Nanotechnology for sustainable agriculture: 3D-printed polymer nanocomposites loaded with TiO2 for water purification

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The growing demand for sustainable agricultural practices requires innovative solutions to optimize resource efficiency, enhance soil health, and ensure water quality. Climate change further amplifies these challenges, intensifying water scarcity and placing additional stress on agricultural systems, particularly in semi-arid and arid regions. To address these issues, the development of advanced materials and technologies that enhance agricultural productivity while minimizing environmental impact is essential. In this context, nanotechnologies offer novel solutions for precision agriculture aimed at improving resource efficiency and promoting sustainable farming practices. This study focuses on the development and characterization of advanced polymer-based nanocomposite materials for one critical aspect of sustainable farming: water purification for safe irrigation. Specifically, the research explores the use 3D printing technology to fabricate nanocomposite structures incorporating titanium dioxide (TiO■) nanoparticles (NPs), known for their photocatalytic properties. These nanocomposites are engineered to degrade organic contaminants under UV light, providing an effective method for improving the quality of stored irrigation water. Different 3D geometries were designed and printed with different TiO■ concentrations (2.5%, 5%, and 10%) to assess both the printability and photocatalytic performance of the structures. The dispersion of TiO■ within the resin was optimized to ensure uniform distribution, and the printed samples were thoroughly characterized using scanning electron microscopy (SEM), energy-dispersive X-ray spectroscopy (EDX), and thermogravimetric analysis (TGA). Photocatalytic performance was evaluated through the degradation of a model organic dye in aqueous solution under UV irradiation. Results demonstrated a clear correlation between increased TiO■ content and enhanced photocatalytic activity. Furthermore, the geometry of the printed structures significantly influenced the efficiency of pollutant degradation, highlighting the critical role of design in maximizing surface area and light exposure. By embedding photocatalytic NPs within stable polymer matrices, the nanocomposites prevent uncontrolled nanoparticle release, thereby enhancing both safety and reusability. This research illustrates the potential of integrating nanotechnologies with advanced manufacturing techniques to develop scalable, sustainable solutions for agricultural water management. The findings contribute to the broader vision of circular, climate-smart agriculture by promoting efficient resource utilization, environmental resilience, and enhanced food security. Acknowledgments This research has been funded by the European Union (NextGeneration EU) through the MUR-PNRR project SAMOTHRACE–Sicilian MicronanoTech Research and Innovation Center (ECS00000022, CUP B63C22000620005).