In : Lee, Jeffrey A. and Zobeck, Ted M., 2002, Proceedings of ICAR5/GCTE-SEN Joint Conference, International Center for Arid and Semiarid Lands Studies, Texas Tech University, Lubbock, Texas, USA Publication 02-2 p. 92

Characterising soil surface susceptibility to wind erosion using bi-directional reflectance: a preliminary assessment.

A. Chappell, School of Environment & Life Sciences, University of Salford, Manchester, M5 4WT, UK. (*E-mail:a.chappell@salford.ac.uk*)

G. Sheridan, School of Environment & Life Sciences, University of Salford, Manchester, M5 4WT, UK. (*E-mail: g.sheridan2@pgr.salford.ac.uk*)

Introduction

Recent developments in models for the dust cycle (e.g. Sokolik and Toon, 1996) and for wind erosion (Shao and Leslie, 1997) have highlighted the need for information on the spatial and temporal variation of soil surface conditions. This is because soil surface conditions such as structure, aggregation and roughness control the surface susceptibility to wind erosion (erodibility) and the emission of dust. The model requirements are difficult to meet over large areas because surface characterisation is traditionally conducted using labour-intensive *in situ* soil measurements or soil samples. Arguably, these field-based approaches are even inadequate at the field scale to account for the dynamic nature and evolution of surface conditions. Consequently, there is a requirement for an approach that can be used to rapidly assess changes in the compositional and structural nature of a soil surface in both time and space. This would improve model predictions of wind erosion over different spatial and temporal scales and would ensure that soil surface characteristics are considered on a continuum (Geeves *et al*., 2000).

Reflectance of the Earth's surface is directly related to the fundamental vibrational bands determined by the biophysical and geometric characteristics of a surface in the visible and infrared region. The Bi-directional Reflectance Distribution Function (BRDF) of a particular target represents the reflectance at all possible illumination and sensor view angles. It has the potential to provide consistent estimates of the biophysical and three-dimensional structural properties of a soil surface simultaneously over many spatial scales and rapidly over time. This can be estimated by sampling the spectral reflectance of the target (soil surface) at multiple view angles (MVA) (Barnsley *et al*., 1997) on the ground or from air or space-borne platforms. The BRDF can be subsequently estimated following integration of the MVA using established physically-based soil reflectance models, (Cierniewski 1987. Jaquemoud *et al*., 1992). Soil BRDF models utilise radiative transfer theory and the geometric optics principles of anisotropic surface scatter.

The aim here is to present preliminary results of a larger project into the use of the BRDF to characterise soil surface changes due to wind erosion. The results are of initial experiments to (a) determine the resolution of soil surface composition that can be detected using spectral reflectance data; (b) quantify difference in the structure (roughness) of prepared soil surfaces and (c) characterise soil surface change during controlled wetting and drying conditions.

Methods

Analytical laboratory spectroscopy, using an ASD field spec spectroradiometer, a 1000w halogen lamp, and a calibrated spectralon panel was performed on four dryland soil types from around the world. A goniometer was constructed to allow measurements of multi-angular reflectance (including nadir) of the soil surface including 10 degree increments in the sensor zenith from 0 – 50 degrees in the backward scatter, and 0-50 degrees in the forward scatter, and a user defined viewing azimuth plane was used along the principle plane and at two other angles.

Soil moisture, organic matter content, soil texture or mineralogy, and iron oxide content are identified as the central soil compositional features altering the spectral reflectance of dryland surfaces in the visible and near-infrared wavelength spectrum (Heute and Escadafel, 1991). Soil moisture, organic matter content, iron oxide and particle size were artificially altered in the four soils to provide a range of sub-samples with known variation in the key properties controlling reflectance. Quantitative analysis of the samples provided validation of composition using established soil laboratory methods. Nadir reflectance was measured (350 nm – 2500 nm) in a controlled laboratory setting on the sub-samples from each soil types. Angular spectral measurements were also made on all sub-samples for all soils.

The third objective was achieved by loading the four soils into soil trays with perforated bases that allowed drainage. The trays were subjected to a series of treatment cycles consisting of flooding, through a fine noose spray and drying at 40 degrees centigrade for a minimum of twelve hours. Bi-directional reflectance was recorded after each drying stage to allow investigation into the biophysical and micro-topographical changes in the soil surface. Reflectance, using a probe attachment to the ASD field-spec pro radiometer was also recorded at each stage, readings being taken from 15mm below the surface, to quantify any sub-surface changes in the soil composition as derived from the post spectral reflectance analysis. Digital images were taken following every treatment stage to derive accurate, detailed measurements of the 3D geometric structure of the soil surface using digital soft-copy photogrammetry. This information was used to provide validation for investigation into the ability to detect using the BRDF structural changes induced by the environmental processes.

Analysis

A qualitative analysis of the nadir spectra from controlled experiment was undertaken to investigate the composition of the soil samples and to determine the coarse (primary) information content. This subjective analysis rapidly supported many of the findings of soil reflectance evident in the literature. For example, it enabled the measured spectra to be placed within the context of the findings of Heute and Escadafal (1991): variation in spectral reflectance is explained by (and in order or importance) brightness, organic matter and iron oxide.

A semi-quantitative analysis was conducted in order to investigate the more subtle (secondary) information content. For example, figure 1 shows the first order derivative of soil spectral reflectance. This analysis exaggerates the subtle variation in spectra of six samples of soil samples from south-west Niger. Using the findinsg from other literature it is possible to identify the central wavebands responding to changes in iron oxide, organic carbon and water molecule bindings following extreme heating of the soil sub-samples. Magnitude changes in moisture content and organic carbon content can be identified simultaneously from a single spectrum. Variation in iron oxide type can be distinguished and it is perhaps possible to detect its magnitude once the obliteration affects of organic content are removed as in the case of the 8-hour sample (Galvao *et al.*, 1998).

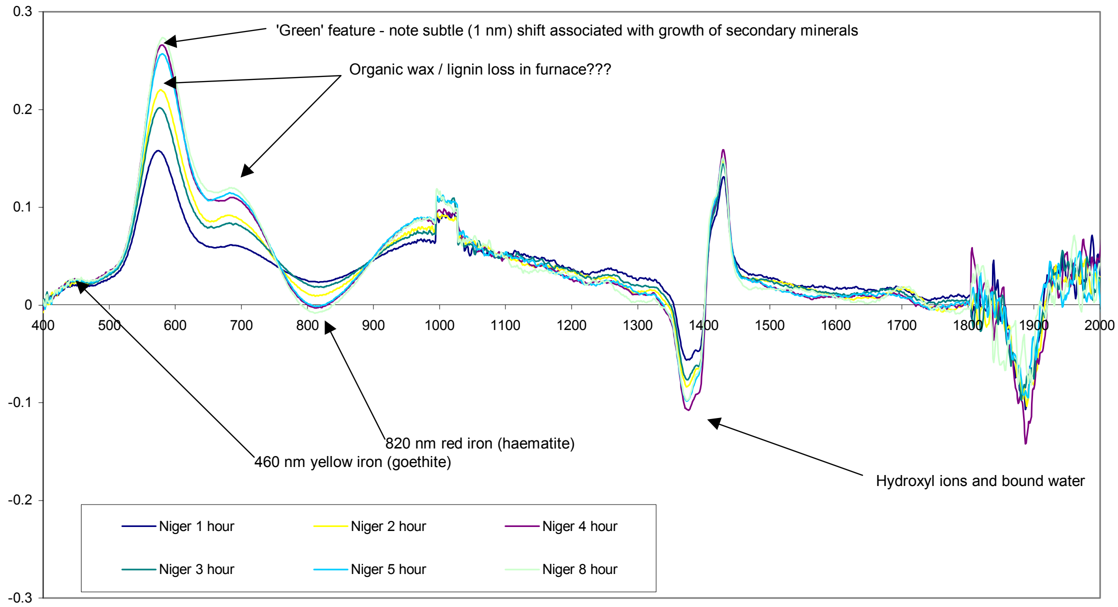

Figure 1. First derivative of nadir soil spectra of soil samples from south-west Niger subjected to different durations in a furnace at 350ºC to remove organic matter.

Quantitative analysis was used in an attempt to determine the resolution at which spectral reflectance data can detect individual magnitude changes in the central biophysical soil properties. Principle Component Analysis (PCA) and Canonical Ordination were used to provide and indirect and direct gradient analysis of the selected wavelengths and soil properties. The analysis initiated the construction of calibration tables of absolute changes in soil properties and corresponding changes in reflectance in specific wavebands.

Difference in the magnitude of reflectance as a function of view angle can be used to quantify the magnitude of shadowing at the soil surface. The shadowing in a soil surface is a direct consequence of illumination and the soil surface micro-topography. Figure 2 shows the results of bi-directional reflectance experiments designed to investigate the ability to detect difference in particle size; a simplified simulation of surface roughness in this case. Changes in reflectance with view zenith angle are indicted by variation in forward (negative view angles) and backward (positive view angles) scatter reflectance following standardisation to the nadir view. Polynomials are fitted as a guide only to the pattern of scattered reflectance for each soil surface. In general the forward scatter direction is better able to separate the shadowing of the surfaces. In this direction at the lowest view angle the surfaces separate according to their respective particle sizes. The results suggest that in this experiment we are able to distinguish the roughness of surfaces upto ca. 250 µm (0.25 mm).

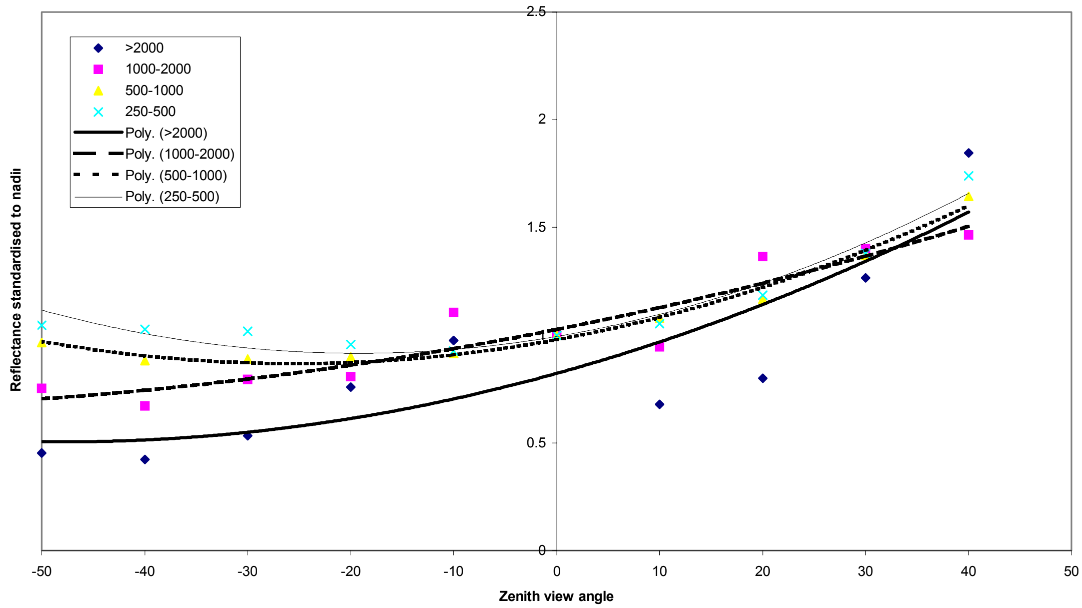

Figure 2. Reflectance in the solar principal plane of material sieved into four separate fractions to provide controlled surface roughness simulations.

The resolution at which roughness can be detected using bi-directional reflectance was validated using photogrammetry-derived digital elevation models of the soil surface.

These analyses were repeated for angular spectral reflectance collected during the process-based wetting and drying experiments (including crusting, cracking and slaking processes). Cierniewski's (1987) soil roughness model was used to investigate the ability to retrieve information on surface roughness. This model is essential for quantifying roughness under less controlled (field) situations.

Conclusion

Properties investigated in these experiments play a direct role in the susceptibility of a soil surface to wind erosion and collectively determine erodibility of an area under investigation at any one time. Preliminary results of this study provide the first indication that these properties may be replaced by spectral reflectance information. Hence there appears considerable potential for this information to be gathered frequently over many scales simultaneously. Continued process-based investigations using the calibrations determined in this study and validation in field settings will enable application of this method directly to the study of wind erosion processes.

References

Barnsley M. Allison D. and Lewis P. 1997. On the Information Content of Multiple View Angle (MVA) Images, *International Journal of Remote Sensing*, **18** (9): 1937-1960.

Cierniewski J. 1987. A model for soil roughness influence on the spectra of bare soils in the visible and near-infrared range. *Remote Sensing of Environment,* **23**: 97-115.

Galvao L.S. and Vitorello I. 1998. Role of organic matter obliterating the effects of iron on spectral reflectance and colour of Brazillian tropical soils, *International Journal of Remote Sensing*, **19, 10**: 1969-1979.

Geeves GW. Leys JF and McTainsh GH. 2000. Soil erodibility, In Charman PE and Murphy B (Ed.) *Soils Their Properties and Management* Oxford University Press, New York, pp.205-220.

Huete A.R. and Escadafal R. 1991. Assessment of biophysical soil properties through spectral decomposition techniques. *Remote Sensing of Environment*, **35**: 149-159.

Jacquemond S. Baret F. Hanocq JF. 1992. Modelling Spectral and bi-directional soil reflectance. *Remote Sensing of Environment*, **41**: 123-132.

Shao Y. and Leslie L.M. 1997. Wind erosion prediction over the Australian continent. *Journal of Geophysical Research*, Vol. **102**, No. D25: 30091-30105.

Sokolik, I.N. and Toon, O.B. 1996. Direct radiative forcing by anthropogenic airborne mineral aerosols. *Nature*, **381**: 681-683.