C-ROOT: a general continuous model of root growth based on root architecture and development of plants

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Abstract

Modelling and simulating plant root growth in connection with soil water and nutrient transport is an important challenge that finds applications in many fields of research. If root architectural models are suited for making the functional link between plant growth and soil (Bonde and Rey, 1997; Pagès et al., 2004) at the individual scale, continuous approaches (Dupuy et al., 2010) based on aggregated variables and density functions, i.e. topologically not explicit, can be necessary to simulate root growth at the stand/crop level. The C-ROOT model presented here belongs to this second category. It is a general continuous root growth model that aggregates architectural and developmental information. The model was implemented in C++ language and tested on three case studies representing different root growth patterns.

Model description

C-ROOT is a continuous model that describes the time and space evolution of $u(x,y,z,t)$, the number of apices per unit of volume, through the equation:

$$\frac{\partial u(x,y,z,t)}{\partial t} = \nabla \cdot (D(x,y,z) \nabla u(x,y,z,t)) + A(x,y,z,t) u(x,y,z,t) - \mu(x,y,z,t) u(x,y,z,t) + R(x,y,z,t)$$

The model is described by reaction, advection and diffusion operators ($R$, $A$, $D$ respectively), which are related to root growth processes such as primary growth, branching and mortality (Bonneu et al., 2012), to the capillary forces and to the branching and the mortality coefficients, $\mu$ and $D$ are the advection and diffusion coefficients, respectively. The reaction operator gives the number of apices produced in time, whereas advection and diffusion are conservative operators that spatially distribute the whole apices within the soil.

Numerical method

Operator splitting techniques were used to solve and fit the model (Hundsdorfer and Verwer, 2003). The calibration method is decomposed into two steps. A temporal calibration of the reaction parameters is first made for each iteration time. Then, the advection and diffusion parameters are optimized on various time intervals, corresponding to development phases of the root system. The optimization process of these two operators is made by using a Levenberg Marquardt method.

Case studies

Various strategies concerning the emission process of root axes can be presented according to the classification of Canon (1949). The continuous approach allows C-ROOT to be easily coupled with other physical models, also based on continuous formulation, e.g. architectural models. Therefore, the model is suitable for the simulation of root growth at the population scale.

References

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