**Motivation**

- Biogeochemical models that explicitly consider functional traits and physiology of microorganisms are complex.
- Mathematical analysis provides a leverage point to reduce the complexity of models and fosters understanding of qualitative system behavior.
- We analyze the PECCAD model applying methods from the field of dynamic systems theory in order to gain a holistic understanding of microbial dynamics and matter cycling in soil.

**PECCAD Main Feature**

- **Direct Pesticide Utilization**
  \[ \frac{dP}{dt} = \alpha \left( \beta_{DPP} \frac{P}{Y_{BRP}} - \frac{P}{Y_{BRP}} \right) - cP + q + I_{P} \]

- **Cometabolic Degradation**
  \[ \frac{dF}{dt} = \alpha \left( \beta_{DPP} \frac{F}{Y_{BRP}} - \frac{F}{Y_{BRP}} \right) - cF + q + I_{F} \]

**Bifurcation Theory**

A bifurcation occurs when a small change made to parameter values in the model leads to a qualitative change in dynamic behavior of the system.

**Physiological Activity**

Active microbial biomass is a driver of biogeochemical cycles, but existing minimal models representing physiological states lack experimental validation. How can we distinguish between models?

**Results**

- Exponential dependence of microbial reactivation rate leads to complex model dynamics.
- Multiple time scales in the PECCAD model make a bifurcation analysis possible.

**Time Scales and Dimensional Analysis**

The complexity of coupled soil models has to be reduced in order to conduct a stability analysis. This is achieved by identifying multiple time scales.

**Kinetic Functions give the Time Scale of a Variable**

As part of a nondimensionalization procedure, three scaling constants are introduced. The scale of a variable provides an estimate of its maximum order of magnitude.

**Carbon concentrations:**

\[ \bar{C}_{i} = k_{i} \bar{c}_{i} \]

\[ (i = \text{io}, \text{iq}, \text{r}, \text{b}, \text{bp}, \text{f}) \]

**Time:**

\[ t = k_{i} \cdot \tau \]

**Kinetic functions:**

\[ \bar{r}_{x} = \max \{ r_{x} \} \]

\[ 0 \leq \bar{c}_{i} \leq 1 \]

**Example: Pesticide Concentration**

\[ \frac{dP}{dt} = \frac{\beta_{DPP} \bar{F} \frac{P}{Y_{BRP}} - \frac{P}{Y_{BRP}}}{\lambda_{BRP}} - cP \bar{r}_{DPP} (P) + q + I_{P} \]

**References**


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