

Smart Micro-Irrigation Systems for Sustainable Agriculture: A Comprehensive Review of Technologies, Applications, and Challenges

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Background: Smart micro-irrigation systems are becoming essential for improving water productivity and sustainability in agriculture amid rising water scarcity, climate variability, and the growing demand for precision resource management. These systems, such as drip and sprinkler irrigation, combined with technologies like IoT, soil moisture sensors, and automated controllers, allow accurate, timely water delivery directly to crop root zones.

Objective: The main objective of this review is to evaluate the technological evolution, practical applications, and challenges of smart micro-irrigation systems within sustainable agricultural practices.

Methods: A systematic literature review was conducted following the PRISMA framework. An initial pool of nearly 500 research articles was identified across databases including Web of Science, ScienceDirect, Springer, Wiley Online Library, Scopus, Google Scholar, and IEEE Xplore. After applying inclusion and exclusion criteria based on relevance, publication quality, and focus on smart micro-irrigation in sustainable agriculture, 50 peer-reviewed English-language articles published between 2012 and 2024 were retained for detailed analysis. Literature searches employed Boolean operators (AND, OR) with keywords such as “Smart irrigation systems,” “Micro irrigation systems,” “Sustainable agriculture,” and “Precision farming.”

Results: The synthesis of findings indicates that smart micro-irrigation systems consistently improve water use efficiency, optimize crop yields, and reduce labor and input costs, with reported water savings ranging from 40% to 70% across different contexts. Their integration with solar energy and mobile-based platforms enhances usability, particularly for smallholder farmers. However, widespread adoption is constrained by high initial costs, limited technical skills, and insufficient policy support.

Conclusion: The review concludes that smart micro-irrigation holds great potential to contribute to climate-resilient, resource-efficient, and sustainable agriculture. Addressing adoption barriers through supportive policies, financial incentives, and farmer education is essential to scale its impact globally.

Keywords: Precision farming; Smart micro-irrigation; Solar energy integration; Sustainable agriculture; Water use efficiency