frontiers | Frontiers in Sustainable Food Systems

TYPE Editorial
PUBLISHED 14 January 2026
DOI 10.3389/fsufs.2025.1772901

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OPEN ACCESS

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RECEIVED 22 December 2025
ACCEPTED 29 December 2025
PUBLISHED 14 January 2026

CITATION
Hu M, Xiao D and Bwambale E (2026) Editorial: Optimizing deficit irrigation for sustainable crop production in water-scarce regions. *Front. Sustain. Food Syst.* 9:1772901. doi: 10.3389/fsufs.2025.1772901

Editorial: Optimizing deficit irrigation for sustainable crop production in water-scarce regions

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KEYWORDS

deficit irrigation, hydroeconomic optimization, soil moisture, sustainable crop production, water use efficiency

Editorial on the Research Topic
Optimizing deficit irrigation for sustainable crop production in water-scarce regions

Global agriculture faces the dual pressures of climate change and groundwater depletion, alongside a continuously growing demand for food. In this context, improving crop yields under limited water resources has become an urgent challenge. More than two billion people worldwide live in water-scarce regions, where traditional irrigation practices increasingly conflict with the declining availability of freshwater and the rising variability of hydrological cycles. Among the various strategies aimed at improving water-use efficiency, deficit irrigation (DI)—applying less irrigation water than the crop's complete requirements during less critical growth stages—has emerged as a practical and cost-effective approach for sustaining agricultural production under water-limited conditions. This Research Topic aims to deepen the understanding of DI's optimal implementation, technological innovations, and management strategies, addressing crop physiological responses, long-term soil–water dynamics, irrigation governance, and farmers' adoption behaviors. A total of six articles were published in this Research Topic, comprising five research articles and one review article. These articles synthesize key principles, modeling tools, management strategies, and policy approaches for achieving resilient, efficient, and sustainable crop production in water-scarce regions (Figure 1).

At the regional scale, changes in crop spatial distribution significantly affect water demand. Long-term, high-resolution remote sensing analyses of the Beijing–Tianjin–Hebei region reveal that the southward migration of winter wheat cultivation has increased blue water dependence and reduced green water availability. This transition has intensified spatial disparities in agricultural water use, highlighting the necessity for regionally differentiated water management strategies. Additionally, crop water consumption is significantly influenced by groundwater depth and salinity, indicating that irrigation volumes should be reduced in areas with shallow groundwater tables to enhance water-use efficiency and mitigate soil salinization. Evidence from the Kurty irrigation massif supports integrated water management through optimized irrigation regimes and water-saving technologies to promote sustainable agricultural production.

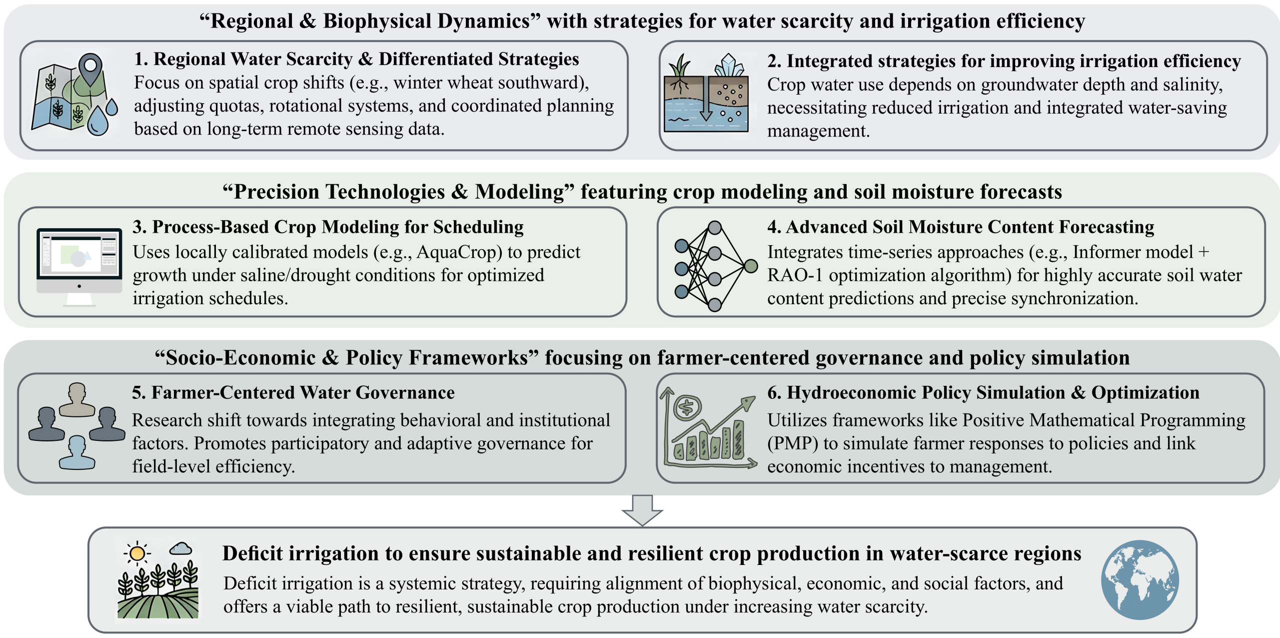

FIGURE 1
Conceptual map of articles addressing the special Research Topic on optimizing deficit irrigation for sustainable crop production in water-scarce regions.

Crop modeling offers essential support for precision DI. In the arid Biskra region of Algeria, a locally calibrated AquaCrop model has demonstrated strong predictive performance for durum wheat growth under saline and drought stress, enabling irrigation managers to optimize irrigation scheduling and enhance yield. Complementing such process-based models, advanced time-series forecasting approaches—such as the Informer model integrated with the RAO-1 optimization algorithm—achieve high accuracy in predicting soil water content. Together, these modeling advances facilitate precise alignment of irrigation applications with crop water requirements.

Beyond biophysical considerations, the economic and social dimensions of irrigation management are increasingly recognized as pivotal. Bibliometric and empirical studies indicate a paradigm shift from purely technology-driven irrigation efficiency toward farmer-centered approaches that integrate behavioral, institutional, and policy factors. Participatory and adaptive water governance frameworks are emerging as key enablers of improving water-use efficiency at the field level. In line with this perspective, integrated hydroeconomic optimization frameworks for canal–well conjunctive irrigation and drainage have been developed, using Positive Mathematical Programming (PMP) to simulate farmers' adaptive responses under policy interventions, thereby linking economic incentives with sustainable water management.

Overall, advancing DI requires a system optimization perspective. Within irrigation management systems, key elements such as water-use efficiency, soil salinity control, and crop water management are critical for achieving both efficient irrigation and sustainable crop production. Achieving this transformation demands strong policy commitment, technological innovation, farmer engagement through incentive mechanisms, and sustained funding and research support. By integrating topography, water temperature, soil conditions, crop requirements, and socioeconomic factors into management practices, DI can be effectively implemented, thereby maintaining basic agricultural productivity and ensuring food security in water-scarce regions.

In conclusion, DI is not merely a water-saving technology; it represents a comprehensive, systemic strategy. Its successful implementation depends on the coordination of the biophysical, economic, and social aspects of irrigation management. With global climate change and increasing water scarcity, integrating DI into data-driven, adaptive irrigation systems offers a path toward resilient and sustainable crop production.

Author contributions

MH: Conceptualization, Supervision, Writing – original draft, Writing – review & editing. DX: Writing – original draft, Writing – review & editing. EB: Writing – original draft, Writing – review & editing.

Funding

The author(s) declared that financial support was received for this work and/or its publication. This work was supported by the National Natural Science Foundation of China (42201401).

Acknowledgments

We extend our gratitude to all reviewers for their expertise and thoughtful feedback, which greatly contributed to the quality of this Research Topic. We thank Yelena Macias for her support in preparing this Research Topic.

Conflict of interest

The author(s) declared that this work was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Generative AI statement

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