Available online at www.sciencedirect.com

ScienceDirect

Geomorphology 85 (2007) 17 – 29

GEOMORPHOLOGY

www.elsevier.com/locate/geomorph

Spatial and temporal distribution of cyanobacterial soil crusts in the Kalahari: Implications for soil surface properties

A.D. Thomas [a,*], A.J. Dougill [b,1]

[a] *Department of Environmental and Geographical Sciences, Manchester Metropolitan University, John Dalton Building, Chester Street, Manchester M1 5GD, UK*
[b] *School of Earth and Environment, University of Leeds, Leeds LS2 9JT, UK*

Received 4 May 2005; received in revised form 10 October 2005; accepted 14 March 2006

Abstract

Localised patterns of erosion and deposition in vegetated semi-arid rangelands have been shown to influence ecological change and biogeochemical cycles. In the flat, vegetated Kalahari rangelands of Southern Africa the factors regulating erodibility of the fine sand soils and the erosivity of wind regimes require further investigation. This paper reports on the spatial and temporal patterns of cyanobacterial soil crust cover from ten sites at five sampling locations in the semi-arid Kalahari and discusses the likely impact on factors regulating surface erodibility and erosivity.

Cyanobacterial soil crust cover on Kalahari Sand varied between 11% and 95% of the ground surface and was higher than previously reported. Cover was inversely related to grazing with the lowest crust cover found close to boreholes and the highest in the Game Reserve and Wildlife Management Zone. In grazed areas, crusts form under the protective canopies of the thorny shrub *Acacia mellifera*. Fenced plot data showed that crusts recover quickly from disturbance, with a near complete surface crust cover forming within 15 months of disturbance. Crust development is restricted by burial by wind blown sediment and by raindrop impact.

Crusts had significantly greater organic matter and total nitrogen compared to unconsolidated surfaces. Crusts also significantly increased the compressive strength of the surface (and thus decreased erodibility) and changed the surface roughness. Establishing exactly how these changes affect aeolian erosion requires further process-based studies. The proportion of shear velocity acting on the surface in this complex mixed bush–grass–crust environment will be the key to understanding how crusts affect erodibility.

Keywords: Cyanobacterial soil crusts; Erodibility; Surface roughness; Cohesivity; Kalahari

---

1. Introduction

The importance of vegetation to geomorphological processes in arid and semi-arid environments has been well-documented (e.g., Thornes, 1990; Bullard, 1997), especially in relation to aeolian erosion (Tsoar and Møller, 1986; Lancaster and Baas, 1998). In the Kalahari region of Southern Africa, geomorphological research has focused on the link between vegetation and dune mobility in the arid southwest of Botswana (Wiggs et al., 1994, 1995) and on the influence of shrubs on nebkha formation in the mixed farming areas of the dry sub-humid Molopo Basin (Dougill and Thomas, 2002). There is, however, less information on aeolian erosion

---

[*] Corresponding author. Tel.: +44 161 247 1568; fax: +44 161 247 6318.

E-mail addresses: a.d.thomas@mmu.ac.uk (A.D. Thomas), adougill@env.leeds.ac.uk (A.J. Dougill).

[1] Tel.: +44 113 343 6782; fax: +44 113 343 6716.

doi:10.1016/j.geomorph.2006.03.029

processes in the more extensive semi-arid savanna rangelands that typify much of Botswana, Eastern Namibia and Northern South Africa and on how surface erodibility is affected by biological soil crusts. There are several reports on the occurrence of biological soil crusts in this region (Skarpe and Henriksson, 1987; Aranibar et al., 2003; Dougill and Thomas, 2004) but little information on the implications for surface erodibility. Improved understanding of aeolian erosion processes will require advances in our assessment of both surface erodibility (the degree to which a surface is susceptible to erosion) and the erosivity (the potential to erode a surface) of wind regimes.

Biological soil crusts are present in all arid and semi-arid regions (Belnap and Lange, 2003) and form from the association of soil particles and organic matter with varying proportions of cyanobacteria, algae, lichens and mosses (Belnap et al., 2003). They have been shown to reduce surface erodibility as filaments of cyanobacterial sheath material entangle surface particles and create a crust that is more resistant to entrainment than the layers below (e.g., Belnap and Gillette, 1997, 1998). Assessing the impact of crusts on surface erodibility and of crusts and vegetation on erosivity are both problematic. Erodibility is a difficult property to quantify (Geeves et al., 2000) as it depends on a variety of inter-related textural, mineralogical, chemical, hydrological and biological characteristics that vary in space and time. Shao et al. (1996) suggest one of the main limitations of contemporary wind erosion models is their inability to incorporate the evolution of surface soil conditions during wind erosion events. There is, therefore, a need to improve the information available on soil surface conditions, such as cohesive strength and roughness that affect erodibility to enable wind erosion models to be improved to incorporate the evolution of soil surface conditions (Sokolik and Toon, 1996; Shao and Leslie, 1997; Chappell et al., 2005). Similarly, improved assessments of erosivity of wind regimes and in particular how this is affected by spatial variations in the nature of vegetation cover at a landscape scale and soil surface roughness on a local scale remains an area of active research (Wiggs, 1997).

Fundamental to understanding the impact cyanobacterial soil crusts have on erodibility is a comprehension of their spatial distribution and temporal variation. Several factors are recognised as influencing crust distribution and development, including substrate, vegetation type and cover, and disturbance levels (Belnap et al., 2003) and each is considered in this study. It has been shown that vegetation and biological crust cover are inversely proportional due to competition for light (Malam Issa et al., 1999) and nutrients (Harper and Belnap, 2001). Trampling damages biological crust surfaces and consequently in grazed areas crust cover is restricted in its spatial cover and longevity. Indeed, Zaady and Bouskila (2002) describe disturbance as the key factor in determining biological crust development in areas where physical conditions are relatively constant. Given the spatial homogeneity of the Kalahari, in terms of altitude, relief and surface water (Thomas and Shaw, 1993), it is reasonable to impart a significant role to grazing disturbances in affecting the distribution of cyanobacterial soil crusts. In this context, Berkeley et al. (2005) have shown that the canopies of woody shrubs represent quasi-discrete environments where crusts can develop despite high levels of disturbance, thus displaying the importance of localised spatial heterogeneity to improved assessments of surface erodibility. Analysis of crust distribution therefore needs to account for the role of different land uses at a landscape scale; differences in grazing intensity at a farm scale; and the relationship between crusts and vegetation at a local scale.

Dougill and Thomas (2004) have documented a biological soil crust cover of between 19% and 40% at a range of regularly disturbed, communal grazing sites on Kalahari Sands. Crusts were typically 3–4 mm thick. Three morphologically distinct crusts were identified: a weakly consolidated crust with no surface discolouration (type 1); a more consolidated crust with a black or brown speckled surface (type 2); and a crust with a bumpy surface with an intensely coloured black/brown surface (type 3). Preliminary taxonomic analyses using light microscopy suggest that the crusts comprise only a few species of cyanobacteria (mainly *Microcoleus* and *Sytonema*) (Thomas and Dougill, 2006). There is no evidence of more diverse assemblages or lichen crusts forming in this environment. In this regard, the Kalahari appears different to many other drylands where with low disturbance levels crusts become dominated by lichens and mosses (Belnap and Lange, 2003).

This paper reports on the impact of cyanobacterial soil crusts on the spatial and temporal patterns of soil surface properties from a range of locations in the semi-arid Kalahari and discusses their likely impact on surface erodibility. The objectives are

1. To determine the influence of grazing levels and vegetation communities on the distribution of soil crusts at a range of sites across the Kalahari.
2. To quantify recovery of cyanobacterial crust cover after removal of disturbance impacts.
3. To determine how different types of cyanobacterial crust affect soil surface nutrients, cohesive strength