agropolis fondation

Modelling of water and nutrients uptake by plant root systems

Modelling of water and nutrients by plant root systems: a mathematical and numerical approach with explicit account of root system architecture

ABSTRACT

A finite element code for 3D water solutes transfer in soils was developed within the FAFEMO and FreeFem++ calculation platforms. The advantage is to have a high performance, parallelized, computer code which can be executed faster for large 3D problems. In collaboration with CReSTIC (Reims), a first code for geometric coupling between soil and root architecture was developed and is presently further implemented. In order to couple efficiently the 3D soil transfer model with water and nutrient uptake by a functional root system architecture, we have developed an "equivalent" modeling at the macroscopic scale (i.e. at the scale of a voxel of the soil mesh). This equivalent modeling represents simplified transfers and interactions taking place at small scale near the roots and results in a water potential or concentration sensed by the roots at the soil-root interface. This allows easier introduction into the soil transfer model of complex root architectures simulated by architectural models, independently of the soil meshing and allowing for efficient and precise calculations. This equivalent model has been tested with an explicit modeling of roots, i.e. by finely meshing soil and roots in the soil transfer model, in 2D and 3D. We have applied these models to an analysis of the impact on water uptake and foraging of the available soil water depending as a function of the spatial distribution of the roots (Beudez et al. 2013). From a more conceptual point of view, works have been done on the "optimality" of the shape and the associated surface of a root system for the uptake of phosphorus in the soil. Mathematically, this translates into a quasi-linear parabolic equation associated with a Freundlich adsorption isotherm, reflecting the transport of P in the soil and coupled to a Michaelis-Menten absorption kinetic of P over the surface area of a shape representing the root. The existence and uniqueness of solution has been demonstrated for this system of differential equation (including shape and boundary conditions). The equation governing the optimal shape for a given root volume (combined with a root radius) has then been derived and solved numerically with FreeFem + +. It is shown that starting with an initial elliptical root the "optimal" deformations of the shape gradually lead to a branching structure, as in a real root system (Comte et al., 2013).
Finally, from an experimental point of view, we conducted experimental works on the combined effects of water and P availability on the growth of maize seedlings in pots. We found the classic limitation of plant growth due to low P availability, after exhaustion of P stored in the seed. It is also shown that an increased water content in the soil (especially for low [P]) has a positive effect on the overall efficiency of P uptake, but this is not clearly reflected in the P influx calculated per unit length of root. In addition, a feedback was apparent between water content and growth of the root system. These data will later help to test the developed root uptake models, but already pose questions about interactions between availability of soil resources and root growth.

Keywords : Plant, Ecophysio/architecture/phenotyping, Operation, Architecture, Model, Water, root

Year : 2009
Project number : 0902-008
Type of funding : AAP
Project type : AAP INRIA
Research units in the network : PSH
Start date : 2009-11-01
End date : 2013-04-30
Flagship project : no

Project leader : Claude Doussan
Project leader's institution : INRA-INRAE
Project leader's RU : EMMAH

Budget allocated : 31035.22 €
Total budget allocated (including co-financing) : 42514 €
Funding : RTRA

PERSPECTIVES

Owing to the developments in this project, we could propose and participate to larger projects: Rhizopolis (unifying project from Agropolis Foundation) and EuRoot (European project). In these two projects, we aim to refine the root functional architecture models, interacting with transfer processes in the soil, in collaboration with physiologists, geneticists and bio-geochemists. The deliverables aim at a characterization of the functioning in soil of different phenotypes of root systems, particularly in relation with the spatial heterogeneity of resources.