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Soil Penetration Rates by Earthworms and Plant Roots- Mechanical and Energetic Considerations

Siul Ruiz, Stan Schymanski, and Dani Or
Switzerland (siul.ruiz@usys.ethz.ch)

We analyze the implications of different soil burrowing rates by earthworms and growing plant roots using mechanical models that consider soil rheological properties. We estimate the energetic requirements for soil elasto-viscoplastic displacement at different rates for similar burrows and water contents. In the core of the mechanical model is a transient cavity expansion into viscoplastic wet soil that mimic an earthworm or root tip cone-like penetration and subsequent cavity expansion due to pressurized earthworm hydrostatic skeleton or root radial growth. Soil matrix viscoplatic considerations enable separation of the respective energetic requirements for earthworms penetrating at 2 μm/s relative to plant roots growing at 0.2 μm/s . Typical mechanical and viscous parameters are obtained inversely for soils under different fixed water contents utilizing custom miniaturized cone penetrometers at different fixed penetration rates (1 to 1000 μm/s). Experimental results determine critical water contents where soil exhibits pronounced viscoplatic behavior (close to saturation), bellow which the soil strength limits earthworms activity and fracture propagation by expanding plant roots becomes the favorable mechanical mode. The soil mechanical parameters in conjunction with earthworm and plant root physiological pressure limitations (200 kPa and 2000 kPa respectively) enable delineation of the role of soil saturation in regulating biotic penetration rates for different soil types under different moisture contents. Furthermore, this study provides a quantitative framework for estimating rates of energy expenditure for soil penetration, which allowed us to determine maximum earthworm population densities considering soil mechanical properties and the energy stored in soil organic matter.