

An integration data-model study of the plant uptake process using a virtual 3D soil-root system

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Introduction

Plant uptake is an important factor in environmental exposure assessment for the authorization of plant protection products (PPPs). For a better mechanistic understanding, we present a novel process-based model as a virtual 3D soil-root system that simulates water flow, solute movement, plant root growth, and plant uptake. In the virtual system, the plant uptake process can be considered as an active process with Michaelis-Menten kinetics (for fertilizers) or a passive uptake (for PPPs) which is caused by the diffusion and leakage through the root membrane. In the case study, the virtual system was integrated with experimental data of rice plant uptake with different levels of Phosphate (P) fertilization and revealed in-depth mechanisms of the plant uptake.

Method

Rice was grown in large columns with P-deficient soil at three P levels in topsoil (NoP, SubP, PlusP) in the combination of two water regimes (field capacity (FC) versus drying periods (DC)).

- Phenological root parameters were collected (nodal root number, lateral types (S-type, L-type), interbranch distance, root diameters, root biomass allocation among soil layers).
- Water use and total P uptakes were determined.
- The soil hydraulic and sorption properties were measured.

The *in silico* experiments were setup using the multiscale 3D soil-root model developed by Mai et al. 2019.

- Using root model CRootBox (Schnepf et al. 2018) the 3D root systems were reconstructed by calibration with observed phenological root data.
- The water and solute transport in 3D soil-root system were simulated by solving the Richards equation and transport equation with Freundlich isotherm sorption.
- Plant uptake was described by Michaelis-Menten kinetics.
- The irrigation data were used as boundary conditions in the simulations



Figure 1: Rice root in the top soil

The *in silico* experiments

- The *in silico* experiments were carried out with exact soil and water conditions from the lab study.
- The simulation results were evaluated with the lab data for validation.
- Detail analysis was conducted to obtain a more mechanistic understanding of the uptake process of the plant root systems.

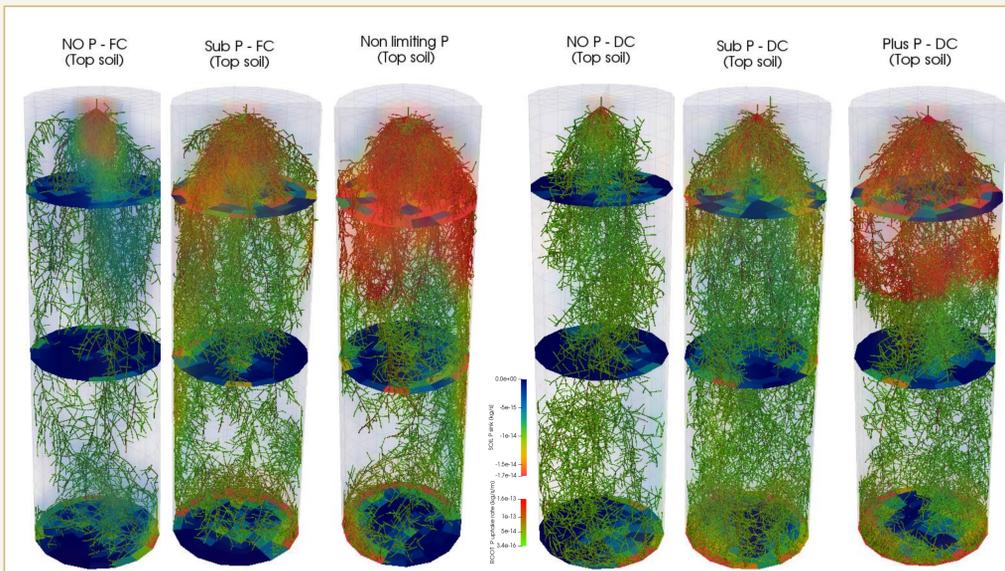


Figure 2: 3D simulations of water and P uptake of rice root systems under various P levels in soil and irrigation conditions

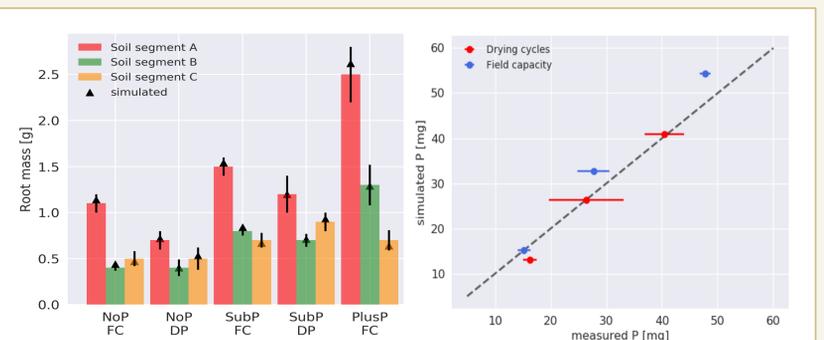


Figure 3: The fitness of root mass between reconstructed root systems and experimental data (left) and the comparison of P uptake from the *in silico* experiments with lab data (right).

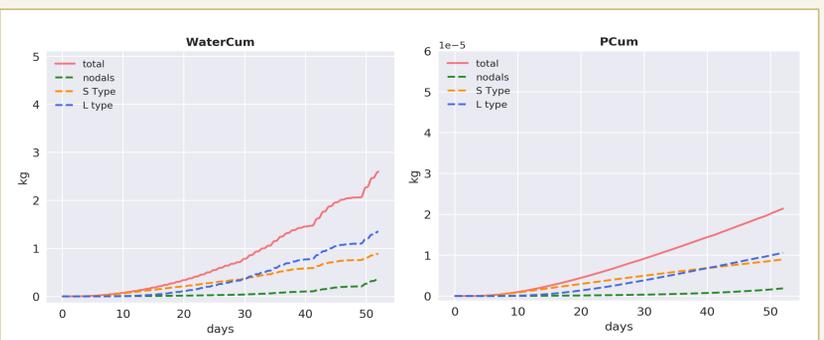


Figure 4: The contribution of lateral roots in total water (left) and P (right) uptake of rice plants. In non-stress conditions, the S-type roots contribute the most in the uptake. In contrast, the L type roots become an important role in water stress cycles condition

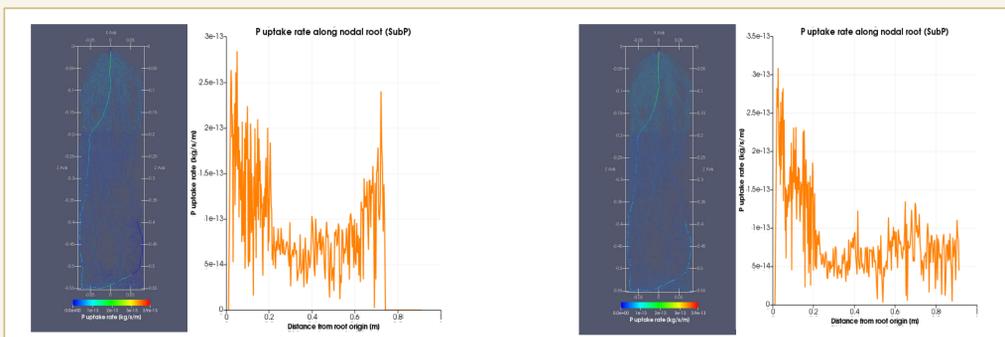


Figure 5: The uptake rate along a nodal root in growing (left) and well developed non-growing state (right). It shows that the root tips play an important role in the P uptake during the growth of the root system.

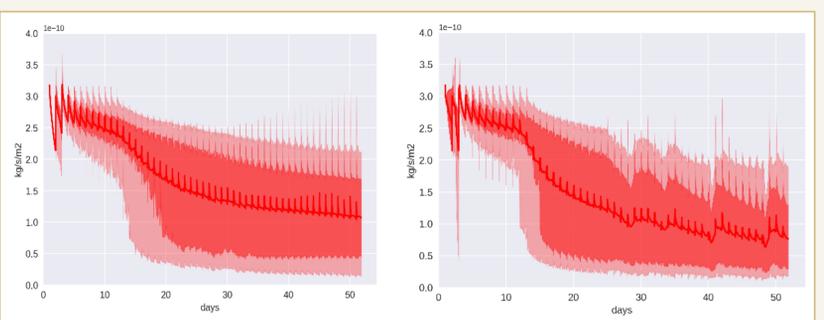


Figure 6: The mean, the band of 50 percentile and 90 percentile of uptake rate by root segments in field capacity (left) and water stress cycles (right). It reveals the strong effect of water stress cycles on the uptake process due to the reduction of effective diffusion in low water content conditions.

Results and Conclusions

- The data-integrated simulations predicted well the P uptakes and reflect the effect of water regime and P levels in soil on plant uptake.
- The simulations reveal the underlying mechanism in water uptake and solute uptake process of the root systems such as the important role of lateral roots, root tips which growing to explore soil resources.
- The virtual 3D soil-root system showed its capability to study plant uptake process virtually and enhance the mechanistic understanding, which cannot be discovered by experimental observation only.

References

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Schnepf, A. et al. (2018). CRootBox: a structural-functional modelling framework for root systems. *Annals of botany*, 121(5), 1033-1053.

* T. Mai was funded by the German Federal Ministry of Education and Research (BMBF) in the framework of the funding initiative "Soil as a Sustainable Resource for the Bioeconomy BonaRes".