



5th International Symposium ISMOM 2008 - November 24th - 28th, 2008 - Pucón, Chile

Plenary papers

Soil Physicochemical and Biological Interfacial Interactions in the Rhizosphere: Impacts on Food Security and Ecosystem Integrity

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Introduction

The soil root interface (the rhizosphere) plays a vital role in sustaining life in the terrestrial ecosystem in the Earth's Critical Zone (CZ). The CZ is defined as the volume extending from the upper limit of vegetation down to the lower limit of groundwater (Anderson et al., 2004).

The CZ is the system of coupled chemical, biological, physical, and geological processes operating together to support life at the Earth's surface (Brantley et al., 2007). While our understanding of this zone has increased over the last hundred years, further advance requires scientists to cross disciplines and scales to integrate understanding of processes in the CZ, ranging in scale from the mineral-organic matter-organism-water-air interfaces at a molecular level to the globe. Soil is the central organizer in the CZ. The rhizosphere is a hot spot of activity within soils.

The rhizosphere is the 'bottle neck' of the supply of vital elements to sustain ecosystem productivity and integrity and food security. The rhizosphere is also the 'bottle neck' of the contamination of the terrestrial food chain by inorganic and organic pollutants to endanger human and animal health.

Physical, Chemical and Biological Interactions at the Soil-Root-Biota Interfaces

Solid-liquid interface character should vary substantially with lithology, climate, vegetation, below-ground biota, landscape position, time, and anthropogenic activities. The rhizosphere should greatly influence solid-liquid interface character and, thus, the nature and properties of their reactive surfaces. In the rhizosphere, the kinds and concentrations of substrates are different from those in the bulk soil because of root exudation. This leads to colonization by different populations of bacteria, fungi, protozoa, and nematodes. The plant-microbe interactions result in intense biological processes in the rhizosphere. These interactions, in turn, affect physicochemical reactions in the rhizosphere. Physicochemical properties that can be different in the rhizosphere include: acidity, concentration of complexing biomolecules, redox potential, ionic strength, nutrient status, enzyme activity, bulk density and porosity, and moisture.

These differences in soil physicochemical properties would, in turn, influence biological processes in the rhizosphere (Huang and Germida, 2002; Huang, 2008). The total rhizosphere environment is governed by an interactive trinity of the soil, the plant, and the organics associated with the roots. The reactions and processes in the rhizosphere can only be understood satisfactorily with interdisciplinary approaches. The impacts of physicochemical and biological interfacial interactions on food security and ecosystem integrity, thus, merit serious attention.



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Rhizosphere Interfacial Interactions and Food Security

The rhizosphere chemistry, biology, and physics and their interactions at the molecular level are of fundamental and practical importance in sustaining food security. The rhizosphere is the “bottle neck” of the supply of nutrients and the ecotoxicological effect of inorganic and organic contaminants to plants. Therefore, the impacts of the rhizosphere on plant health and crop production is a critical issue in feeding the world population. 30% of farmers in developing countries are food-insecure. Some of the most profound and direct impacts of climate change over the next few decades will be on agricultural and food systems (Brown and Funk, 2008).

Therefore, food insecurity is likely to increase under climate change, unless early warning systems and development programs are used more effectively. Managing world soils for food security and environmental quality (Lal, 2001) is an extremely important mission of soil scientists. Transform agricultural systems through improved seed, cropping system, fertilizer, land use, and governance, and food security may be attained by all (Brown and Funk, 2008; Lobell et al., 2008). In this context, rhizosphere management deserves close attention in sustaining and enhancing soil productivity and crop production.

Impacts of Rhizosphere Interfacial Interactions and Ecosystem Integrity

- Carbon Transformation, Storage, Emission, and Climate Change

The CO₂ emission from the soil to the atmosphere is the primary mechanism of soil C loss. Agricultural practices contribute about 25% of total anthropogenic CO₂ emission. Soil minerals control carbon storage and turnover (Torn et al., 1997; Davidson and Janssens, 2006). Respiration by plant roots contribute about half of CO₂ emitted from the soil. The rhizosphere significantly controls SOM decomposition (Cheng and Kuzyakov, 2005). Given abundant mineral nutrient supply, soil microbes prefer labile root-derived C to SOM-derived C, resulting in a decreased SOM decomposition in the rhizosphere. If mineral nutrients are in short supply, soil microbes prefer nutrient-rich SOM to root-derived C, resulting in increased SOM decomposition in the rhizosphere. Root effects on the rate of SOM decomposition can range from negative 70% to as high as 33% above the unplanted control.

- Formation and Transformation of Nanoparticles and Ecosystem Health

Nanoparticles are discrete nanometer (10⁻⁹ m) scale assemblies of atoms. A significant fraction of atoms are exposed on surfaces rather than contained in the particle interior of nanoparticles (ca. 1-100 nm). The biogeochemical and ecological impacts of nanomaterials are some of the fastest growing areas of research today, with not only vital scientific but also large environmental, economic, and political consequences (Wigginton et al., 2007). Most biominerals generated by microorganisms are nanominerals. Therefore, microbial processes play an important role in nanoparticle formation and fate. Little is known on nanoparticles in the rhizosphere. Formation, transformation, and fate of nanoparticles in the rhizosphere and the impacts on food security and safety and ecosystem health merit increasing attention.



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- Transformation of Metals, Metalloids, and Xenobiotics and Food Safety

The interactions at physical-chemical-biological interfaces govern the kinetics and mechanisms of transformation, speciation, transport, bioavailability, toxicity, and fate of metals and metalloids in soil and related environments (Huang, 2008). Fundamental understanding of soil physical, chemical, and biological interfacial interactions at the atomic and molecular levels is essential to understanding the behavior of metals and metalloids in the pedosphere and restoring terrestrial ecosystem health on the global scale. We are still at the eve of fully understanding the processes controlling the mobility and bioavailability of metals and metalloids at the soil-root interface (Hinsinger and Courchesne, 2008). Unraveling the biogeochemistry of trace elements in the rhizosphere and the impact on food safety and ecosystem health is both a challenge and an opportunity for soil and environmental scientists for years to come. The multiple interactions between microorganisms and soil which take place at the soil-root interface can have a dramatic impact on anthropogenic organic pollutants in the terrestrial environment (Anderson et al., 2002). The characteristics of the rhizosphere allow for a unique environment which encourages biotic and abiotic interactions in greater magnitude and diversity than in bulk nonvegetated soil. These interactions generally resulted in the decrease in the toxicity of organic contaminants through increased degradation and decreased availability of these contaminants. As the importance of bioavailability has increased in regulatory decision making, a greater understanding of the plant, soil, and managing factors affecting the bioavailability of contaminants is warranted.

- Ecotoxicological Problems

Ecotoxicology is defined as “the study of fate and effect of toxic agents in ecosystem”. Ecotoxicology research deals with the interactions among organisms, toxic agents (in this case metals and metalloids), and the environment. Long-term ecological effects of metals and metalloids introduced to soils remains to be investigated, as only a few such experiments exist. Even less is known about the adverse long-term effects of metals and metalloids on soil microorganisms (McGrath et al., 1995; Huang, 2008.)

- Biodiversity

The functioning and stability of the terrestrial ecosystem are determined by plant biodiversity and species composition (Tilman et al., 1996). Above and below ground communities can be powerful mutual drivers, with both positive and negative feedback (Wardle et al., 2004). Above- and belowground components are closely interlinked at the community level, reinforced by a greater degree of specificity between plants and soil organisms. The impact of soil physicochemical and biological interfacial interactions in the rhizosphere on belowground biodiversity remains to be uncovered.

- Geomedical Problem and Human Health

Geomedicine is the science dealing with the environmental factors that influence the geographical distribution of pathological and nutritional problems relating to human and animal health (Låg, 1980). Knowledge of soil science is indispensable for solution to many geomedical problems (Låg, 1994). The effects of soil physical, chemical, and biological interfacial interactions in the rhizosphere on quality of vegetation and the food and feed



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produced and related geomedical problems warrant in-depth research (Huang, 2008). The transformation and bioavailability of trace elements are profoundly influenced by soil physical, chemical, and biological interfacial interactions in the rhizosphere (Huang and Gobran, 2005). Many trace elements are of concern to animal nutrition and human health. These include Se, Fe, I, Zn, Cu, Mn, Mo, Cr, F, Co, Si, V, Ni, As, and Mg. It is essential to promote research on the relationship between soil physicochemical-biological interfacial interactions, especially in the rhizosphere and the impacts on the transformation, transport, and toxicity, and fate of trace elements in the terrestrial environment. This would facilitate fundamental understanding of the linkage of trace elements in soils with plant-animal-human-environmental systems and related geomedical problems. This is essential to provide practical solutions to their deficiency and toxicity problems.

Significance of Rhizospheric Interfacial Interactions in Risk Assessment and Restoration of Ecosystem Integrity

Regulatory-driven risk assessment and management are essential in restoration of ecosystem integrity. Assessing exposure to contaminants in soil environments includes determination of the pathways to human exposure. The cleanup of soils polluted by hazardous contaminants has become a matter of urgent concern. Physical, chemical, and biological interfacial interactions in the rhizosphere play a significant role in the natural remediation and restoration of the terrestrial ecosystem. Bioremediation, phytoremediation, and chemical remediation have been commonly used in land management practices.

Combined biotic and abiotic remediation would enhance remediation efficiency. The impact of physical, chemical, and biological interfacial interactions in the rhizosphere on risk assessment and management of contaminants and restoration of ecosystem integrity merits increasing attention.

Conclusions and Future Prospects

Soil is the most diverse ecosystem and most important terrestrial resource in sustaining life in the Earth's CZ. Soil physical, chemical, and biological interfacial interactions in the rhizosphere play a vital role in carbon cycling and climate change, the formation and transformation of environmental nanoparticles, the fate of nutrients, metals, metalloids, and xenobiotics, ecotoxicological problems, biodiversity, and geomedicine. Fundamental understanding of soil physical, chemical, and biological interfacial interactions in the rhizosphere at the molecular level is essential for developing innovative strategies for land resource management to sustain food security and ecosystem integrity. Future research on this extremely challenging and important area of science should be stimulated to sustain and enhance ecosystem productivity, services, and integrity in the Earth's CZ and the human welfare.

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