

Editorial

Advancing Irrigation and Water Management Strategies for Sustainable Horticultural Systems

Juan Wang ^{1,*} , Chuncheng Liu ²  and Bingjian Cui ²¹ College of Hydraulic Science and Engineering, Yangzhou University, Yangzhou 225009, China² Institute of Farmland Irrigation, Chinese Academy of Agricultural Sciences, Xinxiang 453002, China; liuchuncheng@caas.cn (C.L.); cuibingjian@caas.cn (B.C.)

* Correspondence: wangjuan@yzu.edu.cn

Water scarcity remains a defining constraint for global agricultural development, particularly in arid and semi-arid regions where horticultural production is often concentrated. As the largest consumer of freshwater, agriculture faces mounting pressure to reconcile increasing food demand with limited water supply. This challenge is further intensified by rapid urbanization, industrial competition for water, and the escalating impacts of climate change, which collectively threaten the stability of horticultural production systems worldwide. This Special Issue, titled “Irrigation and Water Management Strategies for Horticultural Systems”, provides a multidisciplinary platform for addressing these urgent challenges by exploring how optimized water management can enhance plant growth, improve resource-use efficiency, and mitigate environmental stresses. It also explores how the sustainable use of both conventional and unconventional water resources can be promoted.

Nine manuscripts have been published in this Special Issue, reflecting the multidisciplinary nature of modern horticultural water management. A prominent theme is the optimization of irrigation and nutrient coupling. It is illustrated how irrigation levels, nitrogen fertigation, soil types, and microbial amendments affect plant performance. For instance, Li et al. (Contribution 1) explored the single and combined effects of two greenhouse soil types and 50% deficit irrigation on single-plant yield and fruit quality of cherry tomatoes. It was proven that cutting irrigation water by half exerted no significant negative impacts on cherry tomato output and fruit nutritional quality, offering a feasible cultivation adaptation strategy amid climate crisis and water shortage. Building on this agronomic perspective, Liu et al. (Contribution 2) explored how different irrigation volumes and nitrogen application rates jointly affect tomato photosynthesis, biomass, yield and fruit quality. The combination of full crop water requirements (1.0 ET_c) and 320 kg N·hm⁻² was identified as the optimal fertigation scheme.

Similarly, a pot trial examined the single and interactive effects of two irrigation regimes and two microbial fertilizers on rhizosphere soil enzyme activity, yield and quality of *Brassica chinensis* L. The combination of 80–90% field water capacity irrigation and Maya 85 microbial fertilizer proved optimal for enhancing crop yield, leaf nutrition and soil enzyme activity while reducing nitrate levels (Contribution 3). Complementing these studies, Li et al. (Contribution 4) and Li et al. (Contribution 5) investigated drip irrigation performance under water–fertilizer–gas (WFG) coupling. Their findings demonstrate that WFG coupling, particularly via micro–nano aeration, alleviates emitter clogging, extends emitter service life and improves irrigation uniformity. Moreover, it was found that system working pressure critically regulates irrigation performance, and micro–nano aeration at



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0.1 MPa achieves optimal system operation, highlighting the necessity of rational hydraulic parameter and aeration mode configuration for efficient WFG coupling drip irrigation.

Another significant highlight is insight into physiological responses to abiotic stress and the use of unconventional water resources, focusing on topics that align closely with the Special Issue's emphasis on salt regulation in saline soils and the use of brackish and reclaimed water, and biostimulants. With salinity being a major limiting factor, research by Sogoni et al. (Contribution 6) explored the efficacy of the seaweed-based biostimulant Kelpak® in mitigating salt stress in spinach. The results revealed that high salinity severely impaired spinach growth, water status, chlorophyll content and nutritional quality while inducing intense oxidative stress, while the 5% seaweed extract application effectively alleviated salt-induced damage, reduced oxidative stress, and improved crop growth and nutritional quality. Furthermore, Liu et al. (Contribution 7) studied how exogenous silicon regulates soil secondary salinization risk, silicon distribution and growth physiology of pakchoi under three unconventional water irrigation modes (single brackish water, single reclaimed water, 1:1 mixed irrigation). Appropriate silicon spraying optimizes soil ion indicators, raises plant silicon accumulation and pakchoi yield, and effectively mitigates secondary salinization risks especially under mixed brackish–reclaimed water irrigation. These findings are vital for promoting the safe utilization of non-traditional water sources.

Additionally, novel factors such as water temperature effects on seedling quality and modeling approaches for estimating grapevine transpiration further broaden our understanding of the soil–plant–atmosphere continuum (SPAC). Zamljem and Slatnar (Contribution 8) investigated how irrigation water temperatures (17 °C, 24 °C and 34 °C) affect the seedling growth indicators of kohlrabi, tomato and lettuce. Higher irrigation water temperature lowered water oxygen content, while 34 °C water significantly promoted seedling growth of kohlrabi and tomato, filling the research gap concerning the effects of irrigation water temperature-induced heat stress on vegetable seedlings. On the modeling front, Kokkotos et al. (Contribution 9) developed piecewise transpiration estimation models for grapevines under both full-irrigation and water-limited conditions based on sap flow measurements. Vapor pressure deficit (VPD) dominated canopy conductance, solar radiation exerted segmented effects on transpiration, and cross-validation verified the stable prediction performance of the established models across well-irrigated and rainfed environments. Collectively, these works underscore the idea that efficient horticultural water management requires integrating agronomic strategy, engineering precision, physiological understanding, and modeling tools to regulate the soil–plant–water continuum across diverse production environments.

While the contributions in this Issue mark significant progress toward resilience, the optimization of water management for highly efficient horticultural systems requires continuous exploration and innovation. Based on the insights derived from publications and the broader challenges identified in the Special Issue introduction, we outline several future research perspectives below:

- (1) **Physiological and Quality Responses to Multifactorial Stresses.** Horticultural plants are increasingly exposed to combined stresses, such as water deficit, salinity, extreme temperatures, and fluctuating water quality [1]. Future experiments should evaluate how ameliorants, including biostimulants, silicon and microbial fertilizers, perform under compound stress scenarios [2]. Also, it is necessary to clarify their links to quality traits.
- (2) **Rhizosphere Processes and Water Uptake Mechanisms.** More attention needs to be paid toward how root architecture and rhizosphere microorganisms interact with heterogeneous soil water distributions. Understanding the signaling pathways through which plants perceive and respond to water deficits in rhizosphere soil can inform the

design of deficit irrigation strategies that maintain yield and quality while conserving water [3].

- (3) Long-Term Sustainability and Ecological Impacts of Unconventional Water Use. Although brackish water, reclaimed water, and other alternative sources offer promising solutions to water scarcity [4], long-term field experiments are urgently needed. Future studies should monitor the cumulative effects of their repeated application on soil physicochemical properties, heavy metal accumulation, greenhouse gas emissions, and rhizosphere microbial diversity. Particular attention should be paid to the dynamics of secondary salinization and sodicity in horticulture. Mitigation strategies, such as silicon amendment, biochar application [5,6], or crop rotation, should also be developed to ensure that productivity gains do not come at the cost of irreversible soil degradation.
- (4) Integration of Smart Sensing and Predictive Modeling. There is a pressing need for integrated smart technologies that combine real-time monitoring of plant water status with automated irrigation scheduling [7]. Future studies should prioritize development with AI-driven algorithms. Such systems would enable dynamic, site-specific irrigation scheduling that moves beyond fixed thresholds toward predictive adjustments based on instantaneous crop responses and weather forecasting. Coupling empirical models with machine learning approaches could further refine water-use efficiency at field and farm scales [8].

In summary, this Special Issue shifts irrigation from simply supplying water to managing it as an integrated process that links plant physiology, soil health, engineering design, and environmental stewardship. We thank all contributing authors for their high-quality research and the reviewers for their constructive feedback. We hope this collection will inspire continued collaboration and innovation, helping to build horticultural systems that are both productive and resilient under water limitation.

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