter variation and leaf turgor pressure) integrated with canopy temperature readings for assessment of plant-water stress of crop areas with different conditions. Finally, the author recommends wise production targets for achieving maximum profitability, especially in a context of deficit irrigation and for woody crops in arid and semi-arid areas, when farmers have to control excessive crop growth.

5. Improving Plant Water Use Efficiency through Molecular Genetics. Ruggiero, A., Punzo, P., Landi, S., Costa, A., Van Oosten, M.J., and Grillo, S., Italy

The review study shows various complex gene networks involved in water uptake and loss related to the novel opportunities and strategies for genetic improvement of WUE and drought tolerance in different crops. The molecular breeding programs of the authors aimed to identify and characterize the major genetic and physiological responses developing the water uptake and losses, including guard cell transport mechanisms, stomatal development, cuticle development, root morphology, and root architecture. The study further represents an essential approach to identify and elucidate various developed molecular mechanisms for enhancing WUE. The authors have addressed improved and characterized genes related to molecular genetics and identified the control of water uptake and loss patterns. Authors further stress utilizing an integrated approach to implement functional characterization of promising QTLs, high-throughput phenotyping, field validation of traits, and stacking/pyramiding of traits into WUE, to fully utilize the knowledge of these genes to improve WUE, and they recommend that molecular genetics will be essential in identification and characterization of genes that play an important role in increasing WUE and drought tolerance.

6. Soil Salinity: Effect on Vegetable Crop Growth. Management Practices to Prevent and Mitigate Soil Salinization. Machado, R.M.A., and Serralheiro, R.P., UE Portugal

The authors analyzed the positive and negative effects of salt in the soil that revealed tolerance and unsuitable impacts on different crops while the salinity threshold of the majority of vegetable crops is low. Most vegetable crops in the study showed a sensitive or moderately sensitive response, while asparagus, purslane and beet were considered the most salt-tolerant vegetable crops. Authors further analyzed the main management practices, including soil reclamation, fertilization, irrigation, and maintenance leaching practices. In particular, they emphasized that fertilization and irrigation management strategies must consider different effects of salinity on vegetable growth, crop salt tolerance, soil proprieties, and effects on WUE and soil salinity. The authors suggest that the application of fertilizers through irrigation water (fertigation) can reduce soil salinization and mitigate salt stress effects because it improves the efficiency of fertilizer use and increases nutrient availability and timing of application, and the concentration of fertilizers can be easily controlled. In contrast, while drip and subsurface drip irrigation enhance irrigation efficiency and develop a suitable root-zone salinity, fertigation enhances nutrient-use efficiency (NUE), which further allows fertilizer application without provoking excessive increases in soil salinity.

7. New Approaches to Irrigation Scheduling of Vegetables. Cahn, M.D., and Johnson, L.F., USA

The review reveals trends on scheduling irrigation on vegetable farms as a challenging task due to imprecise crop coefficients, time-consuming computations, and the need to simultaneously manage many fields. Adoption of soil-moisture monitoring in vegetables has historically been limited by sensor accuracy and cost, as well as labor required for installation, removal, and collection of readings. Improving efficiencies through more-accurate scheduling of irrigation can conserve water and address water quality impacts associated with commercial vegetable operations. Crop types, intensive rotations, number of fields to manage, and competing cultural operations involving growing marketable crops are some of the challenges. The study describes a robust irrigation advisory tool to help farmers accurately determine and meet irrigation requirements and recommends that continued collaboration between public research institutions, universities, commodity boards, and commercial firms will likely be needed to develop simple-to-use tools that will be broadly accepted by vegetable growers.

8. Climate Change Impacts on Water Use in Horticulture. Snyder, R.L., UC Davis, USA

The review study describes the evapotranspiration equations with its components explaining which variables may increase or decrease depending on the magnitude of atmospheric changes on meteorological variables and its consequences on plant parameters. Snyder speculates that major changes in transpiration rates are uncertain for the following effects that oppose the effects of a temperature increase: (i) increase in air vapor content as the air temperature rises, (ii) decrease in canopy conductance of C_3 plants caused by expected atmospheric CO_2 growth and (iii) a slight decrease in K_c, due to changes in canopy conductance, in particular for taller, rougher canopies (e.g., vine). Conversely, projected changes in precipitation seem to be important, and water resources would become less reliable in many regions.

9. Nitrogen Related Diffuse Pollution from Horticulture Production—Mitigation Practices and Assessment Strategies. Cameira, M.D.R., and Mota, M., University of Lisbon, Portugal

The authors analyze the literature on mitigation practices and assessment strategies for diffuse pollution in horticulture systems. They focus on the most common mitigation practices that benefit crops, irrigation strategies, and efficient fertilization management. They suggest the most common mitigation strategies relating to crops, irrigation and fertilization management and reveal that assessment methods are needed to evaluate and quantify the impact of mitigation strategies in horticultural production systems and to select the most promising ones. Examples of mitigation practices and assessment strategies at plot and farm scales are source, timing, and transport, and must consider threats related to NO_3^- leaching, and NH_3 and N_2O emissions separately. A combination of optimal water management and applying recommended fertilization rates should be the most profitable choice for farmers. The study further considers uses of fast-growing rootstocks, mycorrhizal plants with more ready-to-assimilate fertilizers and reveals gaps by suggesting that further studies are necessary to create complete reference databases related to climatic data, physical and chemical soil parameters, and crop calibration factors for different European areas to promote the use of prediction models.

10. Stress Coefficients for Soil Water Balance Combined with Water Stress Indicators for Irrigation Scheduling of Woody Crops. Ferreira, M.I., University of Lisbon, Portugal

The concept review reveals an overview on the basic general principles of irrigation scheduling and its underlying assumptions: the classical water balance models used to estimate soil-water depletion and calculate irrigation depths, where actual crop evapotranspiration is an input variable. This introduces the reader to a discussion on its use under deficit irrigation (DI) and the reasons for possible failure. The author contributes by defining ways to address the problem in tall, uneven, DI crops mainly of Mediterranean species, where roots are particularly deep due to summer water scarcity in Mediterranean climates. The author describes the differences in the trial-and-error approach of using solely water-stress indicators and the more complete and potentially self-learning approach of combining water-stress indicators with the use of a water-balance equation, including stress coefficients (Ks) estimated, for instance, in relation to estimated soil-water status. Furthermore, the combination of modeling ET and directly using water stress indicators has the potential for gathering self-experience transferable to farmers, technical advisors, and locations, and will develop stepwise independence of various controlled measurements for various regions.

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