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Bridging the Gap: A Multilevel Approach to Soil Health Assessment across Various Land Uses

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To address the challenge of soil degradation among different land uses, development of precise indicators that accurately reflect the current state of soil health is crucial. Soil structural attributes, such as the volume of percolating pores and the connectivity of the pore network are inextricably linked to processes such as nutrient dynamics, carbon cycling, root penetration, biological activity, and rainfall partitioning. Hence, they play a significant role in determining the soil susceptibility to erosion and offer great potential as soil health indicators. These attributes are directly reflected in the hydraulic properties of the soil, particularly in its capacity for water infiltration and retention. Notably, high rates of infiltration and drainage are associated with the presence of well-connected macropores. However, these structural attributes typically have to be quantified using costly and time-consuming imaging methods, while obtaining accurate estimates in lab and field experiments has proven challenging. Our multilevel approach is designed to link directly measured structural attributes (macropore volume and connectivity) to standard field or lab measurements.

More specifically, macropore volume and connectivity were quantified using X-ray imaging across diverse land use types, including arable land, grassland, and forest. Structural characteristics were then correlated with key hydraulic properties, such as water retention and both saturated and unsaturated hydraulic conductivity, measured using the Hyprop system. We further compared the imaged and measured hydraulic properties with predictions from the European soil texture-based pedotransfer function EUPTF, to contrast texture- and structure-related soil hydraulic properties. As an additional exploratory angle, we related mid-infrared (MIR) spectral reflectance to our previously obtained hydraulic property data, to evaluate if MIR could serve as a less laborious alternative to traditional lab-based analyses. Finally, to develop applicable user-friendly and sensitive indicators, we correlated our findings with the classifications from in-situ Visual Evaluation of Soil Structure (VESS) and infiltration experiments.

Preliminary results of X-ray CT data and Hyprop measurements revealed significant differences in the volumetric fraction and drainage capacity of macropores as well as in the saturated hydraulic conductivity between arable land, grassland, and forest. Forest soil showed the largest drainage

capacity of macropores, but also the largest variability between samples. Despite exhibiting similar pore size distributions, arable land samples showed, as a result of tillage, larger pore connectivity than grassland. Larger connectivity did, interestingly, not result in larger hydraulic conductivity of macropores.

Our novel multilevel approach reveals clear distinction of land use regarding the complex interplay between soil structural continuity, soil texture, and hydraulic behavior. Such knowledge is crucial in formulating sensitive, quantifiable, and scalable indicators for soil health evaluation and management. These indicators are instrumental for creating more accurate models, for designing sensitive monitoring networks and ultimately advancing sustainable practices in agriculture, forestry, and environmental conservation.