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Directional anisotropy in hyperspectral reflectance data: application to soil degradation monitoring.

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It is widely acknowledged that soils experience rapid degradation of structure and composition in response to human induced land use and land cover changes. Traditional soil monitoring techniques for monitoring soil degradation processes are generally unable to provide spatially distributed information owing to the high processing demands and discrete sampling methods employed. As a result, many of the effects of anthropogenic activities on soil properties are known qualitatively, but spatially distributed quantitative information is scarce. There is a necessity for accurate spatial data for soil assessment, so that these studies can contribute to wider understanding of the global soil system, and for estimation of carbon release from degraded soils.

Remote sensing techniques have long been recognised as a means of providing spatial data for monitoring soil properties. Key variables of interest to soil scientists (e.g. moisture, organic matter, mineralogy and roughness), are detectable from remote sensing devices. Of particular relevance to this study is the link between soil surface roughness and reflectance. Previous studies have highlighted that roughness is one of the key variables influencing soil reflectance. Furthermore, the rate of rainfall-induced aggregate destruction, compaction and crusting lead to a decline in soil roughness which can provide information on the stability of soil aggregates, and of organic matter status.

This paper details the results of an experiment designed to test the feasibility of using multiple view angle optical reflectance data for monitoring soil condition. A luvisol sampled in the Eifel region in Germany with high sensitivity to crusting was used. A range of soil crusting phases were generated using an artificial rainfall simulator, which generated crust phases at 0 minutes (control), 5, 15, 25, 40, and 60 minutes,

respectively. Prior to spectral measurements, soils were dried so that spectral measurements could focus on changes in structure in the absence of soil moisture variations. Field measurements of spectral reflectance were collected in the visible, near-IR and shortwave IR range (350-2500 nm), using an Analytical Spectral Devices (ASD) FieldSpec Pro spectroradiometer system. These measurements aimed to sample the bidirectional reflectance distribution function (BRDF) – the 3D shape of the reflected radiation field, which is known to convey information on surface structure. In order to do this, reflectance measurements were collected in the solar principal plane (SPP) using an A-frame device, at various look angles in the back- and forward-scatter directions (θ_r = 0^o (nadir), -15^o, - 30^o, -45^o, -60^o, +15^o, +30^o, +45^o, +60^o, where positive angles indicate the backscattering or down-sun direction).

Digital surface models of each crusting phase, generated from a laboratory laser profilometer, were used to generate geostatistical measures including variograms and relative roughness. These characterised the spatial continuity of the central 5x5cm area measured by the spectroradiometer. Linear regression models were used to relate back- and forward-scattered reflectance factors to these statistical measures of roughness. The results demonstrate that changes in soil structure (quantified by sill variance measures extracted from variogram analysis), were best described by backscattered radiation measured at +30^o in the visible and near-infra-red (e.g. R^2 = 0.947 (658 nm)), and at +15^o in the shortwave infra-red (e.g. R^2 = 0.992 (1700 nm)). View zeniths are expressed from the nadir, and were relative to the solar zenith angle, which ranged from 80.76^o to 74.55^o during the measurement sequences. The results from these tests show great promise for broader-scale monitoring of soil condition, particularly when considered in the context of new pointable remote sensing systems in operation, coupled with new generation sensors with in-built directional capabilities.