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A novel remote sensing method for monitoring soil degradation: a combined spatial, spectral and directional approach.

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Soil degradation generally occurs as a direct result of anthropogenic land use or land cover modification. Traditionally, soil degradation monitoring has been undertaken using field-based sampling methods utilising discrete spatial intervals. However, these methods are unable to provide spatially distributed information on soil condition, due to the high processing demands and effort involved in analysing the relevant soil properties. There is a clear need for a holistic understanding of the global soil system, and for information on the contribution made by degraded or degrading soils to the global carbon budget. Remote sensing can potentially provide spatial products for use in the assessment of soil condition and it has long been recognised as a highly capable method for discriminating soil properties.

Previous studies have shown that many of the variables which are of interest to soil scientists (moisture, organic matter, mineralogy and roughness), are distinguishable from remote sensing measurements made at close-range using spectroradiometers. Of particular relevance to this research is the inherent link between soil surface roughness, organic matter content and reflectance. Soils with higher organic matter content generally exhibit larger, more stable aggregates which degrade more slowly after rainfall. This provides a useful variable for monitoring in a remote sensing context because increases in soil particle size have previously been linked to decreasing soil reflectance, due to shadowing effects caused by soil particulates. These factors, combined with recent advances in sensor design (which have given rise to new instruments with enhanced spatial resolution, and off-nadir capabilities) mean that remote sensing is now in a strong position to benefit soil science by providing a novel means of monitoring soil condition synoptically.

This paper describes the results of a controlled experiment, aimed at determining the directional reflectance and spatial statistical variations which occurred when a crusting-sensitive luvisol was subjected to quasi-natural rainfall conditions. Soil sampled in the field after tillage was sieved into free-draining trays, and exposed to artificial rainfall for differing periods of time, ranging from 5 to 60 minutes. The resulting samples demonstrated different stages in the development of a structural crust, the topography of which was characterised using a laboratory laser profilometer. Resultant digital surface models were subsequently analysed using spatial statistics and variogram models.

Directional reflectance factors of each sample were characterised in the solar principal plane under clean skies using an ASD FieldSpec Pro spectroradiometer attached to an A-frame device, and these were subsequently analysed in relation to the spatial statistics for each sample. The results demonstrate that changes in the sill variance of soil samples following crusting (and hence changes in soil structure) were best described by backscattered radiation in the visible and near-infra-red (VNIR, $R^2 = 0.947$ (at 658 nm)). The results also showed interesting wavelength-dependent patterns, with different optimal view zeniths and regression coefficients in the shortwave infra-red (SWIR).

In the SWIR, the results suggested that the optimal view angle was reduced from $+30^o$ (in VNIR wavelengths) to a smaller view zenith of $+15^o$ (where + indicates the backscattering direction). The physical reason underpinning this is thought to be due to the complex processes of multiple scattering which occurs over structured surfaces such as bare soils. Furthermore, lower R^2values for the relationship between directional reflectance factors and spatial statistical measures, at short wavelengths ($<$500 nm) were attributed to a combination of reduced instrument signal-to-noise ratios coupled with a strong multidirectional irradiance component. The latter would have been caused by the relatively long path length (caused by the large solar zenith angle), and hence a large Rayleigh scattering contribution in this part of the spectrum.

Subsequent research on this topic has focussed on developing the methodology so that it can be made operational for *in situ* soil degradation monitoring. The ASD device has been substituted with a smaller, more portable spectroradiometer system (an Ocean Optics USB2000 device) and further tests on different soil samples have used to demonstrate its capability. The results from these experiments show great promise for broader scale monitoring of soil condition, particularly when considered in the context of the new pointable remote sensing systems (IKONOS, Quickbird), coupled with new generation sensors with in-built directional capabilities (MISR, CHRIS on

Proba).