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The mechanics and energetics of soil bioturbation by earthworms and plant roots – Impacts on soil structure generation and maintenance

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Soil structure is the delicate arrangement of solids and voids that facilitate numerous hydrological and ecological soil functions ranging from water infiltration and retention to gaseous exchange and mechanical anchoring of plant roots. Many anthropogenic activities affect soil structure, e.g. via tillage and compaction, and by promotion or suppression of biological activity and soil carbon pools. Soil biological activity is critical to the generation and maintenance of favorable soil structure, primarily through bioturbation by earthworms and root proliferation. The study aims to quantify the mechanisms, rates, and energetics associated with soil bioturbation, using a new biomechanical model to estimate stresses required to penetrate and expand a cylindrical cavity in a soil under different hydration and mechanical conditions. The stresses and soil displacement involved are placed in their ecological context (typical sizes, population densities, burrowing rates and behavior) enabling estimation of mechanical energy requirements and impacts on soil organic carbon pool (in the case of earthworms). We consider steady state plastic cavity expansion to determine burrowing pressures of earthworms and plant roots, akin to models of cone penetration representing initial burrowing into soil volumes. Results show that with increasing water content the strain energy decreases and suggest trade-offs between cavity expansion pressures and energy investment for different root and earthworm geometries and soil hydration. The study provides a quantitative framework for estimating energy costs of bioturbation in terms of soil organic carbon or the mechanical costs of soil exploration by plant roots as well as mechanical and hydration limits to such activities.