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# Role of Rhizosphere and Rhizoplane Microflora in Plant Disease Management

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The rhizosphere includes plant roots and the surrounding soil that is influenced by plant roots. This definition is more inclusive than traditional definitions that include roots and the soils that adhere to them, by emphasizing that the rhizosphere extends into soils by roots and the actions of root products (Moore *et al.*, 2003). The traditional definition does more than omit important biological interactions with soil biota, as it perpetuates a framework that views soils as a physical entity, as opposed to a biologically complex and active environment. In this article and treatments elsewhere emphasize the diverse and complex nature of these interactions between plants and soil biota within the rhizosphere, and the important roles of soil biota operating within the rhizosphere to plant growth and community dynamics. Our aim is to present a modeling framework that demonstrates that there are generalities in rhizosphere interactions and functions that can be captured and explored mathematically.

The rhizosphere food web we present is compartmentalized into assemblages of organisms in food sub-webs supported by bacteria and their consumers, fungi and their consumers, and the plant roots and their consumers. Three key features that distinguish the organisms within one assemblage from another are that (1) they process different types of energy inputs at different rates; (2) they possess different life-history characteristics and (3) they occupy different microhabitats. We argue that trophic interactions within the rhizosphere are best studied as a grouping of these sub-webs operating in concert, and also possessing quasi-independent tendencies. There is a solid rationale for this approach (Bender *et al.*, 1984), particularly when it comes to subsets of species sharing similar and intertwined dynamics, per capita effects, feeding rates, death rates, and growth rates.

## Rhizosphere

The rhizosphere is a dynamic region governed by complex interactions between plants and the organisms that are in close association with the root. The composition and pattern of root exudates affect microbial activity and population numbers, which in turn have an impact on the nematodes and micro arthropods that share this environment. Beneficial or harmful relationships exist between rhizosphere organisms and plants, which ultimately affect root function and plant growth.

**Rhizosphere Ecology:** The rhizosphere is a nutrient-rich region of the soil immediately surrounding the plant root. This region is highly dynamic and supports a dense and diverse fauna. Despite the challenges associated with studying ecological interactions in a soil matrix, researchers are beginning to understand the complex ecological interactions occurring in the rhizosphere. Chemical communication plays an integral role in the ecology of the rhizosphere, and new functions for intra- and interspecific signals continue to surface. Much of the knowledge on rhizosphere biology has been revealed by agricultural researchers, who have studied many of the positive and negative relationships between plants and soil microbes. Though detailed descriptions exist for many rhizosphere interactions, the complex and cryptic nature of the rhizosphere will continue to challenge scientists interested in the ecology of the plant–soil interface and its associate biota.

**Rhizosphere Microzone:** The rhizosphere, first described in 1904 by Lorentz Hiltner, has been the focus of intensive research for many years because of its importance in plant nutrition and pathogenesis. More recently, research on the rhizosphere has been directed toward its influence on controlling the persistence, mobility, and bioavailability of contaminants in soils.

The rhizosphere generally refers to the portion of soil found adjacent to the roots of living plants. The rhizosphere is subject to the influence of chemicals excreted by roots of living plants and the microbial community in this microzone. Its domain varies for different plant species and for age and morphology of roots. Depending on plant species, the width of the rhizosphere zone has been shown to extend from 2 to 80 mm away from the root surface. The soil in the rhizosphere supports a typically diverse and densely populated microbial community and is subject to chemical transformations caused by the presence of root exudates and metabolites of microbial degradation.

The rhizosphere microzone is distinguished from the bulk soil zone, more commonly known as the edaphosphere, by enhanced microbial activity and increased concentration of root exudates. Nevertheless, it is rather difficult to separate this zone physically from the root surface or rhizoplane. The rhizosphere effect is expressed quantitatively as the ratio of the number or activity of microorganisms or level of root exudates in rhizosphere soil ($R$) to that in the edaphosphere soil ($E$), i.e., the $R/E$ ratio. The $R/E$ ratio for microorganisms and root exudates is often found to range, respectively, from 2 to 20 and from 5 to 100, indicating enhanced microbial activity in the rhizosphere.

Root exudates are known as one of the most important factors affecting microbial growth in the rhizosphere. For example, cell numbers are several orders higher in the root zone than in the background soil lacking plants. The microbial community is more diverse, active, and synergistic than in non-rhizosphere soil. Root exudates can also selectively influence the growth of bacteria and fungi that colonize the rhizosphere by serving as selective growth substrates for soil microorganisms. For example, *Pseudomonad* species are particularly stimulated by enhanced carboxylic acid production from root exudation. Rhizosphere microbial communities can also vary in structure and species composition in different root locations or in response to other environmental factors, including soil type, plant species, or nutritional status.

**Rhizosphere as Plant Disease Management:** In the rhizosphere, plants and microorganisms are permanently interacting in a continuum ranging from deleterious to beneficial and based on their effects on the plant growth can be classified into beneficial, deleterious and neutral groups (Dobbelaere *et al.*, 2003). In negative interactions, the phytopathogenic rhizobacteria produce phytotoxic substances such as hydrogen cyanide or ethylene, thus, exhibiting negative influence on the growth and physiology of the plants. Apart from these deleterious bacteria, there are PGPR that exert a positive impact on plant growth by direct mechanisms, such as solubilization of nutrients, nitrogen fixation, production of growth regulators, etc., or by indirect mechanisms such as stimulation of mycorrhizae development, competitive exclusion of pathogens or removal of phytotoxic substances (Bashan and de-Bashan, 2010). Neutral interactions, on the other hand, do not benefit or harm the plant directly, but the microbes' presence is vital for the soil fertility. Based on their degree of association with the plant root cells, PGPR can be further classified into extracellular plant growth promoting rhizobacteria (ePGPR) and intracellular plant growth promoting rhizobacteria (iPGPR) (Martinez-Viveros *et al.*, 2010).

The bacterial genera such *Caulobacter, Chromobacterium, Erwinia, Flavobacterium, Micrococcus, Pseudomonas* and *Serratia* belong to ePGPR (Gray & Smith, 2005). The iPGPR includes the endophytes (*Allorhizobium, Azorhizobium, Bradyrhizobium, Mesorhizobium* and Rhizobium of the family *Rhizobiaceae*) and *Frankia* species both of which can symbiotically fix atmospheric $N_2$ with the higher plants (Verma *et al.*, 2010). ePGPR represent a wide variety of soil bacteria that may induce plant growth by direct or indirect modes of action. The direct modes include (1) the production of phytohormones and stimulatory bacterial volatiles (2) the lowering of plant ethylene levels (3) the improvement of plant nutrient status by either making available macro- and micronutrients from insoluble sources or by non-symbiotic nitrogen fixation and (4) the stimulation of disease-resistance mechanisms such as induced systemic resistance (ISR). Indirect effects arise when ePGPR act as biocontrol agents leading to reduced diseases (Compant *et al.*, 2005), when they stimulate other beneficial symbioses or when they protect the plant by degrading xenobiotic in inhibitory contaminated soils.

## Rhizoplane

Roots are the primary site for plant-microbe interactions. Among the three root-associated layers (i.e., rhizosphere, rhizoplane, and endorhiza), the rhizoplane is a key component serving a critical gating role that controls microbial entry into plant roots. The microbial communities colonizing the three layers are believed to be gradually enriched from the bulk soil inoculum. However, it is unknown how this enrichment process, particularly the rhizosphere to rhizoplane step, is affected by biotic stresses, such as disease. In this study, we address this question using the citrus root-associated microbiome as a model. We identified the rhizosphere-to-rhizoplane-enriched taxonomic and functional properties of the citrus root-associated microbiome and determined how they were affected by Huanglongbing (HLB), a severe systemic disease caused by *Candidatus* Liberibacter asiaticus, using metagenomic and metatranscriptomic approaches. Multiple rhizoplane-enriched genera were identified, with *Bradyrhizobium* and *Burkholderia* being the most dominant. Plant-derived carbon sources are an important driving force for the enrichment process. The enrichment of functional attributes, such as motility, chemotaxis, secretion systems, and lipopolysaccharide (LPS) synthesis, demonstrated more active microbe-plant interactions on the rhizoplane than the rhizosphere.

**Use in Plant Disease Management and Growth:** The role of plant growth-promoting rhizobacteria (PGPR) in the phytoremediation of heavy-metal-contaminated soils is important in overcoming its limitations for field application. A plant growth-promoting rhizobacterium, *Serratia* sp. SY5, was isolated from the rhizoplane of barnyard grass (Echinochloa crus-galli) grown in petroleum and heavy-metal-contaminated soil. This isolate has shown capacities for indole acetic acid production and siderophores synthesis. Compared with a non-inoculated control, the radicular root growth of Zea mays seedlings inoculated with SY5 can be increased by 27- or 15.4-fold in the presence of 15 mg-Cd/l or 15 mg-Cu/l, respectively. The results from hydroponic cultures showed that inoculation of *Serratia* sp. SY5 had a favorable influence on the initial shoot growth and biomass of Zea mays under noncontaminated conditions. However, under Cd-contaminated conditions, the inoculation of SY5 significantly increased the root biomass of Zea mays. These results indicate that Serratia sp. SY5 can serve as a promising microbial inoculant for increased plant growth in heavy-metal-contaminated soils to improve the phytoremediation efficiency.

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