Geophysical Research Abstracts
Vol. 16, EGU2014-4039, 2014
EGU General Assembly 2014

Integrating models to simulate emergent behaviour: effects of organic matter on soil hydraulics in the ICZ-1D soil-vegetation model

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Soil develops as a result of interacting processes, many of which have been described in more or less detailed models. A key challenge in developing predictive models of soil function is to integrate processes that operate across a wide range of temporal and spatial scales. Many soil functions could be classified as “emergent”, since they result from the interaction of subsystems. For example, soil organic matter (SOM) dynamics are commonly considered in relation to carbon storage, but can have profound effects on soil hydraulic properties that are conventionally considered to be static.

Carbon fixed by plants enters the soil as litterfall, root turnover or via mycorrhizae. Plants need water and nutrients to grow, and an expanding root system provides access to a larger volume of soil for uptake of water and nutrients. Roots also provide organic exudates, such as oxalate, which increase nutrient availability. Carbon inputs are transformed at various rates into soil biota, CO_2, and more persistent forms of organic matter. The SOM is partly taken up into soil aggregates of variable sizes, which slows down degradation. Water availability is an important factor as both plant growth and SOM degradation can be limited by shortage of water. Water flow is the main driver for transport of nutrients and other solutes. The flow of water in turn is influenced by the presence of SOM as this influences soil water retention and hydraulic conductivity. Towards the top of the unsaturated zone, bioturbation by the soil fauna transports both solid material and solutes. Weathering rates of minerals determine the availability of many nutrients and are in turn dependent on parameters such as pH, water content, CO_2 pressure and oxalate concentration. Chemical reactions between solutes, dissolution and precipitation, and exchange on adsorption sites further influence solute concentrations. Within the FP7 SoilTrEC project, we developed a model that incorporates all of these processes, to explore the complex interactions involved in soil development and change. We were unable to identify appropriately-detailed existing models for plant productivity and for the dynamics of soil aggregation and porosity, and so developed the PROSUM and CAST models, respectively, to simulate these subsystems. Moreover, we applied the BRNS generator to obtain a chemical equilibrium model. These were combined with HYDRUS-1D (water and solute transport), a weathering model (derived from the SAFE model) and a simple bioturbation model. The model includes several feedbacks, such as the effect of soil organic matter on water retention and hydraulic conductivity.

We encountered several important challenges when building the integrated model. First, a mechanism was developed that initiates the execution of a single time step for an individual sub-model and accounts for the relevant mass transfers between sub-models. This allows for different and sometimes variable time step duration in the submodels. Secondly, we removed duplicated processes and identified and included relevant solute production terms that had been neglected.

The model is being tested against datasets obtained from several Soil Critical Zone Observatories in Europe. This contribution focuses on the design strategy for the model.