

Rational management of the plant microbiome for the Second Green Revolution

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ABSTRACT

The Green Revolution of the mid-20th century transformed agriculture worldwide and has resulted in environmental challenges. A new approach, the Second Green Revolution, seeks to enhance agricultural productivity while minimizing negative environmental impacts. Plant microbiomes play critical roles in plant growth and stress responses, and understanding plant–microbiome interactions is essential for developing sustainable agricultural practices that meet food security and safety challenges, which are among the United Nations Sustainable Development Goals. This review provides a comprehensive exploration of key deterministic processes crucial for developing microbiome management strategies, including the host effect, the facilitator effect, and microbe–microbe interactions. A hierarchical framework for plant microbiome modulation is proposed to bridge the gap between basic research and agricultural applications. This framework emphasizes three levels of modulation: single-strain, synthetic community, and *in situ* microbiome modulation. Overall, rational management of plant microbiomes has wide-ranging applications in agriculture and can potentially be a core technology for the Second Green Revolution.

Key words: Second Green Revolution, plant microbiome, rational management, host effect, microbiome heritability

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INTRODUCTION

Food security stands at the core of humanity's challenges, shaped by a complex interplay of factors. Key among these are agricultural productivity and environmental quality. The past seven decades have witnessed remarkable strides in food production, marked by the advent of the "First Green Revolution," which continues to sustain a global population of 7.5 billion people today (Evans and Lawson, 2020). Agricultural technologies are expected to advance during the Second Green Revolution and support the diversifying food habits of 10 billion people by 2050 (Awan et al., 2022).

Global changes are imposing pressure on modern agriculture worldwide, which is required to produce more food. The Second Green Revolution includes sustainable agricultural practices that

involve less labor, land, and water and fewer chemicals; such practices are crucial to addressing future challenges, including food security (Figure 1). During the First Green Revolution, the growth of major crops occurred mainly because of increased land use, irrigation, and intensive agrochemical inputs. The use of nitrogenous fertilizers increased globally from 51.7 kg per hectare in 1990 to 69.4 kg per hectare in 2020. Crops underutilize around 50% of applied nitrogen fertilizer (Cassman and Dobermann, 2022), contributing to an agricultural nitrogen surplus. This surplus has significantly influenced global nitrogen cycling, leading to extensive eutrophication of terrestrial and aquatic ecosystems, as well as

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