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Synchrotron and Conventional Analyses of Soil Pore Properties Influencing Cohesion in Coastal Tablelands Soils

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Many soils in the Coastal Tablelands of Brazil have limitations in their physical quality because of subsurface cohesive horizons [1]. The consistency of cohesive soil horizons is hard to extremely hard when dry, restricting root development, while its structure slakes under high water content, reducing the support of plants and drainage [2,3]. Often, sand constitutes 70% to 80% of cohesive soil horizons, and thus fine illuvial clay is considered to have an important role in the formation of cohesion by promoting pore obstruction and decreasing total porosity [1,4]. Soil cohesion is assessed by penetration resistance (PR) measurements, often exceeding 2 MPa at field capacity, a threshold that can restrict root growth [5].

The CNPEM-Embrapa Cohesive Soils Program launched in March 2024 aims to determine mechanisms causing cohesion in subsurface horizons of soils found in ~100,000 km2 of the Tablelands region of Brazil. The program analyzes synchrotron and conventional data from samples of three soil profiles with cohesive horizons, designated as profiles P1 and P2 in Pernambuco and C1 in Ceará. The present study is part of this collaborative program and aims at determining contributing conditions for the cohesion mechanism to be effective. For example, we hypothesized that: 1) cohesion increases with decreasing total porosity due to a lower proportion of macropores between sand grains and an increase in micropores within the clay infilling between sand grains; and 2) cohesion increases with decreasing connectivity of pores in the clayey fabric.

To investigate these hypotheses, 19 samples (seven from P1, six from P2, and six from C1) were scanned by X-ray computed tomography at the MOGNO beamline of the Sirius synchrotron in Brazil [6], yielding 3D images with pixel size of 3.4 µm. Image based total porosity, and fractions, connectivity, and tortuosity of macro (>50 µm diameter), meso (15-50 µm), and micropores (3-15 µm) were determined. In addition, laboratory and field PR were measured in samples from the same profile depths.

Cohesion increased significantly ($p < 0.01$) with decreasing total porosity for the combined data from profiles P1 and P2, and more specifically, cohesion increased significantly ($p < 0.01$) with increasing proportion of micropores and decreasing proportion of macropores. Although not statistically significant ($p > 0.05$), data from profile C1 suggested the same trends. More generally, PR showed significant ($p < 0.01$) inverse linear relationships with connectivity of macropores for profiles P1 and C1 (same trend for P2, not significant), and with connectivity of mesopores for profiles P1 and P2. However, although micropores should be more prevalent within the clay (<2-µm particle) fabric, simple linear regression models between PR and connectivity of micropores were not significant ($p > 0.05$). No trend between PR and micropore connectivity was shown by the lab data for profile C1. The results support hypothesis 1 and refute hypothesis 2. Although the present study does not explain the cohesion mechanism, it contributes to understanding porosity conditions in the cohesive horizons.

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