Soil–Plant Microbiome for Enhanced Productivity & Climate Change Resilience

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ABSTRACT

The soil–plant microbiome plays a vital role in enhancing plant growth, stress tolerance and soil health under changing climatic conditions. Beneficial microorganisms improve plant resilience to drought, salinity, temperature extremes and flooding through mechanisms such as nutrient mobilization, phytohormone regulation, antioxidant production and induced systemic resistance. They also contribute to soil fertility by driving nutrient cycling, improving soil structure and increasing organic matter. In addition, soil microbes aid in climate change mitigation through carbon sequestration and regulation of greenhouse gas emissions. Overall, microbiome-based approaches offer a sustainable strategy for improving crop productivity, reducing reliance on chemical inputs and supporting climate-smart agriculture.

INTRODUCTION

Climate change, soil erosion and increased food demand of agriculture increasingly threatens the agriculture sector. Drought, salinity, heat and flooding are extreme conditions that cause low productivity of crops. The soil-plant microbiome is a key to better plant growth and stress tolerance, as well as the soil health and is critical to sustainable and climate-resilient agriculture. (Berg *et al*. 2020; Trivedi *et al*. 2020).

Microbiome and Climate Stress Tolerance

- Drought stress: Microbes produce osmoprotectants, enhance root growth and reduce stress ethylene, improving water uptake and retention (Nadeem *et al*. 2014; Yang *et al*. 2009).
- Salinity stress: They regulate ion balance, produce exopolysaccharides and enhance antioxidant activity to reduce salt toxicity (Upadhyay *et al*. 2011; Egamberdieva *et al*. 2017).
- Temperature stress: Microbes produce heat shock proteins and antioxidants, protecting plants from heat and cold damage (Hasanuzzaman *et al*. 2013; Meena *et al*. 2017).
- Flooding: They support root health under low oxygen and improve nutrient availability (Colmer and Voesenek, 2009).

Mechanisms of Action: Phytohormone regulation, induced systemic resistance, antioxidant production, nutrient mobilization and biofilm formation are some of the processes through which microbes can help the plants to be able to adapt to the environmental stress. (Pieterse *et al*. 2014; Backer *et al*. 2018).

Role of Key Microbial Groups

- PGPR: Promote growth and stress resistance (Vessey, 2003; Gupta *et al*. 2015)
- Mycorrhizae: Improve water and nutrient uptake (Smith and Read, 2008)
- Endophytes: Provide internal protection against stresses (Hardoim *et al*. 2015)

Climate Buffer and Mitigation

The microbiome serves as a biological buffer to stabilize plant functionality and climatic stability in the environment (Berg *et al*. 2020). Microbes in soil also help to mitigate climate by: Sequestering carbon Controlling of greenhouse gases (CO_2, CH_4, N_2O). Increasing the oxidation of methane. Heavy metal stabilization of soil organic matter. (Lal, 2010; Lehmann and Kleber, 2015)

Soil Health Improvement

- Nutrient cycling: Nitrogen fixation, phosphorus solubilization and the decomposition enhance nutrient availability (Richardson *et al*. 2009)
- Soil structure: Microbial products increase soil aggregations and decrease soil erosion (Six *et al*. 2006).
- Organic matter of soil: Fertilizes and holds water (Lehmann and Kleber, 2015).
- Disease suppression Disease suppressors stop the pathogens and minimize the pesticides (Mendes *et al*. 2011).

Climate and Agricultural Benefits Microbes in soil enhance carbon sequestration, mitigate greenhouse gases, resilience of the ecosystem and sustainable agriculture through the minimization of chemical additions.

CONCLUSION

Climate-resilient agriculture depends on soil-plant microbiome. It increases stress resilience of plants, augments the health of soil and helps in mitigating climate change. The use of microbial functions is one of the reasons why efficient food production and environmental protection are sustainable.

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