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# Experimental study of penetration-cavity expansion soil bioturbation models using miniature cone penetrometers

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A recently developed model of soil penetration mechanics and energetics by earthworms and plant roots is based on analogy with cone penetration and cavity expansion. Model predicted resistive forces for different geometries were tested using miniature cone penetrometers at sizes compatible with burrowing earthworms and growing roots. Experiments using cones of different radii (1.0 to 2.5 mm) and different semi-apex angles (15-300) were conducted using an apparatus enabling insertion at constant (prescribed) rates while obtaining highly resolved penetration resistance force measurements. Penetration experiments used soils at different water contents where soil mechanical parameters were determined independently using Oedometer tests under confined and unconfined conditions. Measurements were compared with predictions by analytical expressions for earthworm or root burrowing mechanics. Model predictions for the insertion force as a function of cone geometry and soil mechanical properties were in excellent agreement with cone penetration measurements. The study provides the necessary experimental confirmation to support energetic estimates of bioturbation costs in terms of soil organic carbon consumption. The study provides a better understanding of the fundamental duality nature between penetration forces and stresses and the dependency on cone angle. The measurements suggest that friction plays a relatively minor role as confirmed by experiments using recessed cones (no soil-shaft friction). Differences in application of the model to plant roots and earthworms will be discussed.