Global Soils: Germany

New Developments in Rhizosphere Research

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The rhizosphere is the soil compartment with the highest metabolic activity and fluxes of matter. It is defined as the small volume of soil directly adjacent to the root and being heavily influenced by root growth and metabolism. Plants and microbes interact and stimulate each other in this narrow compartment by emitting exudates and signal substances. Herewith they generate a micro-environment with optimal conditions for root performance, but also for bacterial growth and substrate turnover. Considering that the total root length of a putative crop plant (e.g. barley) might be several hundred meters long, the rhizosphere might be a narrow, but by no means a small compartment of the soil. The efficiency of the root system to explore the soil for nutrients and water is even more enlarged by the widely occurring symbiosis of roots with fungi in the ecto- and endomycorrhizae. Albeit of such importance, the root zone was not regarded as major focus of plant and soil research in the last decades. Book titles referring to 'The hidden half' (Plant roots. The hidden half, by Waisel Y, Eshel A and Kafafi U, 2002) spot the problem of this lack of results on the rhizosphere. Today we know, that any environmental impact will result in a chain of feedback reactions in the whole plant, including the coordinated interaction between above- and below-ground plant components, by that affecting the root zone.

The conditions in the rhizosphere soil reflect processes that are induced by root uptake of nutrients and water as well as by exudation and proliferation of cells. Conversely, the rhizospheric processes exert feed back to the development of the whole plant.

Concepts for sustainable soil use require a sound data base on these fluxes to evaluate the functional performance of sites and regions. Consequently, rhizosphere research is implicitly confronted with the challenge to connect information obtained at various scales.

Roots affect their environment by a highly selective uptake of water and minerals and by releasing various chemical compounds. From a physico-chemical point of view, these influxes at the root surface will create ion-specific gradients. The exudation of large amounts of organic compounds of different chemical characteristics creates a milieu inducing subsequent physical, chemical and microbial feedback reactions in the rhizosphere soil.

Although our analytical possibilities have considerably improved during recent years, measurements in the rhizosphere are mostly restricted to the qualitative descriptions of metabolites and inhabitants. Quantitative investigations of matter fluxes and simultaneous measurement of the underlying driving forces are mostly lacking, although they would be pre-requisite for a sound process analysis.

Root-induced changes in the rhizosphere soil may be continuously superimposed by various processes determined by the plant as such, i.e. species specific rooting pattern or nutrient uptake. These processes are characterized by a huge heterogeneity in space and time and heavily determined by the soil type. Therefore, one of the major scopes for future research is the scaling-up from individual rhizosphere processes to whole plant development under field or canopy conditions. Rhizosphere models (of single roots) and nutrient uptake models of the whole rooting system and plant seem to be not appropriately related at all. Most of the water and nutrient uptake models regard nutrient uptake as a passive process, treating the root as a 'wick' and computing nutrient uptake fluxes from the product of water flux density and soil solution concentration within a predefined small root zone volume.

Various patterns of water and nutrient flow as induced by precipitation events, irrigation or fertilizer treatment will provide increased access of dissolved nutrients to roots and create gradients, whereas small water flow velocities in the bulk soil will tend to create more steep gradients around the roots.

Over the last decades, one of the main problems of rhizosphere research was the failure to cultivate the majority of soil and rhizosphere bacteria. With modern molecular genetic techniques, including PCR-analysis and cloning techniques using the availability of information on 16S rRNA, it is possible to identify even non-culturable bacterial populations in the soil. Novel data indicate that structure and abundance of these populations are dependent both on the plant and the soil type, but can be highly variable. The in-situ identification and localization of bacterial populations and their in situ activity can now be studied at single cell resolution using molecular probing and tagging techniques with, e.g. green fluorescent protein and bioimaging supported confocal laser scanning microscopy. In the postgenome aera, both the plant as well as particular rhizosphere bacterial populations can be studied at the transcriptome and proteome level which certainly opens new horizons for a more mechanistic understanding of microbe-plant and soil-plant interactions. Of particular importance is the possibility of biological control of phytopathogenic microbes by competing microbes in the rhizosphere and the induction of systemic resistance against pathogens by the interaction with certain non-pathogenic bacteria in the rhizosphere.

Finally, highly resolving analytical techniques have elucidated that distinct metabolic profiles exist in the rhizosphere dependent on the plant type. These findings will of course influence future agricultural practice as well as applications of green technologies such as phytoremediation.