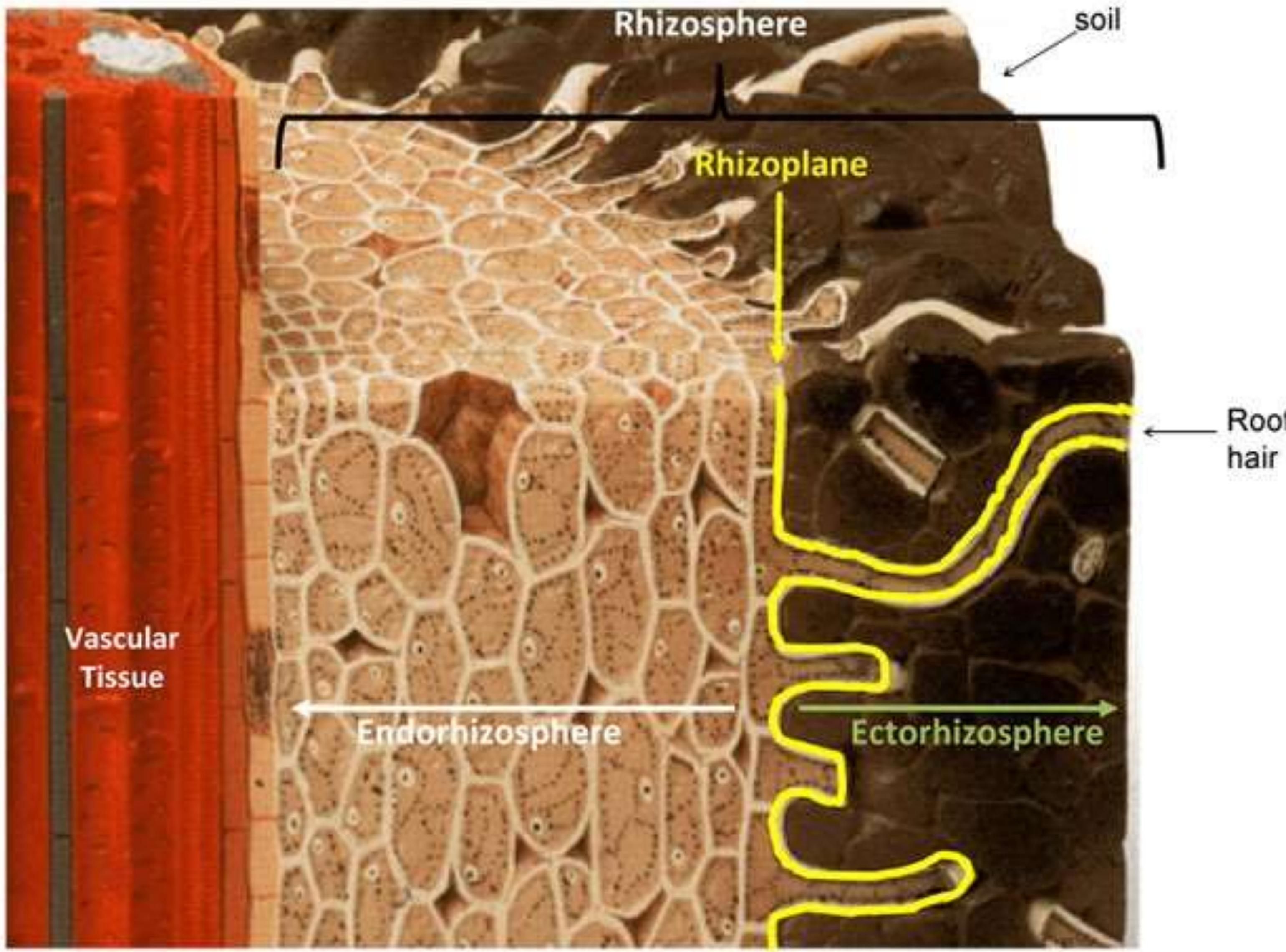
Plant-Microbe Interactions

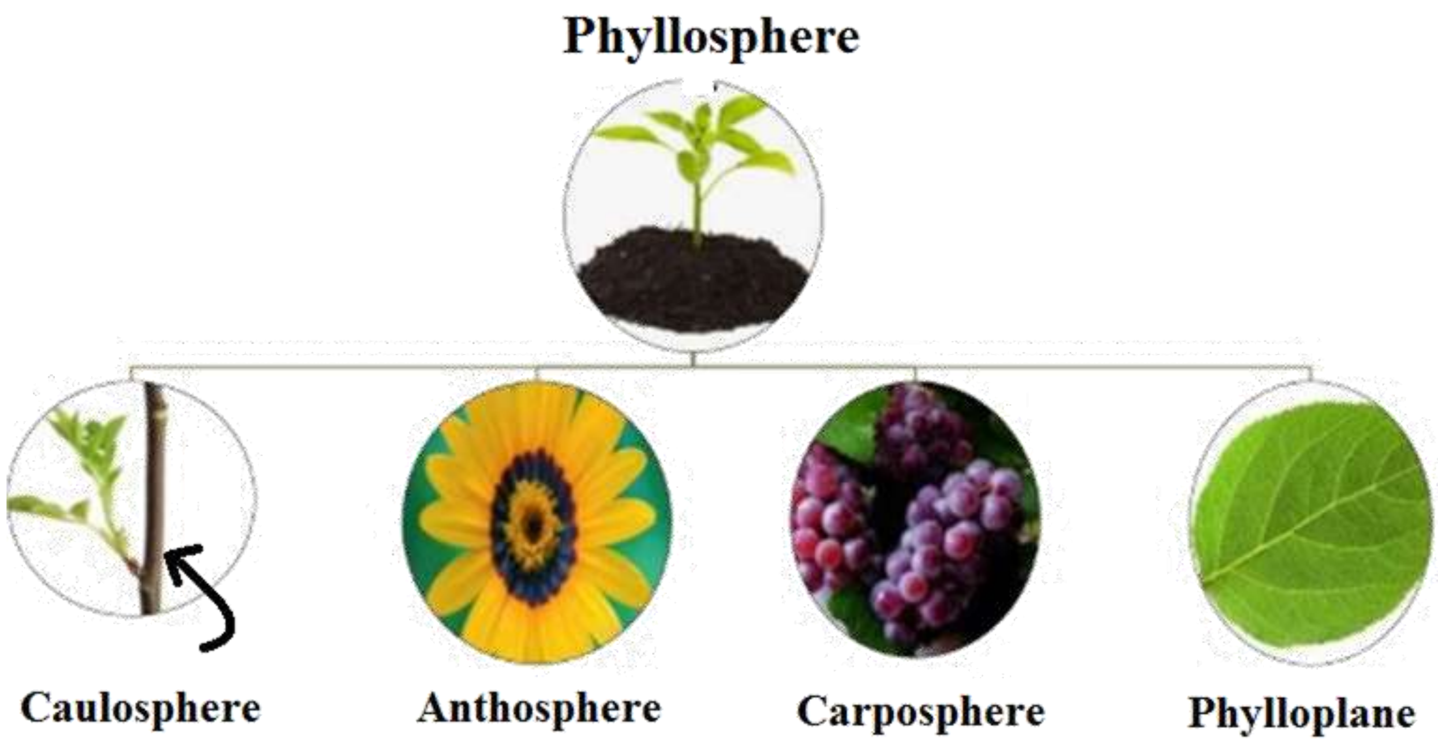
Rhizosphere

- In 1904, L. Hiltner for the first time coined the term ‘rhizosphere’ to denote the area of intense microbiological activity that extends several millimeters from the root system of the growing plants.
- Hiltner described the rhizosphere as the area around a plant root that is inhabited by a unique population of microorganisms influenced, he postulated, by the chemicals released from plant roots.
- The rhizosphere definition has been refined to include three zones which are defined based on their relative proximity to, and thus influence from, the root:
  – The **endorhizosphere** includes portions of the **cortex** and **endodermis** in which microbes and cations can occupy the "free space" between cells (apoplastic space).
  – The **rhizoplane** is the medial zone directly adjacent to the root including the root epidermis and mucilage.
  – The outermost zone is the **ectorhizosphere** which extends from the rhizoplane out into the bulk soil.


Rhizosphere
soil
Rhizoplane
Root
hair
Vascular
Tissue
Endorhizosphere
Ectorhizosphere

Phyllosphere

- The term phyllosphere was coined by 'Ruinen' in 1956.
- The phyllosphere is the aerial region of the plant colonized by microbes; its colonists are often called epiphytes.



Root exudates

- Roots can release about 10-40% of their total photosynthetically fixed carbon.
- The C released is in both organic (e.g., low molecular weight organic acids) and inorganic (e.g., HCO_3) forms, however, the organic forms are the most varied and can have the most influence on the chemical, physical and biological processes in the rhizosphere.
- The composition and amount of the released compounds is influenced by many factors including plant type, climactic conditions, insect herbivory, nutrient deficiency or toxicity, and the chemical, physical and biological properties of the surrounding soil.
- Root **exudates** include both **secretions** (including mucilage) which are actively released from the root and **diffusates** which are passively released due to osmotic differences between soil solution and the **cell, or lysates** from autolysis of epidermal and cortical cells
- The root products imparted to the surrounding soil are generally called **rhizodeposits.**
- The many functions of root exudates:
  - –as a means of acquiring nutrients (e.g. acquisition of Fe and P),
  - –agents of invasiveness (i.e. allelopathy)
  - –as chemical signals to attract symbiotic partners (chemotaxis) (e.g. rhizobia and legumes)
  - –the promotion of beneficial microbial colonization on root surfaces (e.g. *Bacillus subtilis*, *Pseudomonas florescence*)

Rhizospheric effect

- Compared to non-rooted bulk soil, the soil compartment directly around the plant root contains much larger populations of microorganisms, known as rhizospheric effect.
- The increased microbial numbers and activities in the rhizosphere are due to the release of large amounts of organic carbon by the plant roots.
- Soil microorganisms are chemotactically attracted to the plant root exudates, after which they proliferate in this carbon rich environment.
- Carbon limitation could be demonstrated in bulk soil but not in the rhizosphere.
- Given the fact that plant root exudates differ between plant species, differences in rhizosphere microbiomes of different plant species are to be expected.
- This influence can be measured simply by plating technique and expressed as a rhizosphere effect (i.e. a stimulation that can be measured on quantitative basis by the use of rhizosphere: soil (R:S) ratio, obtained by dividing the number of microorganism in the rhizosphere soil by the number of microorganisms in the non-rhizosphere soil).

Effect of Rhizosphere on Host Plants

The rhizosphere microorganisms have either beneficial or harmful effects on the development of plant:

- The microbes catalyse reactions in the rhizosphere and produce CO_2 and form org. acids that in turn solubilize the inorg. nutrients of plants.
- Some of the rhizosphere microorganisms produce growth-stimulating substances and release elements in organic forms through the process of mineralization.
- Plant growth regulators such as indole acetic acid, gibberellins, cytokinins, etc. are known to be produced by the rhizosphere microflora.
- They influence phosphorus availability to plant through the process of mineralization and immobilization.
- Plant pathogenic microorganisms can cause severe harm to plants. Though plant growth promoting bacteria can inhibit phytopathogens through several mechanisms (competition for nutrients, production of antibiotics, lytic enzymes etc.)
- Microorganisms in the rhizosphere zone change the availability or toxicity of sulphur to plants.
- The products of microbial metabolisms sometimes have toxic effect on plants; therefore, these are termed as phytotoxins.

Rhizosphere Microorganisms

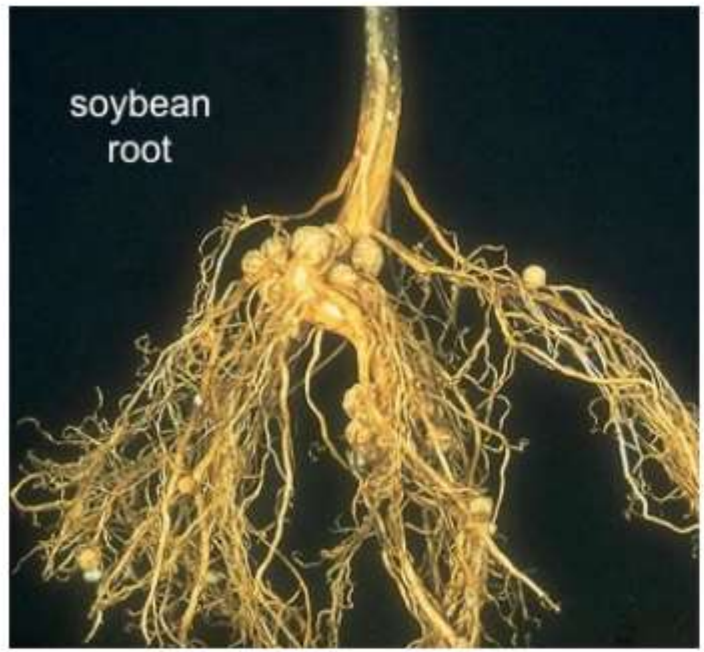
- Bacteria reported from the rhizosphere and rhizoplane regions irrespective of their dominance are: *Arthrobacter, Pseudomonas, Bacillus brevis, B. circulans, B. polymyxa, B. megaterium, Agrobacterium radiobacter, A. tumifaciens, Azotobacter, Flavobacterium, Rhizobium* spp., *Cellulomonas, Micrococcus, Mycobacterium*, etc.
- Common actinomycetes are *Actinomyces chromogenes, Frankia* (inside root tissues), *Nocardia* spp., *Micromonospora* spp., *Streptomyces antibioticus, S. scabies, S. griseus* etc.
- The dominant fungi of rhizosphere were *Aspergillus flavus, A. fumigatus, A. luchuensis, A. niger, A. terreus, Cladosporium cladosporioides, Curvularia lunata* and *Fusarium oxysporum*, whereas the dominant fungi of rhizoplane were *A. niger, Cladosporium herbarum, F. oxysporum, F. solani, Macrophomina phaseolina, Neocosmospora vasinfecta* and *Rhizoctonia solani*. In addition, mycorrhizal fungi are also known to be present in rhizosphere soil and rhizoplane of roots.

Legume-rhizobium symbiosis

- The legume-rhizobium symbiosis is one of the most celebrated mutualistic plant-bacteria interactions.
- Rhizobia colonize the plant root and provide the plant with the nitrogen, a growth limiting macronutrient, through a process called Symbiotic Nitrogen Fixation.

Rhizobium-Legume symbioses

5. Plants of the legume family (soybeans, clover, alfalfa, beans, peas) can grow in soils lacking nitrogen compounds required by other plants. How?



6. These plants contain endosymbiotic Rhizobium bacteria that grow in root nodules. Rhizobia can fix atmospheric Nitrogen gas $(N_2) N_2 + 6[H] \;\; 2\ NH_3$
7. The reaction requires total lack of oxygen and lots of energy as ATP. To bind oxygen and get rid of it, bacteria use protein called leghemoglobin, somewhat similar to animal hemoglobin. Globin part is encoded in plant genome, heme group is encoded in bacterial genome. Neither partner can fix nitrogen alone, only in symbiosis.

Azolla-Anabaena symbiosis and N_2 fixation

- ***Azolla*** leaf (water fern) consists of a thick, greenish (or reddish) dorsal (upper) lobe and a thinner, translucent ventral (lower) lobe emersed in the water.
- It is the upper lobe that has an ovoid central cavity, the "living quarters" for filaments of ***Anabaena azollae* (cyanobacteria)**. The cavity open to atmosphere through pore on upper side.
- The *Anabaena azollae* colony associated with Azolla's shoot apex comprises generative filaments without heterocysts and it is therefore unable to fix nitrogen from the atmosphere.
- In the cavity of mature leaves, the cyanobacteria filaments cease to grow and differentiate heterocysts, which reach a maximum of 25–45% of the cell population in leaves, coinciding with increased nitrogenase activity.
- Nitrogenase is oxygen labile and is protected in part by the thickened cell walls of the heterocyst, which results in them being immune to the oxygen concentrations in the *Azolla* leaf cavity.

Microbial communities of phyllosphere

- Fungi, algae, protozoa, and nematodes inhabit the leaf and stem surfaces, but the most abundant epiphytes are bacteria (averaging 10^6–10^7 cells cm^{-2}).
- Leaf exudates contains amino acids, glucose, fructose and sucrose that provides nutrition for growth of phyllospheric microorganisms.
- Moisture released during transpiration provides water for growth of microorganisms on leaf.
- Plants usually support growth and activities of phyllospheric microorganisms. However sometimes plant produce phytoalexins that kills many phyllospheric microorganisms.

Role of phyllospheric microorganisms

- Some phyllospheric microorganisms such as **Cyanobacteria** and ***Azotobacter*** fix atmospheric Nitrogen and provide it to plant growth.
- Phyllospheric microorganisms produce various plant growth hormones such as indole acetic acid (IAA), which is used by plant for their growth.
- Phyllospheric microorganisms provide stimulus for production of phytoalexin by plants. Phytoalexin is the defensive chemical produced by plants that kill pathogenic as well as other microbes.
- Phyllospheric microorganisms decompose leaf and help in formation of humus after falling of leaves from plant.
- Some phyllospheric organisms have antagonistic effects against fungal pathogen and hence protect the plants from fungal diseases.
- The phyllospheric microorganisms colonize the surface of leaf forming a layer. Therefore these organisms compete with pathogenic microorganisms for habitat and nutrients.
- Some phyllospheric microorganisms degrade wax and cuticle of leaf and damage it.