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The Dynamic Effect of Root Exudates on Soil Structure – Characterization by X-ray Tomography

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Soil mucilage strongly affects soil structural packing and stability. We characterized the effects of mucilage and the subsequent effect of wetting and drying on the microstructure of three agricultural soils: clayey, sandy-clay-loam, and loamy-sand soils. Soil stability measurement trends, assessed by a laser granulometry based aggregate durability index (ADI), varied between the soils. While aggregates stability of the clayey and loamy-sand soils decreased after subjecting soil samples to wetting and drying, stability increased in the case of the sandy-clay-loam soil. This observation can be explained by the high $CaCO_3$ content in the loamy-sand soils (19.5%) which contributes to the formation of durable aggregates induced by calcite cementation. ADI values of all soils increased following mucilage amendment (0.035 w/w). Mucilage, consisting mainly of polysaccharides and lipids, may affect soil mechanical properties and structure by binding soil particles due to its adhesive properties, thus reinforcing the internal structure of the aggregates. Stability was further analyzed after subjecting the mucilage amended samples to a wetting and drying cycle, and a diverse trend was measured. While stability increased for the clayey and the loamy-sand soils, it decreased for the sandy-clay-loam soil. Mucilage is known to induce surface hydrophobicity, following its dehydration, which may lead to a decrease in the wettability of soil particles and protect aggregates from deterioration by water. However, in the sandy-clay-loam soil, the cumulative effect $CaCO_3$ and mucilage which increases entropy overpowers the mucilage stabilizing effect.

The packing of the microstructure as a function of mucilage amendment and wetting and drying was characterized by quantifying morphological and geometrical changes within the pore-network, extracted by X-ray computed tomography (XCT). Pore volume in all soils decreased upon mucilage amendment, correlating with the observed increase in stability. However, while porosity of the clayey soil increased after wetting and drying, it decreased or remained the same in the Loamy-sand and sandy-clay-loam soil, respectively. To evaluate pore connectivity, we calculated the Euler number (c) in which smaller values (negative) indicate better pore-connectivity. Poor connectivity was assessed in the amended clayey (c=1128) and sandy-clay-loam (c=172085) soils, probably due to soil aggregation which is in correlation with porosity assessment. Following wetting and drying, connectivity improved in the clayey soil

(c=-17281), while in the sandy-clay-loam it remained poor (c=143119). As expected, pore connectivity ($c<0$) of the loamy-sand soil remained in all treatments. These observations are in agreement with the stability results. As stability increased in all soils following mucilage amendment, pore-volume, and connectivity decreased. Wetting and drying of the stabilized clayey soil increased porosity and connectivity. However, the decreased stability of the sandy-clay-loam soil, due to the cumulative effect of CaCO3 and mucilage, was expressed by poor connectivity and porosity. These results demonstrate the effect of mucilage amendment and wetting and drying cycle on soil structure. Finally, applying X-ray tomography and laser granulometry measurements to characterize soil structure as a function of soil amendments may shed light on how soil structure controls the storage and fluxes of water, nutrients, and gases.