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Review Article

BIOLOGY AND CHEMISTRY OF RHIZOSPHERE: THEIR ROLE IN NUTRIENT MOBILISATION

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Abstract- Rhizosphere is a region of soil in the vicinity of plant roots in which the chemistry and microbiology is influenced by their growth, respiration, and nutrient exchange. It is, therefore, an extremely important and active area in regulating nutrient bioavailability, plant communities, adaptation processes, and the growth environment. The chemical and biological processes occurring in the rhizosphere not only determine mobilization, acquisition of soil nutrients and microbial dynamics, but also control nutrient use efficiency by crops, and thus profoundly influence crop productivity and sustainability .The availability of nutrients in the rhizosphere is controlled by the integrated effects of soil properties, plant characteristics, and the interactions between plant roots and microorganisms .In the rhizosphere ecosystem, plants, via root exudation and release of specific signalling compounds, effect the composition and structure of the rhizosphere microbial community So, rhizosphere management strategies emphasize maximizing the efficiency of root and rhizosphere processes in nutrient acquisition and use by crops rather than solely depending on excessive application of chemical fertilizers. The strategies mainly include manipulating root system, rhizosphere acidification, carboxylate exudation, microbial associations with plants, rhizosphere interactions in terms of intercropping and rotation, localized application of nutrients, use of efficient crop genotypes, and synchronizing rhizosphere nutrient supply with crop demands. From study it has been observed that Probacteria and Bacteriodates are the most abundant bacterial community in maize rhizosphere. In recent study it has been shown that gross N mineralisation rate is higher in rhizosphere than bulk soil. It is also clear that Fe and Zn availability also increases by localized ammonium-N application .it has also been observed that rhizosphere priming can promote mobilisation of N-rich compounds from soil organic matter. Moreover, rhizosphere influences on soil solution composition and mineral stability. Still future research work is needed to identify the un-known organic compounds and their specific roles in nutrient mobilization in the rhizosphere. Knowledge on microbial population, their roles, dynamics in nutrient mobilisation for specific crop and soil needs further extension.

Keywords- *Rhizosphere, Mobilisation, Soil Matrix, Root Exudation, Phytosiderophores, Rhizosphere eco-system*
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Introduction

Attaining and maintaining of high nutrient use efficiency together with high crop productivity has become a major challenge in both developed and developing countries as well as in India with an increasing global demand for food for a growing population, depletion of natural resources, and deteriorating environmental conditions. In agriculture our main aim is to increase food production and feed the ever-increasing population, this can be attained through rhizosphere management. Nutrients are taken up by the plant roots from soils through the rhizosphere which is the central zone of interactions among plants, soils, and microorganisms. Rhizosphere processes are the linkage between plant process-es and soil processes. Rhizosphere processes are influenced by plant root exudation, soli processes, soil pH, and soil organic matter content and microbial activity. The biochemical processes undergoing in the rhizosphere determine solubilisation and uptake of soil nutrients in relation with microbial population dynamics, and control nutrient use efficiency by crops, hereby, influencing crop productivity and sustainability in cropping system [1,2]. Moreover, understanding the biology and chemistry of rhizosphere will be helpful in rhizosphere management to increase the nutrient use efficiency and crop productivity in sustainable agricultural system. It will also help in managing rhizosphere nutritional environment with implementation of best crop-soil management practices. Main objectives of this review are to a) Understand the biology and chemistry of rhizosphere in relation to nutrient mobilisation
b) Know the specific roles of different root exudates
c) Discuss some recent important practical facts where rhizosphere nutritional environment modification really helped in nutrient mobilisation and acquisition

Rhizosphere

The concept of rhizosphere was first introduced by Hiltner (1904) [3]. He described it as the narrow zone of soil surrounding the roots where microbial populations are stimulated by root activities and rhizosphere is directly influenced by root secretions and associated soil microorganisms. In the plant soil system, central area of interactions among plants, soils, and microorganisms. Marshner (1995) [4] defined it as the region of soil in the vicinity of plant roots in which the chemistry and microbiology is influenced by their growth, respiration, and nutrient exchange. Brimecombe *et al*. (2007) [5] extended the concept to include the soil surrounding a root in which physical, chemical, and biological properties have been changed by root growth and activity both in a radial and longitudinal direction along an individual root as well as spatial and spatiotemporal changes. The rhizosphere is a dynamic changing environment that differs from bulk soil both in physical and chemical and biological properties. The soil rhizosphere, located within the soil matrix, plays an important role root growth, exudate production and community development of macro and micro biota, maintenance of their structure and dynamics. Hence the rhizosphere can be described as the longitudinal and radial gradients occurring in the soil in relation to root growth, nutrient and water uptake, exudation, and subsequent microbial growth.

The extent of the rhizosphere gradient into the soil will depend on the diffusion away from the root of the many compounds released from the root, their diffusion characteristics, and the water status of the soil as well as the soil organic matter content. The rhizosphere varies in size from several millimetres (specifically 0-2mm) from the root surface. It has three distinct parts

a) Root-soil interface (epidermis of root)

b) Inner rhizosphere (0-15μm)

c) Outerrhizosphere (15-1500μm)

Rhizoplane

The Rhizoplane is the root epidermis and outer cortex where soil particles, bacterial cells and fungal hyphae adhere Scherer (2006) [6]. It is the microenvironment of a root system near the surface. The functional definition is the remaining microorganisms and soil particles after the roots have been shaken vigorously in water. There are more microbes in the rhizoplane than in the more loosely associated rhizosphere. Microbes are most abundant where the density of the root is heavy. Due to the presence of microorganism it is he determining region for soil and plant in terms of nutrient mobilisation and uptake [2].

Bulk soil

The soil not immediately affected by the active functioning of roots, but which may well be transformed by rhizosphere over pedogenic time.

Rhizosphere ecosystem

Rhizosphere ecosystem has 3 components a) Plant roots b) Soil c) Microbes. These components have specific role to play in the rhizosphere. Plants plays significant role by providing food and energy in the system. Roots release compounds like carbohydrates, amino acids, lignin etc. that serves as source of energy and food material to the microbes. These root exudates determine the dynamics of microbial population in rhizosphere. They help in nutrient chelation, solubilisation, maintenance of equilibrium between soil solution nutrients and the pools of nutrients (organic pool, inorganic pool, nutrients fixed in clays). Their degradation also alters the soil pH and redox potential. In turn the root exudates composition and its chemistry depend upon the plant types, its species, its age, its environmental condition and nutrient status of the rhizosphere [7].

Driving forces of rhizosphere

There are many factors that influences rhizosphere activity, among them most important ones are 1. Microbial activity, 2. Soil processes, 3. Soil solution pH, 4. Soil organic matter, 5. Plant root exudation.

These five factors interact simultaneously in rhizosphere and modify the rhizosphere environment to facilitate plant for nutrient mobilisation and acquisition [7]. Their role in nutrient mobilisation is given by the following diagram [1].

Nutrients in soil remain in 3 main pool- a) Organic pool, b) Inorganic pool c) Colloid. Soil solution nutrients remain in equilibrium with those pools via the process of mineralisation immobilisation, dissolution precipitation, and fixation release from the pools. This process is influenced by rhizosphere element like microbial activity, enzyme activity, root exudates, rhizosphere pH. The nutrients in solution are up taken by plant roots and transported through xylem and helps in food synthesis. The synthesized foods are translocated downward through phloem and in the meantime undergo transformation to several root exudates and released in rhizosphere. This root exudates again influence the soil processes that affects nutrient equilibrium in soil solution.

Mechanism of root exudation

Root exudates that influence the nutrient equilibrium in soil solution have definite mechanism to be released. They are a) Diffusion b) Anion channel c) Vesicle transport.

Diffusion

In this release mode, low molecular weight organic compounds such as sugars, amino acids, carboxylic acids, and phenolic are released in response to concentration gradients between the cytoplasm of intact root cells (millimolar range) and the soil (micro molar range) [8]. Membrane permeability, which depends on the polarity of the molecules to be released, determines if direct diffusion through the lipid bilayer of the plasma lemma is possible. Lipophilic exudates are mainly releasing through this method. Diffusion induced exudation of amino acids or malate from plant roots has been calculated at rate of approximately 0.3 nmol/hr/cm root length or 120 nmol/ hr/ g root fresh weight [9]. Root exudation of amino acids and sugars occurs by passive diffusion, and is enhanced under stress by modification of the membrane integrity under nutrient deficiency (K,P, Zn), temperature extremes, or oxidative stress[10].

Anion channel

Root exudation of carboxylates (e.g., citrate, malate, oxalate), which are generally exuded in high concentrations, is through ion channel is under specific stress such as nutritional deficiency or Al toxicity [2]. Experimental studies using anion channel indicated the release of malate and citrate in wheat and maize under Al stress [1] and citrate exudation under P deficiency in Lupinusalbus. Further studies are needed to investigate physiology of the membrane to characterize the mechanism of transport specifically. In addition, the cloning of anion channel genes would also be helpful to further our understanding of root exudation mechanisms.

Vesicle transport

Through vesicular transport of high molecular weight compounds are released [11]. Golgi vesicles transport mucilage polysaccharides across the root cap while proteins such as (acid phosphatase, peroxidase) are transported from polysomes to endoplasmic reticulum through vectorial segregation [12]. Through vesicle high molecular weight substances like phenolics, phytosiderophores released, but the exact mechanisms utilized remain unknown. Root exudate chemical composition is altered in rhizosphere through, physical, chemical and biological processes in the soil like sorption, metal oxidation, microbial degradation 13]. The biological activity of chemicals in the rhizosphere may be altered rapidly in terms of their efficacy because of chemical oxidation, microbial breakdown or immobilization by irreversible binding to soil particles. This alteration in activity can occur before the compound(s) in question reach a biological target [13].

Role of different exudates in nutrient mobilisation acquisition by plant

Role of phytosiderophores

Romheld and Marschner (1995) [30] isolated a phytosiderophores from roots of grasses, Mugienic acid. This acid is synthesized from methionine through the intermediate of nicotianamine (as described below). Mugineic acid chelates iron under stress condition makes iron available to plant through formation of ferric mugeneate. Mugineic acid synthesis is induced by Fe deficiency where as its chemical constituents, number and amount synthesized and secreted into the rhizosphere depends on species and even cultivars of crops [14].

Role of organic acids

Organic acid released under metal stress

Plants show Fe deficiency under calcareous soil due to its insolubility in high pH. Organic acids that can bind Fe like citrate, malate is released in rhizosphere from plants and induce the solubility of Fe oxyhydroxides. Organic acids like malate, citrate can also release Mn from synthetic MnO_2[15]. Organic acids are also able to mobilize Cu, Pb and Cd through complexation.

Organic acid released under Al excess

Al toxicity in rhizosphere of gramineceous plant like corn, rice in acidic soil is of great concern. Some plant species has mechanisms to survive and grow satisfactorily on acidic soils that have Al^{3+} toxicity which hinder crop growth through release of organic acids. Some plants detoxify aluminum in the rhizosphere by releasing organic acids that chelate aluminum, making it unavailable to the growing crops like rice releasing oxalate, citrate, malate [16].

Organic acid released under P deficiency

P has been a great concern to the scientists in respect to its availability to plants due to its nature of forming insoluble compounds with Fe and Al in acid soil and with Ca under alkaline soil.

It is reported that plants like *Brassica napus* asrelease organic acids like malate, citrate under P deficiency [38] also confirmed this concept for radish plant proving that under P deficiency radish release succinic acid, malic acid and tartaric acid. Maize is also reported to release mono (acetic, formic, glycolic and lactic), di (malic, oxalic and succinic) and tri (citric and transaconitic) carboxylic organic acids under P stress condition.

2)Organic acid in mineral dissolution and pedogenic process: First Sene (2001,) [18] and Jianguo and shuman (1991) [19] argued that soil organic acids play an important role in mineral dissolution. Dissolution of Fe and Al oxyhydroxides is enhanced in presence of organic acids.

Mode of action of organic acid in nutrient mobilisation

We discuss here with respect to Fe stress condition. Under Fe stress condition H+-ATPase enzyme get activated and release H+ in rhizosphere in consequence to maintain eletroneurality in rhizosphere a citrate is released in rhizosphere, that chelates the Fe from iron hydroxides as Fe citrate. This compound is taken up by the plant and Fe3+ is reduced in plasma membrane to Fe2+ and citrate is released in rhizosphere for further chelation.

Microbial Dynamics in rhizosphere

Microbial population decreases with increasing distance from the root surface. A maximum population of microbes is found in the rhizoplane (root soil interface). Microbial population decreases rapidly thereafter. A sharp fall in microbial population is observed in inner rhizosphere and a gradual fall in the outer rhizosphere.

The interactions of plant species, the chemical nature of root exudates, soil properties, and many other factors with the unique ecological niche in rhizosphere shapes the structure of bacterial community [20]. Rhizosphere bacterial communities differ across plant species, soil type, and root architecture and growth stage of plant. Root physiology, and the quality and quantity of root exudates is dependent on plant growth stage. The changes in root exudates composition, quality and quantity selects different root associated microorganisms at different growth stages. The detrimental microbes affect plant health, where as beneficial rhizosphere microbes help plants with by releasing mineral nutrients, phytohormones, and protect the plant against phytopathogens.

Li *et al* (2014)[21] showed that in maize rhizosphere of organic matter rich soil, population of copiotrophic microbes is prevalent in early stages of crop growth whereas oligotrophic microbes dominates in the later stages of crop growth. Dominace of Massilia in early stages of crop growth is due to higher availability of carbon, whereas Sphingobium dominates in the later stages due to its ability to decompose lignin derived aromatic compounds and Chitinophaga dominates in the later stages due to its ability to decompose chitin. Population of Burkholderia increased significantly in the later stages as they had the ability to utilize root metabolites, degrade aromatic compounds and produce antimicrobial substance. Population of Rhizobium was always low as maize is a cereal plant, nodulation and nitrogen fixation is not required.

Rhizosphere priming and C mineralisation

The newly applied plant residue can either stimulate or retard decomposition rate of soil humus. The change in decomposition rate is described as priming and is generally positive.

Mechanisms of rhizosphere priming

1.Drying effect or drying and wetting hypothesis: Drying and rewetting cycles enhances SOM decomposition in cultivated top soil than unplanted soil.

2.Aggregate destruction hypothesis: Growing roots break down aggregates thereby causing exposure of SOM to microbial action and increase SOM decomposition [22].

3.Root uptake of soluble organic substances: Microbial activity is reduced in rhizosphere when roots uptake released exudates in significant amount, C source is also reduced as a result SOM decomposition also decreases [22].

4.Enhancing microbial turnover rate due to faunal grazing: Microorganism predation by fauna in rhizosphere increases mineralised N and CO_2 release.

5.Competition for N mineralisation between plant root and rhizosphere microorganism: Plant root uptake N causing a deficiency of N for microbes in rhizosphere, thereby, declining microbial growth and metabolism as well as soil organic matter decomposition.

6.Preferred substrate utilisation: Root exudates and soil organic matter vary in availability to microbes. They first take up easily available root exudates followed by SOM. So, SOM decomposition rate is low at the initial stages [23].

7.Microbial activation: By easily available substrates.

An increase in rhizodeposition enhances the population of strategist microorganisms, they have a high reproduction rate. For this they need C and energy that comes from oxidation of SOM releasing CO_2.

Phosphorus mobilisation and acquisition

Phosphorus solubilizing capacity of microbes is related to release of metabolites such as organic acids, which through their hydroxyl and carboxyl groups chelate the cation bound to phosphate, and soluble phosphorus released in soil [24]. Inorganic P solubilisation is carried out by PSB through the action of organic and inorganic acids, in which hydroxyl and carboxyl groups of acids chelate cations (Al, Fe, Ca) and decrease the pH of basic soils. Organic P mineralization is car ried out by the action of several phosphatases (also called phosphohydrolases) [25].

Inorganic P

Phosphorus, the second most important element, faces a problem of fixation and largely of precipitation. P is mobilised by microbes through by a) chelation b) acid action c) release of CO_2.

Chelation

We know from different study that phosphate solubilised by the combined effect of pH decrease and organic acids production [26].PSB produces carboxylic acids which have high affinity to calcium, and is able to solubilize more phosphorus than acidification alone. Organic anions and associated protons are also effective in solubilizing precipitated forms of soil P (e.g. Fe - and Al - P in acid soils, Ca - P in alkaline soils) through chelation of metal ions and facilitate the release of adsorbed P through ligand exchange reactions (Jones, 1998) [9] showed that phosphorus de-sorption potential of different carboxylic anions lowers with decrease in stability constants of Fe - or Al - organic acid complexes (log KAl or log KFe) in the order: citrate >oxalate >malonate / malate >tartrate > lactate >gluconate>acetate >formiate .

Acid action

Oxidation of nitrogenous and inorganic S compounds produces inorganic acids like nitric acids and sulphuric acids, which react with rock phosphate and increase soluble P.

Microbial release of CO_2

In calcareous soil P solubility is governed by CO_2 production by microbes established the equation $\log H_2PO_4 - \log Pco_2 = -9.23 + pH$, which implies that at any given pH Increase in concentration of CO_2 will also increase the solubility of H_2PO_4 by decreasing the activity of Ca2+ in soil by formation of $CaCO_3$ showed that in rhizosphere of wheat, lentil, and chickpea, intercrop wheat-chickpea and intercrop wheat-lentil than bulk soil due to the higher activity of microbes and subsequent release of CO_2.

Organic P

Organic matter decomposition in soil is carried out by numerous saprophytes, which influence the release of orthophosphate from the carbon structure of the molecule. The degradability of organic phosphorous compounds depends mainly on the physicochemical and biochemical properties of their molecules, *e.g.* nucleic acids, phospholipids, and sugar phosphates are easily broken down, but phytic acid, polyphosphates, and phosphonates are decomposed more slowly [27]. The dephosphorylating reactions involve the hydrolysis of phosphoester or phosphor anhydride bonds.

The phosphohydrolases are two typesin acidic or alkaline. The acid phosphohydrolases, unlike alkaline phosphatases, show optimal catalytic activity at acidic to neutral pH values. Release of acid phosphatase by plant roots or microbes [28].

When nitrogen is applied in soil in ammonium form it has 4 fates: a) plant uptake b) transformation to organic form c) fixation to clay d) nitrification where valency of N changes from -3 to +3 by activity of Nitrosomonas and then to +5 by the activity of Nitrobacter through formation of NO_2- and NO_3- respectively through the intermediate of hyponitrite. Nitrate thus formed also have 3 fates: a) plant up-take b) leaching c) denitrification to N_2 or N_2O by the activity of *Pseudomonas*, *Bacillus* etc. N_2O is responsible for global warming and N_2 is fixed by *Rhizobium*.

S transformation in rhizosphere:Fe solubilization in rhizosphere

Fe in rhizosphere is solubilised by three mechanism

(i)Acidification through proton extrusion and organic acid secretion

(ii)Chelation through secretion of complexing molecules with variable affinity for iron (phytosiderophores, siderophores, phenolics, and carboxylic acids), and

(iii) Reduction through secretion of compounds characterized by reducing properties or through the expression of a membrane bound reductase activity.

On the basis of mechanism utilised by plants, they are classified in two groups

Strategy Iplant: In this type of plants Fe (III) is solubilised usually by rhizosphere acidification, followed by complexation with chelating compounds and subsequent reduction of Fe(III) to Fe(II) which plant takes up by the roots through a transporter that have high affinity for Fe(II) [29]. Under Fe stress condition the plasmalemma H+-ATPase is activated and rhizosphere is acidified followed by a concomitant release of phenolic acids and carboxylates for Fe (III) complexation and also for Fe(III) reduction in the rhizosphere[30]. Dicotyledonous plants and non gramineceous monocotyledons are typical example of this group.

Strategy II plant: Under Fe deficient condition, gramineceous plants release large amounts of non proteinaceous amino acids i.e. phytosiderophores predominantly from sub apical root zones [31], which have the capacity to chelate effectively Fe(III) [32].

The Fe(III)-PS chelates are stableat high soil-pH levels >7 [33].As a result of high-affinity of PS for Fe(III) to form complexes chelation with Ca^{2}+, Mg^{2}+, and Al^{3}+ is minimized [34]. However, recent studies have showed that sulphate supply increases phytosiderophores mediated Fe uptake [35] but phosphate applied as fertilizers at high rates may inhibit PS-promoted Fe(III) dissolution, mainly by displacement of PS from the surface of Fe hydroxides. Grasses are typical example of this group.

Metal solubility in rhizosphere

Metal solubility in rhizosphere have been attributed to three mechanisms

(1) Adsorption of metals by roots and subsequent translocation of metal from roots to the shoots [37].

(2) Increasing availability of metals in the rhizosphere resulting from modification of pH, redox potential, and release of organic acids and/or chelation by roots[38]; and

(3) Foraging of metals by the roots, involving preferential allocation of root biomass into regions of metal enrichment [39].

Metal solubilisation by DOM

Dissolved Organic matter is a complex mixture of many molecules that passes through a 0.45-mm filter. They can strongly bind heavymetals such as Cu, Pb, Cd, Zn, and Ni, and play an important role in controlling heavy metal speciation in soil.DOC in soils may facilitate the release of adsorbed heavy metals from the solid phase to the soil solution as metal-DOC complexes [40].

Energy flow model:The energy flow web defines the food web structure in rhizosphere depicting population sizes (biomass) and feeding rates. The parameters used are population sizes, turnover rates, consumption rates, prey preferences, and energy conversion parameters. Using this concept, the food web equation is:

F = (DnatB+P)/easseprod).

Where F is the feeding rate (biomass time-1), Dnat is the specific death rate, or turnover rate (time-1) of the consumer, B (biomass) is the population size of the consumer, P is the death rate to predators (biomass time-1), and eass and eprod are the assimilation (%) and production (%) efficiencies, respectively.

Interaction web model: The interaction web describes the strengths of the interactions among the functional groups of organisms in rhizosphere. The interaction strength model employs two parameters related to biomass to predict interaction at any given time change in biomass (population) of one organism (prey or predator) and in the same time change in biomass (population) of another organism of interest. The interaction strengths are defined by the partial derivatives of the equations describing the growth and dynamics of the functional groups at or near equilibrium.

Strategies for rhizosphere managements

From the above discussions it is clear rhizosphere processes reflect integrated interactions among plants, soils, and microorganisms in both natural and managed ecosystems. So, the management of rhizosphere ecosystems and rhizosphere processes toward sustainable development of the plant soil system may be one of the most important approaches to enhance the utilization efficiency of nutrient resources and crop productivity in various cropping systems.

The concept of rhizosphere management can be described as manipulating and managing various components in the rhizosphere ecosystems a. manipulation of crop and cropping system b. manipulation of root system c. manipulation of rhizonutitional environment d. manipulation of microorganisms. We concentrate on some specific nutrient's management like C, N, P, S, Fe, and Zn. Rhizosphere priming effect on C and N: The fundamental theory underlying rhizosphere priming effects is not clear. But the positive rhizosphere priming effect on SOC decomposition has been more pronounced than the negative rhizosphere effect. One well accepted mechanism to explain the positive rhizosphere effect is that the root released available substrates encourages microbial growth in the rhizosphere which leads to release of extracellular enzymes that enhance decomposition of SOM.

Zhu *et al* (2014) [35] performed an experiment in a greenhouse at University of California, Santa Cruz. During the experimental period, they maintained a constant CO_2 concentration (400 ± 5 ppm) and δ13C value (-18.0 ± 0.5‰) inside the greenhouse by automatically adjusting the flow rate of CO_2 free air and pure CO_2 into the greenhouse including two soil types (farm soil and prairie soil), two plant species (soybean and sunflower) as well as with an unplanted control, and two destructive samplings (53 and 88 days after planting). They observed that both C and N mineralisation was higher in crop rhizosphere soil than bulk soil. On special remarks to C mineralisation which was significantly higher in sunflower rhizosphere irrespective of soil type and sampling time.

The reason may be that B. japonicum inside soybean root nodules can fix N from the atmosphere and reduce the N demand in the rhizosphere, consequently lessening N mining from soil organic matter [43] thereby, reducing soil organic matter decomposition. But in soybean sunflower there is no mechanism of such N fixation, so they depend on applied fertilizer and SOM bound N to meet their N demands. So, C mineralisation is higher in sunflower.

The gross nitrogen mineralisation rate was higher in rhizosphere soil than bulk soil. The reason may be that for assimilation of rootderived labile carbon substrates, rhizosphere microbe needs to take up inorganic nitrogen in a specified amount for synthesis of enzymes that would cause N mineralisation. But on depletion of soil mineral N, microbes produce extracellular enzymes that break down generallyusable organic N compounds [44]. Lastly different priming effect on C and N mineralisation was observed due to difference in rhizodeposition in different soils and sampling times as priming effect is positively correlated with amount of rhizo deposition [45].

Effect of rhizosphere acidification on Zn and Fe content in maize shoots in calcareous soil

Micronutrient availability in soil largely depends on type of soil and environmental factors, such as pH, redox potential and applied N sources [46], Especially zinc (Zn) and iron (Fe) deficiencies occur in alkaline and calcareous soils because high pH and high bicarbonate concentration reduce solubility of Zn and Fe in soil and their subsequent uptake.

Rhizosphere processes and root characteristics play an important role in mobilisation and acquisition of such micronutrients such as root induced changes in the rhizosphere pH and root exudates release Root characteristics can be improved by banding of phosphorus and ammonium fertilizer that enhance root proliferation and modify root spatial distribution. An experiment was performed in calcareous soil of china with maize crop where they use three treatments each.

for two years (1) localized supply of superphosphate as starter fertilizer at sowing and as side dressing at jointing (P), (2) localized supply of urea plus superphosphate as starter fertilizer at sowing and as side dressing at the jointing stage (urea + P) and (3) localized supply of ammonium nitrogen (as ammonium sulphate) plus superphosphate as starter fertilizer at sowing and as side-dressing at jointing (NH_4-N + P).

The figure suggests that the localized NH_4-N + P treatment had a significant effect on Zn and Fe accumulation in shoot at different stages. The Zn and Fe contents significantly increased in plants in the localized NH_4-N + P compared with the localized P and urea + P treatments at seedling (39 or 35 DAS), flowering (73 or 75 DAS) and grain harvest (140 or 145 DAS). The cause may be the proton excretion from ammonium-fed plants into the cell wall (apoplast) and the rhizosphere, reducing pH, stimulation of root branching due to localized ammonium supply. They hypothesized the mechanisms driving the accelerated uptake of Fe and Zn under localized NH_4-N + P supply: (1) Urea on hydrolysis produces HCO_3- and increase pH of microrhizosphere, reducing solubility of Fe and Zn whereas localized application of acid-forming N fertilizer, such as ammonium sulphate, enhanced availability of Zn and Fe to plants by affecting the cation/anion uptake ratio and reducing the rhizosphere pH in calcareous soils. (2) Stimulation of root Zn and Fe uptake may be due to improved N status and growth potential of maize [49], and (3) Due to localised application of N lateral root proliferation of plants increases their capacity to acquire nutrients from nutrient-rich patches [48]. They also hypothesized that auxin a plant hormone plays a significant role in cell division and elongation, and Zn deficiency affects auxin synthesis in plants [47]. But increased Zn availability and accumulation in shoot in the localized NH_4-N + P treatment may lead to increase auxin synthesis, resulting in lateral root proliferation in the nutrient rich zone.

Conclusion

Throughout the discussion we have discussed various area of rhizosphere biology that interplay with soil, plant, and biological factors and we also have presented ideas on management of the rhizosphere to improve plant growth. Achieving high nutrient use efficiency, high crop productivity and environmental risk management has become major challenge in intensive agriculture. The principle of rhizosphere management is to manipulate the main components of rhizosphere processes efficiently, which include manipulation of root system, rhizosphere acidification, carboxylate exudation, microbial associations with plants, rhizosphere interactions in intercropping, localized application of nutrients, and use of crop genotypes efficient in nutrient acquisition. Future work should focus on 1.Further investigation of rhizosphere processes related to crop nutritional enhancement at the molecular, cellular, individual, and ecosystem levels, and development of the integrated rhizosphere management in combination with best crop soil management to achieve sustainable agriculture with high nutrient use efficiency, high crop productivity, and reduced resource inputs and minimal environmental impact.2.Characterizing the unidentified root exudates of many crops in rhizosphere and their role in nutrient mobilisation.

Application of review: Finding the direct effect of nutrient interaction on phytosiderophores and mycorrhiza. Identifying and characterizing major fungal group and bacterial group present in rhizosphere of different crops and their role in nutrient acquisition. Developing a model integrating soil C, soil property, soil microbes, climatic parameter

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