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Rhizosphere :Hotspot of Soil- Microbes-Plant Interaction

Drishty Katiyar
Ph.D. Research Scholar (Soil Sc. & Ag. Chem.), Chandra Shekar Azad University of Agriculture and Technology, Kanpur (U.P.) Pin-208002, India.

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Abstract

The rhizosphere is a limited soil zone surrounding and influenced by the roots of vascular plants. The rhizosphere is a dynamic habitat affected by complex interplay between plants and creatures that live near the root. Microbial activity and population numbers are affected by the composition and pattern of root exudates, impacting the nematodes and microinteractions that affect root function and plant growth. In addition, the rhizosphere can encompass organisms that do not directly assistance or harm plants, but have a substantial effect on their growth and productivity. Some of the microbes that live in this area are bacteria, which are able to colonize the roots or rhizosphere soil of crops very efficiently. These bacteria are called plant growth promoting rhizobacteria (PGPR). To manage the rhizosphere, promote plant development, and alleviate the environmental influence of crop production and agriculture, a improved understanding of the soil-root and soil-seed interface is required. The application of plant growth promoting organisms as well as the application of biological pest control to diminish plant diseases and weeds are some of the advantages of understanding the rhizosphere.

Keywords:- Crop,Plant growth, Root, Rhizosphere, Soil

Introduction

Lorenz Hiltner, a German agronomist and plant physiologist, devised the term rhizosphere in 1904 to illustrate the plant-root interface, a term derived in part from the Greek word rhiza, meaning root ***(Hiltner, 1904; Hartmann et al., 2008).*** The rhizosphere, or root microbiome, is a confined soil or substrate zone that is directly controlled by root fluids and associated soil microbes. Lorenz Hiltner defined the rhizosphere as the soil compartment influenced by plant roots that is a hotspot for microbial interactions and activities. The rhizosphere is deemedto be the most species-rich and dynamic habitat on earth ***(Hinsinge et***

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al., 2009). The rhizosphere is also a more metabolically active and competitive environment than the surrounding soil. The rhizosphere is a zone within the soil that is notably affected by microorganisms that feed on the substances released by the roots. Plant roots release materials such as sugars and amino acids through water-soluble substances that evidence and offer microbial survival, demonstrating symbiotic interactions between plants and microbes. Microbial activity in the rhizosphere is imperative to plant health as it assists in nutrient uptake and protects the plant from disease ***(Berendsen et al.2012).***The rhizosphere is known to be a hot spot of plant-microbial interactions and a driving force of soil processes. Plant species could affect quantity and quality of carbon resources in the rhizosphere, which would influence the composition and diversity of microbial community in these environments. Different plant species can promote proliferation of different microbial communities by releasing different amount and kinds of root exudates. Coexistence of numerous plant species may boost the complication of soil microorganisms by increasing the heterogenity of root exudates and carbon thatare contributed from roots and decomposing litter. Moreover, plants may directly or indirectly impact soil nutrient accessibility by impacting soil enzyme activities through releasing extracellular enzymes and altering microbial community that is known to major contributors of enzymes activities in the soil.

Characteristics of the rhizosphere

The rhizosphere, also called the microbial reservoir, is the soil zone surrounding plant roots, where the roots affect the biological and chemical properties of the soil. The release of organic matter into the soil by plant roots is a crucial aspect of the rhizosphere. These secretions can be employed to increase nutrient accessibility in the rhizosphere while providing food for microorganisms. Plants absorb water and nutrients through their roots. This draws water from the surrounding soil toward the roots and rhizosphere. The trade-off between the flow of water and nutrients to the roots and their elimination from the soil by the roots means that their concentration in the rhizosphere is usually vastly dissimilar from that in the soil mass.

Zone of Rhizosphere

- **Endorhizosphere :** Endorhizosphere is a portion of endodermis and cortex in which the free space is occupied by microorganisms and cations.

- **Rhizoplane :** It is the site of water and nutrients uptake and release of plant exudates in soil.
- **Ectorhizosphere:** The ectorhizosphere is the outermost zone, extending from the rhizoplane into the soil.

Rhizosphere is the storehouse of organic matter, root exudates, microorganisms, enzymes and growth hormones.

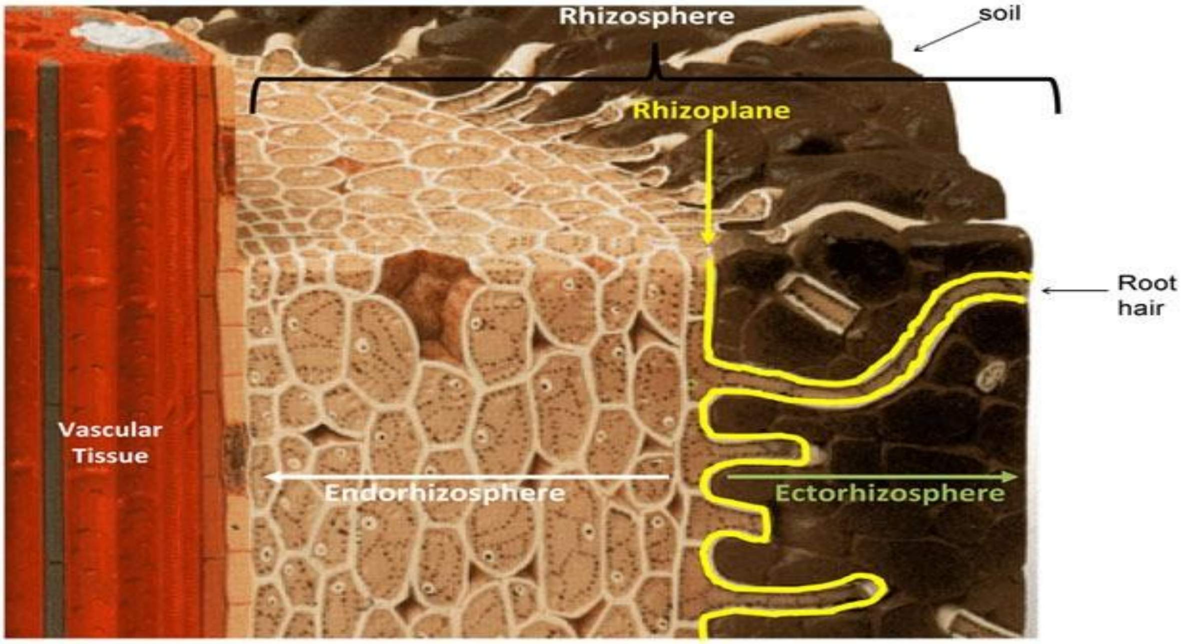

Figure 1: Schematic of a root section showing the structure of the rhizosphere.

Source : ***David H. McNear., 2013***

Root exudates: secretions of exudates from the plant roots may be divided into two types:

- ✓ Low molecular-weight substances such phenolics, sugars, organic acids, sugars and
- ✓ High-molecular-weight exudates like mucilage (polysaccharides) and proteins.

Functions of Root exudates

- ✓ Keep the soil around the root moist.
- ✓ Change the chemical properties of the soil around the root.
- ✓ Inhibit the growth of competing plant species.
- ✓ Play important important indirect roles in resources competition by altering soil chemistry, soil processes, and microbial populations.
- ✓ Defend the rhizosphere and root against pathogenic microorganism.

Rhizosphere effect

Rhizosphere effect, a term by Starkey (1938), is defined by collective processes occurring at the root-soil interface of a plant and includes root exudation, microbial activity, genetic exchange, nutrient transformation and gradient diffusion***(Starkey,1938).*** In living plants, organic carbon released from plant roots is broken down into CO2 in a mechanism known as the rhizosphere priming effect ***(Kuzyakov,2002).*** Although the estimate of the carbon economy of plants is still controversial, about one-third to one-half of all assimilated carbon is attributed to the subsoil, of which 15-25% is released from the roots into the soil to facilitate rapid carbon turnover in the soil induce rhizosphere ***(Kuzyakov,2002)***. Due to the intensive carbon uptake by the roots, other nutrients in the rhizosphere are severely limited***(Breland et al.,1991)***. In contrast, in a rootless soil, all nutrients except carbon are unlimited ***(Wardle DA, 1992).*** The excess of readily available carbon and severe nutrient limitation combine to make the rhizosphere environment very different from that of the rootless zones. The increased microbial count and activity in the rhizosphere compared to those in the soil is mainly due to the release of organic carbon by the plant roots ***(Hartmann et al.,2009).***

Biological and Biochemical Changes in Rhizosphere

Soil quality does not just depend on the physical and chemical properties of the soil but it is very closely linked to its biological properties also. Biological properties include size and diversity of the microbial, macro and microfaunal biomass, enzyme quantities and activities, mineralizable C, N, P, S etc., respiration and soil organic matter content. Biological processes provide the resilience and buffering capacity to ameliorate stress ***(Karlen et al. 1992)***. Soil biota is considered an important and labile fraction of soil organic matter involved in energy and nutrient cycling. It has been well established that the more dynamic characteristics such as microbial biomass, soil enzyme activity and soil respiration respond more quickly to changes in crop management practices or environmental conditions than do characteristics such as total soil organic matter ***(Dick 1992 ; Doran et al. 1996).***

Enzymes and growth hormones in the rhizosphere

Phosphatase produced by pseudomonas sp. and it is secreted by Rhizospheric microorganisms and stimulates enzyme synthesis by intact roots.

The rhizosphere : Derived from close soil–plant association

The interplay of soil physicochemical properties and plant root exudates can ascertain the composition of microbial communities associated with roots in the rhizosphere and can also select a specific microbial composition by generating niche environments. Although soil pH and nutrient accessibility affect the plethora of crop-pathogenic bacteria, fungi and nematodes, as well as advantageous microbes ***(Dumbrell et al., 2010).*** Furthermore, soil interplays with plant root exudates can generate a rhizosphere environment that progressively alters the soil biome to encourage the provision of a rhizobiome and influence the composition of rhizosphere communities depending on soil type and plant species ***(Tkacz et al., 2015).*** Compounds of plant root exudates modify soil chemistry and offer nutrient causes for microbes in the rhizosphere ***(Miransari, 2013)*** creating a selective environment for these microbes, which as a consequencesof further adaptation have developed mechanisms to colonize the plant root or live in the rhizosphere ***(Bever et al., 2012).*** Predominantly herbal compounds can modify bacterial diversity by stimulating or inhibiting different community members, suggesting that specific kinds of exudates attract or repel specific microbes ***(Berendsen et al., 2012).*** Thus, the rhizosphere is an area where advantageous plant microbes are recruited, utilizing root exudates to attract mutual interactions to boost plant safety against pathogens or boost growth through nutrient uptake capabilities ***(Oldroyd, 2013).***

Microbes-roots-soil interactions in the rhizosphere:

Rhizobia, fungal mycorrhizae, and endophytes (fungal/bacterial symbionts living inside plant cells) are the main organisms that interact directly with plants. Nitrogen fixation, enhanced phosphorus uptake, and disease defense are just a few of the benefits brought by bacteria in the plant's rhizosphere. Plants offer living beings photosynthetic carbon in return, with 15–20% rhizobia tubers, 4–20% mycorrhizae, and 15% rhizoplanes ***(Kiers and Denison, 2008)***. Plants send out recognition signals to potential symbiotic microbes; These signals are not always correct, however, as they can also attract rhizobia and mycorrhizae, which can behave as cheaters.

Soil microbes-plant roots interactions

1. Rhizosphere organisms can influence plant roots by modifying carbon compound transport from roots to shoots.
2. Earthworm burrows in the soil offer a convenient path for plants roots to travel as they develop through the soil.

3. Various root-microorganism interactions, such as those with mycorrhiza, rhizobia, and Azospirillium, can boost nutrient absorption by plants in nutrient-poor conditions.
4. Azospirillium is a bacterium found in the rhizosphere of grass plants. Some strains of this bacterium release hormone that promote plant development, while others fix nitrogen from the atmosphere and make it accessible to the grass.

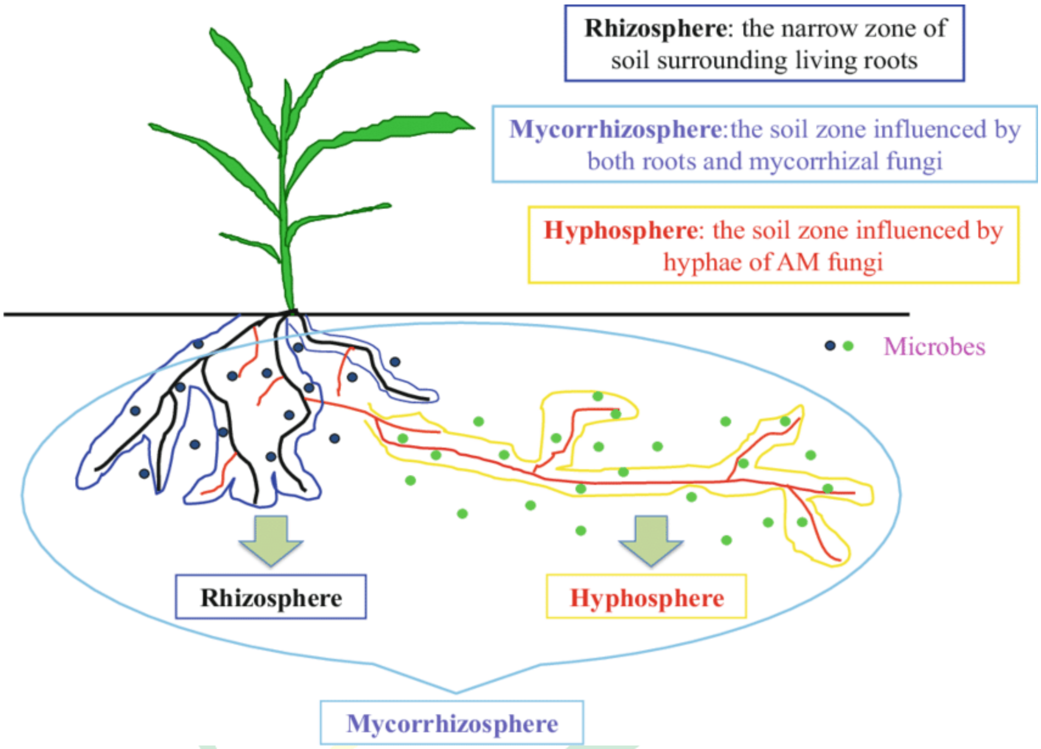

Figure 3:Theoritical diagram of rhizosphere, hyphosphere, and mycorrhizosphere.

Impact of Rhizobial Microbes on Plants

Rhizosphere microorganisms contribute to chemical and physical modifications that directly affect plants. The conversion of organic waste and microbial biomass into a plant-available form, or into a chemical form that provides plants with the nutrients that are freely available for uptake. Rhizobia bacteria reduce manganese (Mn^{4+} to Mn^{2+}) and iron (Fe^{3+} to Fe^{2+}) to make them readily available for plant uptake. Mycorrhizal fungi are involved in optimizing soil aggregation and are of critical value for water and nutrient uptake, notably phosphorus, zinc and copper. In phosphorus-deficient tropical environments, these fungi are involved in a procedure called phosphorus starvation, these fungi are involved in a process

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called phosphorus fixation, which comprises the recovery of phosphorus in the soil profile where rhizobia bacteria consequently solubilize the mineral for plant uptake. Furthermore, both asymbiotic and symbiotic bacteria rectify atmospheric nitrogen, leading to an increment in the accessible nitrogen pool available to plants in the rhizoplane, leading to a continuous supply of nutrients to plant roots ***(Sylvia et al., 2005).*** Physical changes are predominantly caused by the synthesis of extracellular polymer molecules that increase soil aggregation and texture, such as polysaccharides and glomalin. The existence of Mucigel in the Rhizoplane is crucial to the plants' water balance, as the hydrated chemical acts as a protective, lubricating coating for the root cap that helps in water uptake. Plants would be more likely to suffer from extreme water stress without these substances as it would be problematic for them to correctly penetrate the soil and ascertain a symbiotic association with fungi that assistance with water uptake ***(Hinsinger et al., 2008).*** By expanding the food and moisture absorption regions within the rhizospheres, mycorrhizae ascertain symbiotic associations with plants. Certain bacteria in the rhizosphere generate ferric ions that intricate siderophore chemicals. Siderophores are ferric (fe3+) ion-transporting compounds with low molecular weight and high ferric (fe3+) ion affinity. They stabilize soluble (fe3+) for microbial uptake.

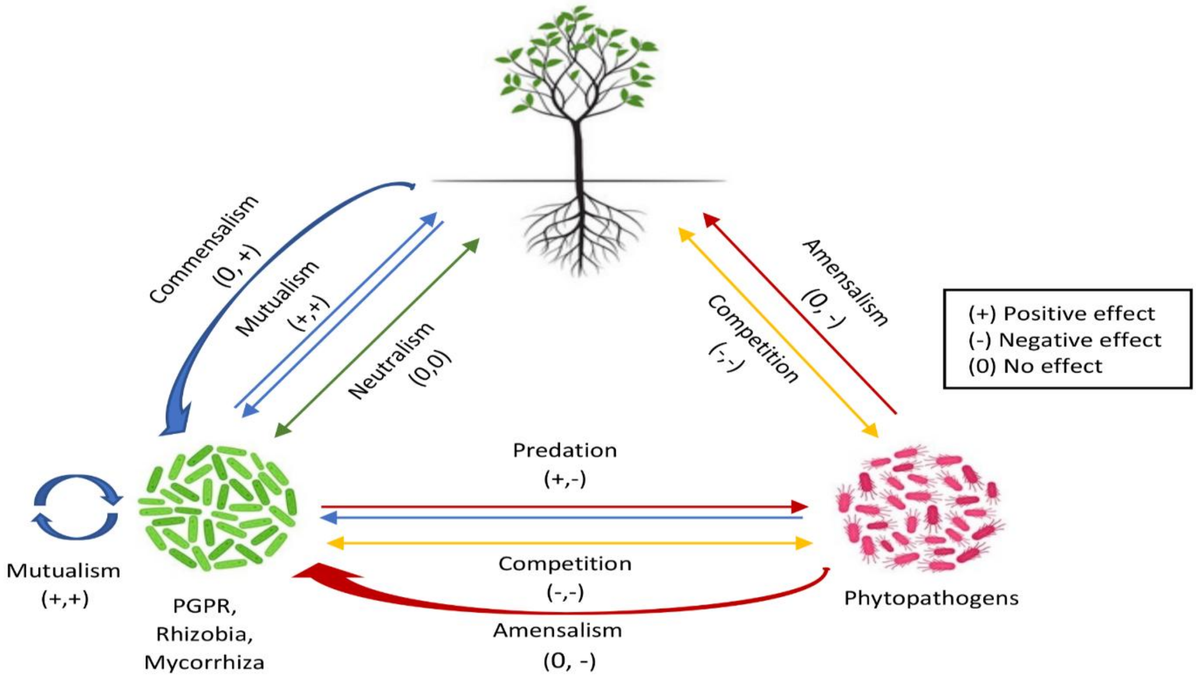

Figure 4. Schematic representation of interactions between rhizo-microorganisms and plants.

Source :*Jamil, F., et al 2022*

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Interactions for improving soil quality Physico-chemical soil properties are fundamental for soil quality, with soil structure being one of the most influential factors (Buscot, 2005). Soil particles are bound together into aggregates and these influence the precise pore structure of the soil (Tisdall, 1996). When the soil is exposed to environmental stresses, maintaining its struc- tural stability is critical in the prevention of soil erosion (Oades, 1993). A well-aggregated soil structure ensures appropriate soil tilth, soil–plant water relations, water in-filtration rates, soil aeration, root penetrability and organic matter accumulation, which all contribute to soil quality (Miller and Jastrow, 2000) Interactions for improving soil quality Physico-chemical soil properties are fundamental for soil quality, with soil structure being one of the most influential factors (Buscot, 2005). Soil particles are bound together into aggregates and these influence the precise pore structure of the soil (Tisdall, 1996). When the soil ismexposed to environmental stresses, maintaining its struc- tural stability is critical in the prevention of soil erosion (Oades, 1993). A well-aggregated soil structure ensures appropriate soil tilth, soil–plant water relations, water in- filtration rates, soil aeration, root penetrability and organic matter accumulation, which all contribute to soil quality (Miller and Jastrow, 2000) nteractions for improving soil quality Physico-chemical soil properties are fundamental for soil quality, with soil structure being one of the most influential factors (Buscot, 2005). Soil particles are bound together into aggregates and these influence the precise pore structure of the soil (Tisdall, 1996). When the soil is exposed to environmental stresses, maintaining its structural stability is critical in the prevention of soil erosion (Oades, 1993). A well-aggregated soil structure ensures appropriate soil tilth, soil–plant water relations, water in- filtration rates, soil aeration, root penetrability and organic matter accumulation, which all contribute to soil quality (Miller and Jastrow, 2000)

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2000).Soil properties affect microbial community structure in the rhizosphere. The microbial characterization of the rhizosphere provides crucial information related to the analysis of the nutrient status of the soil. Nutrient availability in the rhizosphere is determined by soil properties, plant nutrient uptake characteristics, and the interactions of plants, microorganisms, and their surrounding soil environment have significant impacts not merely on soil physical and chemical properties and organic matter quality, but also on abundance and composition of the soil microbial community Bacteria and fungi in the rhizosphere, as well as those living endophytically in the roots, are also known to boost plant growth, either by enabling nutrient uptake and generation of plant growth hormones, or by conferring crop safety against pathogens.Soil physical properties are a necessary section of soil quality evaluation as they cannot conveniently be improved ***(Karlen and Cambardella 1996; Wagnet and Hutson 1997)***. ***Larson and Pierce (1991)*** summarized the physical indicators of soil quality as those characteristics that affect plant productivity through:Whether a soil can accommodate unimpeded root growth and provides a pore space of sufficient size and continuity for root penetration and extension .Extent, in which the soil matrix resists deformation.The soil's potential to supply water and aerate. The physical conditions of a soil have direct and indirect impacts on crop productivity and environmental quality (Fig. These include relatively static parameters (typical soil profile characteristics, root penetration depth, morphological characteristics, texture, etc.) and sensitive parameters (bulk density, aggregate stability, resistance to penetration, etc.).

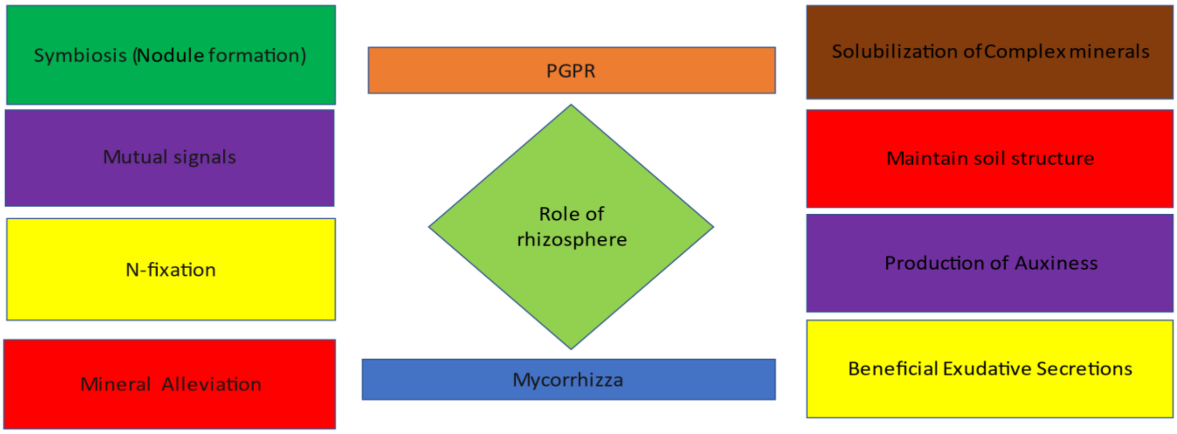

Figure 5: Role of rhizosphere in soil and plant growth.

Source:*Sylvia et al., 2005*

Conclusion

The rhizosphere is a zone of the highest microbial load and interactions. It plays crucial role in nutrient and water supply, accumulation and uptake. It also plays vital role in improving soil functions by optimizing (soil organic carbon) and biologically (microbes). A healthy rhizosphere zone is extremely important for viable crop production and soil health.Interest in rhizosphere and soil ecology is growing among rhizobiologists. Soil microorganisms are essential for nutrient cycling in the biosphere. Studies in Soil microbiology will be crucial in obtaining specialized microorganisms, which can be used to solve various environmental problems.

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