Calcium Diffusion in Ecological Systems

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Acid deposition and the problems of calcium depletion

- Acid deposition (acid rain) impacts the environment
- Acid deposition increases soil acidity and leaching of nutrients → nutrient deficiencies in the soil
- Many forests believed to be undergrown due to calcium depletion
- Calcium deficiencies are usually rare in nature
- Implies depletions are at least partially induced by human impact

Walker Branch Watershed

- Some regions damaged by calcium depletion but others have fared better than anticipated
- Research at the Walker Branch Watershed in Tennessee suggested tree and plant life tapping into alternative sources of calcium

So where is the extra calcium coming from???

Possible theories

- Two main theories have been proposed:
  - Mineral weathering
  - Deep rooting of trees
- These mechanisms alone may not be sufficient to compensate for imbalanced calcium levels
- An additional theory has been proposed: calcium diffusion upward from bedrock sources
- This project evaluates the theory

Diffusion in soil

- Diffusion is an important mechanism of ion movement in soil and of nutrient supply to plants
- Has previously only been examined at soil levels, over shorter distances and time spans

Fick's Laws of Diffusion

- Diffusion is mathematically described by Fick's Laws of Diffusion
- Fick's second law describes how concentration at a point changes with time, which can be applied to modeling calcium diffusion:

$$\frac{\delta C}{\delta t} = D\frac{\delta^2 C}{\delta x^2}$$

- The analytical solution only holds for boundary condition $C(\infty,0)=0$

$$C(x,t) = C_0 erfc\left[\frac{x}{2(D_e t)^{0.5}}\right]$$

- Realistic boundary conditions require numerical solutions

Finite-difference approximations

- Changes a partial differential equation into a system of algebraic equations, which can then be solved numerically
- Used a Taylor series for approximation to obtain:

$$C_t(x,t) \cong \frac{C(x,t+k) - C(x,t)}{k}$$

$$C_{xx}(x,t) \cong \frac{1}{h^2}[C(x+h,t) - 2C(x,t) + C(x-h,t)]$$

- Which can be substituted into Fick's Law:

$$C_t = DC_{xx}$$

- Yielding the following algorithm:

Within the soil:

$$C_{i+1,j} = C_{i,j} D\frac{k}{h^2}[C_{i,j+1} - 2C_{i,j} + C_{i,j-1}]$$

At soil surface (boundary condition):

$$C_{i,n} = \frac{C_{i,n-1} + hg_i}{1+h}$$

Results

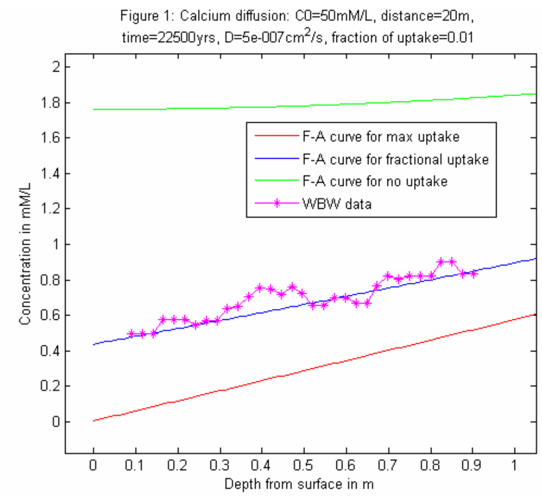

Fig. 1: Surface Concentration of calcium at soil surface
Timescale = 22,500 years
Initial Concentration = 50mM/L
Depth from bedrock source to surface = 20 meters
Surface concentration = 0.4375mM/L
Total uptake = ~6.5ha/yr

What does this mean for ecosystems?

- Most likely, there are a number of sources forests are tapping into
- Results show a consistency between the proposed theory and experimental data
- Still much is unknown about calcium depletion and its impact on forests
- It is important to learn more about the inner-workings of ecosystems and how we influence them

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