Rhizosphere Chemistry in Association with Plant Nutrition

Ajit Kumar Meena[1], Premlata Meena[2], R.S. Meena[3] and Subhash Yadav[4]

[1]Department of Soil Science & Agriculrural Chemistry, RCA, MPUAT, Udaipur-313001(Raj.)
[2]Division of Soil Science & Agriculrural Chemistry, ICAR-IARI, New Delhi-110012
[3]ICAR-NBSS & LUP, Regional Centre, Udaipur-313001 (Raj.)
[4]Department of Animal Production , RCA, MPUAT, Udaipur-313001(Raj.)

ARTICLE ID: 50

Introduction

In agro environments, the rhizosphere is the contact between roots and soil where nutrient absorption for plant growth is enhanced. The soil–root interface, also known as the rhizosphere, was defined by Lorenz Hiltner in 1904 as the volume of soil around the roots that is modified by root activity. The rhizosphere effect is defined as the promotion of microbial development at the root surface in the soil, as well as plant interactions with beneficial or pathogenic microbes, and its possible implications for nutrient cycling in soils, plant nutrition, and plant health. The production of easily decomposable root exudates is primarily responsible for the stimulation of microbial activity and density in the rhizosphere.

Plant roots can modify the rhizosphere chemistry in a number of ways:

1. By release and uptake of organic compounds.
2. By gas exchange (CO_2/O_2) related with respiration of roots and rhizosphere microorganisms.
3. By root uptake as well as release of water and nutrients, which may be associated with uptake or extrusion of protons and modifications of the redox potential.

Spatial Extent of the Rhizosphere

The size of the rhizosphere varies greatly across time and space. Gradients can be found in both a radial direction toward the bulk soil and a longitudinal one along the roots.

Radial Gradients- Radial Gradients are a type of radial gradient. Nutrient solubility and mobility, as well as root absorption capability, determine the radial gradients of nutrients in the rhizosphere. Because nutrient intake is intimately linked to proton uptake or release, root-induced variations in rhizosphere pH are frequently observed.

Longitudinal Gradients: Gradients arise between the apical root zones and the older, more basal sections of the root along single roots. Root hairs improve the surface area accessible for nutrient absorption and may also contribute to an increase in protons and organic chemicals released in this zone.

Inorganic Elements in the Rhizosphere

Despite the fact that total soil nutrient concentration frequently exceeds plant requirements by several orders of magnitude, low solubility of nutrients such as P, K, ammonium, Fe, Zn, Mn, Cu, and Mo limits plant availability. As a result, these nutrients primarily reach the root surface via diffusion. The solubility of seldom available nutrients is improved by modifying the rhizosphere chemistry.

Rhizosphere pH

The intake of nutrients, which is associated with proton transport in higher plants, is the most essential determinant for root-induced variations in rhizosphere pH. H+ extrusion, mediated by the action of a plasma membrane-bound H^+ pumping ATPase (PM-ATPse), drives nutrient absorption by root cells by creating an outward positive electro potential and pH gradient between the cytosol (pH 7–7.5) and the rhizosphere (pH 5–6). Soil pH buffering ability is largely determined by starting pH and organic matter content, but clay content also plays a role. Protons may displace other cations from the soil's cation exchange sites, affecting nutrient mobilization and immobilization (Hinsinger et al., 2009).

Excess anions over cations, net uptake of protons, and hence an increase in rhizosphere pH results from nitrate uptake. Furthermore, nitrate absorption in the root tissue is linked to the formation of OH^-, suggesting that OH^- release into the rhizosphere for intracellular pH stabilization may contribute to rhizosphere alkalinization to some extent. In acid soils, nitrate input increases P absorption by either exchanging phosphate adsorbed to Fe and Al with HCO3- or stimulating microbial P mineralization. Rhizosphere alkalization may also help plants cope with the detrimental effects of soil acidity by increasing the availability of Ca and Mg while lowering the concentration of poisonous Al species in the rhizosphere soil.

Effects of pH on Nutrient Uptake

Changes in rhizosphere pH not only affect nutrient solubility in soils, but also nutrient uptake. Generally, cation uptake decreases with declining pH, nutrient solubility in soils. Gerally, cation uptake decreases with declining pH, whereas anion uptake is inhibited when the pH of the external medium increases. This can be attributed to:

1. Competition between H^+ and OH^- ($HCO3^-$) with cations or anions.
2. External pH effects on the electrochemical potential gradient providing energy supply for nutrient uptake. Excess anions over cations, net uptake of protons, and hence an increase in rhizosphere pH result from nitrate uptake. Furthermore, nitrate absorption in the root tissue is linked to the formation of OH^-, suggesting that OH^- release into the rhizosphere for intracellular pH stabilization may contribute to rhizosphere alkalinization to some extent. In acid soils, nitrate input increases P absorption by either exchanging phosphate adsorbed to Fe and Al with HCO_3^- or stimulating microbial P mineralization. Rhizosphere alkalization may also help plants cope with the detrimental effects of soil acidity by increasing the availability of Ca and Mg while lowering the concentration of poisonous Al species in the rhizosphere soil.
3. pH-induced alterations of root metabolism. However, positive pH effects on nutrient availability may counteract negative pH effects on nutrient uptake.

Redox Potential and Reducing Processes

A drop in redox potential is linked to a variety of changes in nutrient solubility. Low-molecular-weight organic acids, as well as Fe2+, Mn2+, and H2S, can accumulate in phytotoxic amounts as a result of microbial fermentation activities.

Mn Mobilization: Rhizosphere microbe activity is important for plant Mn feeding because microorganisms can mediate Mn immobilization in soils through oxidation processes as well as Mn solubilization through Mn reduction.

Fe Mobilization: Expression of a PM-bound reductase oxidase system with a low pH increases the reductive capability. Rhizosphere acidification, which is caused by increased production of PM H+- ATPase in the sub-apical root zones, further activates the PM reductase-oxidase. The remobilization of Fe precipitated on the root surface and in the rhizosphere has been linked to phenolic chemicals produced from Fe-deficient plant roots.

- **Root Exudates:** High-Molecular-Weight Compounds
- **Mucilage and Mucigel:** Mucilage-mediated intimate contact between soil particles and root surface can be critical for nutrient uptake. This is especially true for micronutrients and P. In dry soils, higher soil mechanical impedance can stimulate

mucilage secretion, which helps to maintain Zn2+ intake by enabling Zn2+ transport from embedded soil particles to the root surface. Mucilage may also help to keep hazardous materials like aluminium and heavy metals out.

- **Secretory Proteins:** Plant roots release a wide range of proteins including various enzymes. A wide range of enzyme activities involved in the hydrolysis of organic P esters, such as phytase, nuclease, pyrophosphatase, apyrase and alkaline phosphatise, have been detected in the rhizosphere. In some plant species, root secretion of carboxylates, such as oxalate and citrate, may enhance the solubility of organic P forms, making them available for hydrolysis by phosphohydrolases in the rhizosphere.
- **Low molecular weight Root Exudates**: Sugars, organic acid anions, amino acids, and different phenolics are among the major components of low molecular weight chemicals found in root exudates. Transporters mediate uptake, which includes an active mechanism including H+ co-transport. When there is a shortage of nitrogen, amino acid and peptide transporters are frequently over expressed. Solubilization and chelation of metal cations allows organic acid anions to mobilise sparingly accessible P adsorbed to Fe and Al oxides/hydrxides or as Fe, Al, and Ca phosphates. PS mobilise Fe3+, as well as other micronutrients like Zn, Mn, and Cu, in the rhizosphere by forming stable complexes, even at high soil pH.

Summary

The activity of plant roots influences the physicochemical processes of rhizosphere soil, as well as the repercussions for plant nutrition. The physiological mechanisms that determine root-induced changes in pH and redox conditions in the rhizosphere are explored in light of the implications for nutrient solubility and plant availability in soils, as well as the impact on plant–microbe interactions.

References

Clarkson D.T. (1991). Root structure and sites of ion uptake. In Plant Roots – The Hidden Half. pp. 417–453.

Gahoonia T.S. and Nielsen N.E. (1992). The effects of root-induced pH changes on the depletion of inorganic and organic phosphorus in the rhizosphere. *Plant Soil*. **143**:185–191.

Gregory P.J. (2006b). Roots, rhizosphere, and soil: the route to a better understanding of soil science. *European. Journal of Soil Science*. **57**:2–12.

Hinsinger P., Bengough A.G., Vetterlein D. and Young, I.M. (2009). Rhizosphere: biophysics, biogeochemistry and ecological relevance. *Plant Soil.* **32**:117–152.

Hinsinger P., Gobran G.R., Gregory P.J. and Wenzel W.W. (2005). Rhizosphere geometry and heterogeneity arising from root-mediated physical and chemical processes. *New Phytol.* **168**: 293–303.

Holden M.J., Luster D.G., Chaney R.L., Buckhout T.J. and Robinson C. (1991). Fe_3+chelate reductase activity of plasma membranes isolated from tomato (Lycopersicon esculentum Mill.) roots. Plant Physiology. **97**:537–544.

Jin C.W., You G.Y., He Y.F., Tang C., Wu P. and Zheng S.J. (2007). Iron deficiency-induced secretion of phenolics facilitates the reutilization of root apoplastic iron in red clover. *Plant Physiology.* **144**:278–285

Neumann G., George T.S. and Plassard C. (2009). Strategies and methods for studying the rhizosphere – the plant science toolbox. Plant Soil. **321**: 431–456.