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Current advancements and challenges in soil-root interactions modelling

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Roots change their surrounding soil chemically, physically and biologically. This includes changes in soil moisture and solute concentration, the exudation of organic substances into the rhizosphere, increased growth of soil microorganisms, or changes in soil structure. The fate of water and solutes in the root zone is highly determined by these root-soil interactions. Mathematical models of soil-root systems in combination with non-invasive techniques able to characterize root systems are a promising tool to understand and predict the behaviour of water and solutes in the root zone. With respect to different fields of applications, predictive mathematical models can contribute to the solution of optimal control problems in plant recourse efficiency. This may result in significant gains in productivity, efficiency and environmental sustainability in various land use activities.
Major challenges include the coupling of model parameters of the relevant processes with the surrounding environment such as temperature, nutrient concentration or soil water content. A further challenge is the mathematical description of the different spatial and temporal scales involved. This includes in particular the branched structures formed by root systems or the external mycelium of mycorrhizal fungi. Here, reducing complexity as well as bridging between spatial scales is required. Furthermore, the combination of experimental and mathematical techniques may advance the field enormously.
Here, the use of root system, soil and rhizosphere models is presented through a number of modelling case studies, including image based modelling of phosphate uptake by a root with hairs, model-based optimization of root architecture for phosphate uptake from soil, upscaling of rhizosphere models, modelling root growth in structured soil, and the effect of root hydraulic architecture on plant water uptake efficiency and drought resistance.