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Reflectance anisotropy for characterising fine-scale changes in soil surface condition across different soil types

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Soils can experience rapid structural degradation in response to land cover changes, resulting in a reduction in soil productivity, an increased susceptibility to erosion and increased release of greenhouse gases. Soil surface roughness at the centimetre scale plays a fundamental role in affecting soil erosion and surface runoff pathways. A decline in surface roughness can also be used to infer soil degradation as soil aggregates are broken down through raindrop impact. However, due to the time and resources involved in using traditional field sampling techniques, there is a lack of spatially-distributed information on soil surface condition. Remotely sensed data can provide a cost-effective means of monitoring changes in soil surface condition over broad spatial extents. Furthermore, a growing recognition into the importance of the directional reflectance domain has led to an increasing number of satellites with multiple view angle (MVA) capabilities (e.g. MISR, CHRIS on Proba). This is potentially useful for monitoring soil degradation and susceptibility to erosion because changes in soil surface roughness, associated with the breakdown of macro-aggregates, have a measurable effect on directional reflectance factors. Consequently, field and laboratory data are required for an empirical understanding of soil directional reflectance characteristics, underpinning subsequent model development.

This study assessed the extent to which a hyperspectral MVA approach (350-2500 nm) could detect fine-scale changes in soil crusting states across five different soil types. A series of soil crusting states were produced for all five soil types, using an artificial rainfall simulator. The controlled conditions allowed the production of a series of stages in the soil crusting process; showing progressively declining surface roughness values. Each soil state was then spatially characterised, using a laboratory laser device at 2 mm sample spacing, over a 10 x 10 cm area. Laser data were analysed within a geostatistical framework, where semi-variogram analysis quantitatively confirmed the change in soil surface structure during crusting. Directional reflectance factors of each soil state were measured using an ASD FieldSpec Pro spectroradiometer, attached to an A-frame device, allowing data acquisition at a range of viewing angles (-60° to +60°) and solar zenith angles (51° to 62°) at 10° sampling angles in the solar principal plane. Directional reflectance factors were then regressed against geostatistically-derived indicators of surface roughness (sill variance) from the laser profiling data. In order to overcome the inherent differences in reflectance factors across the soil types, an Anisotropy Measure (AM) was developed to enhance the structural signal from the soil states. The regression results showed a strong increase in the relationship between sill variance and soil surface roughness. R^2 values increased from 0.673 at θ_r = -40° to 0.898 with the AM. The results provide an empirical and theoretical basis for the future retrieval of spatially distributed assessments of changes in soil surface structure. The ability of this technique to characterise changes in soil surface structure across different soil types is important for making the method operational across coarser spatial extents and for its potential inclusion in soil erosion models.