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Long-Term Ecological Impacts of Engineered Synthetic Microbial Communities (SynComs) in Agricultural Systems

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Abstract This study examines the long-term ecological impacts of SynComs, focusing on their potential to address challenges posed by climate change, limited resources, and land degradation. Key findings indicate that SynComs can significantly improve plant growth and nutrient acquisition, modulate plant physiological responses to environmental stresses, and provide protection against soilborne pathogens. Case studies highlight the successful application of SynComs in various crops, showcasing their potential to enhance crop performance and resilience under various conditions. However, challenges such as ensuring microbial colonization, stability of plant phenotypes, and the dynamic nature of microbial communities over time remain. This study underscores the need for systematic and standardized studies to fully harness the potential of SynComs in sustainable agriculture, and expects to provide valuable insights for researchers, policymakers, and practitioners involved in the design, application, and regulation of SynComs in agriculture.
Keywords Agricultural systems; Synthetic microbial communities (SynComs); Ecological impact; Field trials

1 Introduction

HSynthetic microbial communities (SynComs) are engineered consortia of microorganisms designed to perform specific functions within a host environment, such as plants. These communities are constructed by selecting and combining microbial strains that exhibit beneficial traits for plant growth and health (Bu et al., 2023). The use of SynComs in agriculture has gained significant attention due to their potential to enhance crop resilience, improve nutrient acquisition, and mitigate biotic and abiotic stresses (Souza et al., 2020; Pradhan et al., 2022; Yin et al., 2022). By leveraging advances in microbial ecology, genetics, and computational methods, researchers aim to design stable and effective SynComs that can be applied as inoculants to improve crop performance under various environmental conditions (Sai et al., 2022).

While the short-term benefits of SynComs in agriculture are well-documented, understanding their long-term ecological impacts is crucial for sustainable agricultural practices. The introduction of engineered microbial communities into agricultural systems can have far-reaching consequences on soil health, native microbial diversity, and ecosystem functions (Arnault et al., 2023; Wang et al., 2023). Long-term studies are necessary to assess the persistence, adaptability, and potential unintended effects of SynComs on the environment. This understanding will help in developing guidelines for the safe and effective use of SynComs, ensuring that they contribute positively to agricultural sustainability without disrupting existing ecological balances (Wang et al., 2021; Fonseca-García et al., 2023).

This study aims to provide a comprehensive review of the long-term ecological impacts of engineered SynComs in agricultural systems, and the specific objectives are to summarize current knowledge on the design and application of SynComs in agriculture, highlighting their potential benefits and challenges, to evaluate the long-term ecological effects of SynComs on soil health, microbial diversity, and ecosystem functions, drawing insights from recent studies and field trials, and to identify knowledge gaps and propose future research directions for assessing and mitigating the long-term impacts of SynComs in agricultural systems. By addressing these objectives, this study expects to contribute to the development of sustainable agricultural practices that harness the