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Modelling phosphate uptake by a growing oilseed rape root system as influenced by root exudation

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Mathematical modelling is an important tool in rhizosphere research. Considering that rhizosphere traits govern plant resource use efficiency, accurate modelling of plant nutrient uptake is an important challenge in the light of upcoming shortages of mineral fertilisers and climate change. In this work we show a simulation case study where phosphate uptake of a young oilseed rape root system is investigated.

Root exudation may increase the availability of poorly mobile nutrients such a phosphate (P) to plant roots. In addition to root system morphology and root P transport capacity, this mechanism is particularly important for plant species that do not exhibit symbioses with soil fungi (mycorrhizas) such as oilseed rape.

We present a mathematical model of P uptake by a growing oilseed rape root system as influenced by root exudation. The model includes two spatial scales: the single root and the root system scale. The model was parameterised for two different cultivars of oil seed rape, Caracas and CR 1886; main exudates include citrate, oxalate and malate.

We derive a single root model for the coupled transport of phosphate and root exudates from underlying mechanisms: A single cylindrical root in soil takes up phosphate thus triggering duffusion of phosphate in the soil towards the root surface. Furthermore, root exudates are excreted at the root surface and compete for the same sorption sites with phosphate. This is described by a competitive Langmuir equation for sorption. The resulting model is a nonlinear version of the model of Kirk (1999).

Numerical upscaling of this single root model yields a model on the root system scale. Root growth is modelled according to Leitner et al. (2010a). The parameters of the root growth model are estimated from measured root system architecture parameters as described in Leitner et al. (2010b).

The simulations were performed using Matlab. The partial differential equations of the model were solved using Comsol Multiphysics. A comparison of model results with measurements from a validation experiment is presented. Comparison of the results obtained by mathematical modeling with experimental results provides insight into underlying processes and may be used in improving experimental designs as well as identifying P-efficient root traits in crop breeding programmes.

References

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