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Abstract

Water scarcity in arid and semi-arid regions requires soil amendments that not only enhance moisture retention but are also biodegradable, locally sourced, and environmentally friendly. This study presents the development and evaluation of three biopolymeric hydrogel composites made from sodium alginate extracted from Sargassum spp., and functionally improved with frankincense (Boswellia sacra) extract and palm-derived biochar. A commercially available potassium polyacrylate hydrogel and a research-grade acrylamide–acrylate copolymer were used as benchmarks for these natural formulations. A comprehensive evaluation of soil hydrogel interactions was conducted through RETC-modeled water retention curves, sequential drying-rewetting cycles, ImageJ crack morphology analysis, and post-treatment measurements of soil pH and electrical conductivity (EC). The best results were obtained with the F treatment (alginate + frankincense) which reduced shrinkage-induced cracking and improved water retention while preserving pH stability. The addition of biochar to the F+B composite added mechanical reinforcement while the shallow placement and ionic discharge of synthetic hydrogels caused surface desiccation cracking and increased EC despite their initial effectiveness in retaining moisture. Notably, hydrogel performance differed markedly between isolated (hydrogel-only) and soil-integrated systems, highlighting the importance of testing within realistic matrices. The significance of matrix-specific hydrogel evaluation and the desorption stress dynamics specific to surface-applied superabsorbent are underscored by these results. This study provides a new path toward climate-resilient sustainable soil management systems in desert agriculture by managing the design of biodegradable polymers with capillary behavior and soil–water physics.

Keywords: *Biopolymer hydrogel, sodium alginate, biochar amendment, soil–water retention, desert agriculture, sustainable soil management, RETC modeling*