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Designing sustainable soils in Earth's critical zone

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The demographic drivers of increasing human population and wealth are creating tremendous environmental pressures from growing intensity of land use, resulting in soil and land degradation worldwide. Environmental services are provided through multiple soil functions that include biomass production, water storage and transmission, nutrient transformations, contaminant attenuation, carbon and nitrogen storage, providing habitat and maintaining the genetic diversity of the land environment. One of the greatest challenges of the 21st century is to identify key risks to soil, and to design mitigation strategies to manage these risks and to enhance soil functions that can last into the future.

The scientific study of Earth's Critical Zone (CZ), the thin surface layer that extends vertically from the top of the tree canopy to the bottom of aquifers, provides an essential integrating scientific framework to study, protect and enhance soil functions. The research hypothesis is that soil structure, the geometric architecture of solids, pores and biomass, is a critical indicator and essential factor of productive soil functions. The experimental design selects a network of Critical Zone Observatories (CZOs) as advanced field research sites along a gradient of land use intensity in order to quantify soil structure and soil processes that dictate the flows and transformations of material and energy as soil functions. The CZOs focus multidisciplinary expertise on soil processes, field observation and data interpretation, management science and ecological economics. Computational simulation of biophysical processes provides a quantitative method of integration for the range of theory and observations that are required to quantify the linkages between changes in soil structure and soil functions.

Key results demonstrate that changes in soil structure can be quantified through the inputs of organic carbon and nitrogen from plant productivity and microbial activity, coupled with particle aggregation dynamics and organic matter mineralization. Simulation results show that soil structure is highly dynamic and is sensitive to organic matter production and minearlisation rates as influenced by vegetation, tillage and organic carbon amendments.

These results point to a step-change in the capability to design soil management and land use through computational simulation. This approach of "sustainability by design" describes the mechanistic process linkages that exist between the above-ground inputs to the CZ and the internal processes that produce soil functions. This approach provides a rational, scientific approach to selecting points of intervention with the CZ in order to design methods to mitigate soil threats and to enhance and sustain vital soil functions.

Furthermore, this approach provides a successful pilot study to the use of international networks of CZOs as a planetary-scale laboratory to test the response of CZ process rates along gradients of global environmental change – and to test adaptation strategies to manage the risks arising from the CZ impacts.

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