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Self-organizing biochemical cycle in dynamic feedback with soil structure

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In the present study we perform bifurcation analysis of a physically-based mathematical model of self-organized structures in soil (Vasilyeva et al., 2015). The state variables in this model included microbial biomass, two organic matter types, oxygen, carbon dioxide, water content and capillary pore size. According to our previous experimental studies, organic matter affinity to water is an important property affecting soil structure. Therefore, organic matter wettability was taken as principle distinction between organic matter types in this model. It considers general known biological feedbacks with soil physical properties formulated as a system of parabolic type non-linear partial differential equations with elements of discrete modeling for water and pore formation. The model shows complex behavior, involving emergence of temporal and spatial irregular auto-oscillations from initially homogeneous distributions. The energy of external impact on a system was defined by a constant oxygen level on the boundary. Non-linear as opposed to linear oxygen diffusion gives possibility of modeling anaerobic micro-zones formation (organic matter conservation mechanism). For the current study we also introduced population competition of three different types of microorganisms according to their mobility/feeding (diffusive, moving and fungal growth). The strongly non-linear system was solved and parameterized by time-optimized algorithm combining explicit and implicit (matrix form of Thomas algorithm) methods considering the time for execution of the evaluated time-step according to accuracy control. The integral flux of the CO_2 state variable was used as a macroscopic parameter to describe system as a whole and validation was carried out on temperature series of moisture dependence for soil heterotrophic respiration data. Thus, soil heterotrophic respiration can be naturally modeled as an integral result of complex dynamics on microscale, arising from biological processes formulated as a sum of state variables products, with no need to introduce any saturation functions, such as Mikhaelis-Menten type kinetics, inside the model.

Analyzed dynamic soil model is being further developed to describe soil structure formation and its effect on organic matter decomposition at macro-scale, to predict changes with external perturbations. To link micro- and macro-scales we additionally model soil particles aggregation process. The results from local biochemical soil organic matter cycle serve as inputs to aggregation process, while the output aggregate size distributions define physical properties in the soil profile, these in turn serve as dynamic parameters in local biochemical cycles. The additional formulation is a system of non-linear ordinary differential equations, including Smoluchowski-type equations for aggregation and reaction kinetics equations for coagulation/adsorption/adhesion processes.

Vasilyeva N.A., Ingtem J.G., Silaev D.A. Nonlinear dynamical model of microbial growth in soil medium. Computational Mathematics and Modeling, vol. 49, p.31-44, 2015 (in Russian). English version is expected in corresponding vol.27, issue 2, 2016.