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Popular Article

Article: RT603

Biotica Research Today

Vol 3:5 393/395

2021

Rhizosphere – A Perfect Soil Engineer

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Keywords

Exudates, Mobilization, Rhizosphere, Siderophores

Article History

Received in 26th May 2021

Received in revised form 28th May 2021

Accepted in final form 29th May 2021

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How to cite this article?

Sudhalakshmi, 2021. Rhizosphere – A Perfect Soil Engineer. Biotica Research Today 3(5): 393-395.

Abstract

"Rhizosphere", the hidden half of the plant, although coined in 1904 by German Scientist Hiltner, it still remains an age old infant for exploration. It is the zone of nutrient mobilization and acquisition, a battle field of pathogenic and non pathogenic microbes, a storage godown of root exudates and deposits, a perfect joint family of hormones and microbes. Rhizosphere is the traffic police man which regulates the flow of nutrients between soil and plants. It balances pH, acidifies and solubilizes fixed phosphorus, stores root exudates to attract beneficial microbes, aids in biological nitrogen fixation, protects the plants by evading pathogens in the root zone, mobilizes micronutrients through release of siderophores under Strategy –I and II mechanisms and aids in improvement of soil physical properties through structural stability.

Introduction

Although the term "Rhizosphere" was coined by the German Agronomist and Plant Physiologist Hiltner as early as 1904 (Hiltner, 1904), it still remains the unraveled half of a plant. It is 'No man's land between soil and the root' just extending few mm from the roots to some meters if volatile compounds are exuded by the roots. Though this territory does not have a prominent owner, it is still a factory of nutrient mobilization & acquisition and a battle field of pathogenic & non pathogenic micro organisms. 'Low Input – High Output' is turning as the buzz phrase in modern agriculture despite the great contributions of intensive agriculture with 'High Input - High Output' systems. Achieving high nutrient use efficiency and system productivity has become a great challenge with increasing global demand for food, depletion of natural resources and deterioration of environmental conditions. Rhizosphere is the 'Traffic Police man' which regulates the key interaction between plants and the soil and increases the use efficiency of the applied resources. Plant roots can not only regulate morphological traits to adapt to soil environmental conditions, but also significantly modify rhizosphere processes through their physiological activities *viz.*, exudation of organic acids, phosphatases, signaling substances, proton release and redox changes. Rhizosphere processes not only determine mobilization and acquisition of soil nutrients as well as the microbial dynamics, but also control nutrient use efficiency by crops and thus profoundly influence crop production. Thus Rhizosphere is the perfect soil engineer which regulates the nutrient flows, solubilizes the fixed nutrients, harbours beneficial microbes, defends the plants from pathogens and buffers the root region from getting hurt by the harmful external stimuli.

Nutrient Mobilization in Rhizosphere

To maintain neutral cytoplasmic pH, roots exude H^+ or HCO_3^- ions in response to cation/ anionic uptake. Nitrate supply to the plants is correlated more with a high rate of HCO_3^- net release and ammonium supply to that of H^+ excretion. In neutral or alkaline soils, rhizosphere acidification in plants fed with ammonium can enhance mobilization of sparingly soluble calcium phosphates and thereby favour the uptake of phosphorus and micronutrients.

On severely phosphorus deficient soils, utilization of rock phosphate as a phosphate source for legumes can be low when nodulation is limited by phosphorus deficiency. In inter-planting nitrogen fixing legumes with non legumes, rhizosphere acidification of legumes can increase phosphorus uptake by non legumes. Rhizosphere acidification in cotton and other dicots under zinc deficiency and in non-graminaceous species under iron deficiency are well documented.

Rhizosphere – A Market Place of Deposits and Exudates

On an average, 30-60% of the net photosynthetic carbon is allocated to the roots and appreciable proportion is released as organic carbon into the rhizosphere. This release of carbon is called rhizodeposition which is increased by stress, mechanical impedence, nutrient deficiency and by micro organisms.

Root exudates comprise both high (mucilage, mucigel and ectoenzymes) and low molecular weight solutes (organic acids, sugars, phenolics and aminocids) released by the roots. In alfalfa, under P deficiency, root exudation of citric acid increases two fold. Citric acid is secreted in chickpea and fumaric acid in peanut in response to P deficiency**.** Citric acid in the root exudates of white lupin acidifies the rhizosphere even in calcareous soil and mobilizes sparingly soluble calcium phosphates by dissolution and results in the formation of calcium citrate.

Rhizosphere – A Perfect Joint Family of Hormones and Microbes

As roots serve as source of organic carbon, population density of microbes especially bacteria is considerably higher in the rhizosphere (R) than in the bulk soil (S). R/S ratio varies between 5 and 50. Despite the high supply of organic compounds in the rhizosphere, nitrogen deficiency can limit the growth of the plants. In non-legumes, the rhizosphere bacteria increase with nitrogen fertilization. Rhizosphere serves as the perfect joint family of phytohormones, nitrogen fixers, pathogens, phosphorus solubilizers and antagonists**.**

Biological N_2 Fixation

Rhizosphere is a cross road for nutrient exchange between plant and soil microbes. Biological nitrogen fixation is restricted to prokaryotic organisms. Symbiosis has the highest nitrogen fixation capacity because carbohydrates are provided by the plants and also other conditions are optimized for efficient nitrogen fixation. Majority of soil N is in the organic form, existing primarily as chitin, proteins, ligno proteins and nucleotides. As plants cannot access macromolecular organic N, it must be mobilized and released in a more accessible form. Net N mineralization is the work of rhizosphere microbial communities, a service required for the survival of unfertilized plants. Root exudates fuel microbes to work with a better zeal.

Strategic Planning in Rhizosphere

Iron is an essential micronutrient for plants as it serves as a cofactor of many enzymes and it is required in a number of physiological processes like N_2-fixation, photosynthesis, respiration *etc*. Under aerobic conditions, most iron exists in insoluble form (Fe^{3+}) in soil, which is not easily available to plants or microbes. To meet the iron requirement, micro organisms release siderophores and uptake of iron-siderophore complexes through specific outer membrane receptor proteins is done. Plant roots release citric acid, malic acid and phenolics and forms relatively stable chelates with Fe and Al, thereby increasing the solubility and uptake of phosphorus. Chelation of Al alleviates the harmful effects on root growth exerted by high concentration of aluminium. In certain plant species adapted to acid mineral soils with extremely low phosphorus availability such as Eucalyptus and tea, this mechanism is of major importance for phosphorus nutrition.

The exudation of iron mobilizing agents contains two different strategies which are referred to as Strategy I and Strategy II. Strategy I (A) is typical for dicotyledonous and non-graminaceous monocotyledonous plants. Strategy II (B) is typical for graminaceous monocotyledonous plants (grass). Pigeonpea is highly phosphorus efficient when grown on alfisols but not on vertisols with high pH because piscidic acid is a strong chelator of Fe (III) and thus mobilizes sparingly soluble iron and not calcium (Marschner, 1995).

Rhizosphere Microflora – A Strong Battalion against Diseases

Soil suppressiveness is the phenomenon that in spite of the presence of a virulent pathogen and a susceptible host plant, disease does not occur. General soil suppressiveness is the capacity of the total microbial biomass to suppress the growth or activity of deleterious organisms, whereas specific soil suppressiveness generally depends on a single organism with the ability to antagonize a specific pathogenic species or genus. This knowledge has been implemented by introducing antagonistic bacteria to plants roots to control diseases (Weller, 2007). Diverse PGPR antagonize the root pathogens through one or more different mechanisms *viz*., production of bacterial allelochemicals such as volatile and non-volatile antibiotics, siderophores, detoxification enzymes, lytic enzymes and secondary metabolites like HCN.

Rhizosphere Microflora – A Soil Engineer

An often-overlooked function of soil organisms is their dynamic contribution to soil structure, particularly aggregate formation and stability. Mycorrhizal fungi and other rhizosphere microbes influence soil structure by producing humic compounds, accelerating the decomposition of primary minerals and secreting organic "glues" called extracellular polysaccharides. Extracellular polysaccharides are especially efficient in stabilizing soil structure and act by linking mineral grains, homogenous clays, and humus into stable aggregates that maintain porosity.

Conclusion

Although the term 'Rhizosphere' was coined by Hiltner as early as 1904, it still remains an age old infant because of its complex environment. They behave differently to microbial pathogens and to beneficial micro organisms. New molecular tools and powerful biotechnological advances will continue to provide a more complete knowledge of the complex chemical and biological interactions that occur in the rhizosphere, ensuring that, strategies to engineer the rhizosphere are safe, beneficial to productivity and substantially improve the sustainability of agricultural systems.

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