Can micromorphological characteristics predict infiltration and sediment generation properties of degraded rangeland soils of north-eastern Queensland?

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Abstract

Micromorphological analyses were conducted on samples from two sites representing a range of surface conditions with different crust morphologies typically observed in degraded, grazed rangelands of northern Australia. Crust typologies of the samples studied were consistent with typologies previously reported by Valentin and Bresson (1992). Crust morphology only partially explained the infiltration response, while there was a closer relationship between crust typology and concentration of fine sediments in runoff. Most samples showed a high degree of bioturbation beneath the surface layer, with many macropores in-filled with smaller pellets. It is possible that the signs of bioturbation are relic, given the degraded state of the sites investigated, but these results do point to the potential role biological activity can play in rehabilitating degraded grazed soils, corroborating earlier work by Roth (2004).

Key Words

Micromorphology, crust typology, rangeland soils, infiltration, sediment generation.

Introduction

Soil surface crusts in rangelands and their role in runoff and erosion have long been recognized in tropical Australia. However, these crusts are much less documented than the crusts developed in southern and central arid and semi-arid Australia. The aim of this study was (i) to gain more information about the morphology, genesis and behaviour of soil surface crusts in north-eastern Australian rangelands, (ii) to test the relevance of the crust typology suggested by Valentin and Bresson (1992), (iii) to investigate the possible relationships between crust type and plot infiltration rate and sediment concentration and (iv) to discuss the relevance of integrating crust typology within a soil surface assessment framework suggested by Roth (2004).

Methods

Two degraded rangeland sites were selected for the micromorphological studies, about 80 km west of Townsville. Soil types at both sites were Red Chromosols, derived from metamorphic rocks and sedimentary rocks (Devonian), respectively. Vegetation at site 1 was dominated by Reid River Box (*Eucalyptus brownie*) and Desert Bluegrass (*Bothriochloa ewartiana*), in contrast to Narrow-Leafed Ironbark (*Eucalyptus crebra*) and Desert Bluegrass (*B. ewartiana*) at site 2. Rainfall simulation was used to simultaneously determine rainfall infiltration and sediment detachment for 26 small runoff plots (0.24 m^2, surrounded by a 0.3 m buffer zone) while at the same time providing rainfall impacted plots for micromorphological sampling. Plot selection was carried out on the basis of soil surface condition classes as proposed by Roth (2004). An infiltration index (I_{30}, the infiltration rate in mm/h after 30 mm of simulated rainfall) and a sediment concentration index (Sed_{30}, the concentration of fine silt + clay in runoff in g/L after 30 mm of applied rainfall) were used to compare the infiltration and sediment detachment response of plots with different surface conditions. Details on rainfall experimentation, sampling protocols and site properties are provided by Roth *et al.* (2003).

Undisturbed samples of the top 15 cm of the soil were taken from each plot after rainfall simulation. These undisturbed samples were dried prior to impregnation with epoxy resin in which an ultraviolet fluorescent dye was incorporated. One vertical cross section cut from each impregnated block was photographed under UV light using a digital camera. One 6x13 cm vertical thin section was prepared from each impregnated block and observed using a polarizing stereomicroscope. The samples were classified after the typology suggested by Valentin and Bresson (1992) and Bresson and Moran (2004).

Results and discussion

Crust morphology

Selected images covering the major crust types observed at site 1 are presented in Figure 1. The soil material below the crust (0-5 cm) was characterized by a 70/30 coarse versus fine (C/f) distribution ratio, the C-f limit being 20 µm. The textural fabric was chitonic (packing of clay-coated sand grains) to close porphyric (grains embedded in a continuous fine mass), with 50-100 µm packing voids. The soil matrix was quite heterogeneous, rather dense areas contrasting with loosely packed areas that looked like channels filled in by biological or 'faecal' pellets (Figure 1). Most pellets were irregular microaggregates, 100-300 µm in diameter, only some of them incorporating decayed organic fragments. There were also a few round to oval pellets, 0.5-1 mm in diameter. There were many roots 100-300 µm in diameter. Channels 1-2 mm in diameter were rather common. The surface overlying this material was classified as follows:

No crusts (Figure 1a) were characterized by a litter of leaves and grasses with many organic and organomineral biological pellets, 1-6 mm thick, overlaying a microaggregated layer with many pellets mixed up with microaggregates and with many compound packing voids. There were many channels 1-8 mm in diameter, sometimes filled in with pellets/microaggregates. However, the orientation and continuity of channels could not be reliably assessed from one vertical section and therefore data on orientation was not generated.

In *packing crusts* (Figure 1b), the surface was sealed by a very thin, 250-500 µm thick, structural crust with closely packed microaggregates, overlying moderately packed microaggregated material with compound packing voids. There were channels 1-5 mm in diameter sometimes filled in with pellets/microaggregates.

Pavement crusts (Figure 1c) were characterized by a gravel lag at the soil surface. Most of these gravels were not incorporated within the underlying sandy layer that exhibited many 0.3-3 mm vesicles, especially at the bottom of this layer. Cappings made of fine (silt-sized) particles occurred at the top of some gravels and vesicles. Underneath, a typical thin plasmic layer, 1-3 mm thick, was observed, that included many small vesicles 100-300 µm in diameter.

A thin plasmic layer right at the soil surface characterized *erosion crusts* (Figure 1d). The surface was rather smooth, with a few protruding sand grains. This plasmic layer, 100-500 µm thick, also sealed surface cracks. In the sample shown in Figure 1d there was no cryptogam cover. However, in other plots not shown here, the erosion crust was colonized by filamentous cryptogams that formed a discontinuous, felt-like cover. Crust typologies observed at site 2 were similar to those observed at site 1, despite a slightly lighter texture. In addition, one sample showed a *sieving crust*. The soil material below the crust (0-5 cm) was sandier and more microporous than the soil at site 1, with a 80/20 C/f distribution ratio and a chitonic textural fabric with many 100-200 µm compound packing voids. However, macropores, especially channels 1-2 mm in diameter, were less abundant. Like in site 1 plots, the site 2 soil matrix was strongly affected by biological activity, as evidenced by the occurrence of many channels that was usually filled in by biological pellets.

Relationship of crust morphology with infiltration

At site 1, crust types generally clearly differentiated between $I_{30} > 20$ mm/hr (*packing* and *no crusts)* and $I_{30} < 15$ mm/hr (*erosion* and *pavement crusts*). At site 2 the differentiation was less clear: some *packing crusts* had a higher I_{30} than some *no crusts*. Also, some *erosion crusts* had a rather high I_{30} (16.1 and 18.5 mm/hr, respectively), which is consistent with the weak development of these crusts. On the other hand, the *sieving crust* had an unexpectedly low I_{30} (7.9 mm/hr). The statistical analysis of the relationships between crust types and infiltration rates (Student's T-test) shows that there are only two significant differences between crust types, i.e. *no crust* versus *erosion crust* and *no crust* versus *pavement crust* (Table 1). This suggests that parameters other than crust type controlled infiltration rates. It is suggested that the denser matrix underlying uncrusted surfaces that is presumed to result from hoof compaction (Greene *et al.*, 1994) is likely to contribute to the reduction in hydraulic conductivity.

Table 1. Crust types and infiltration rate. Probability level of significance P(T <= 1) from unpaired, two tailed Student's T-test run after comparison of variances using a F-test.

	No crust	Packing	Pavement	Erosion
No crust	-	0.299	0.025	0.010
Packing	-	-	0.094	0.158
Pavement	-	-	-	0.464
Erosion	-	-	-	-

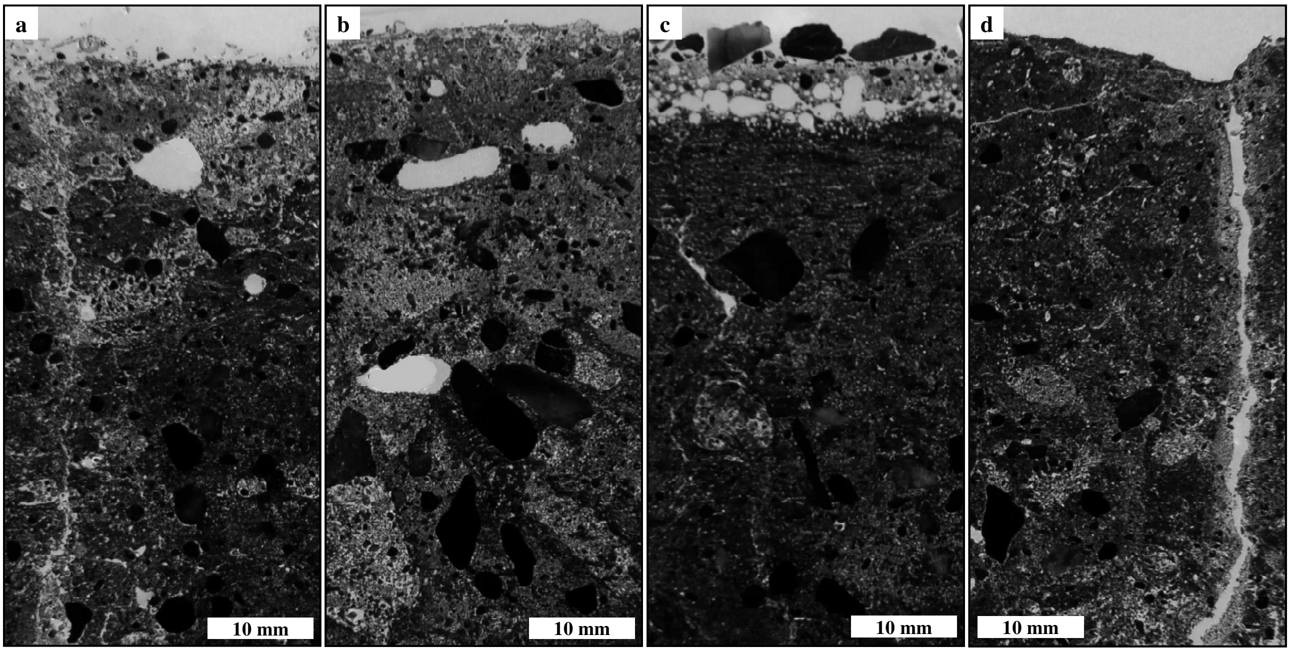

Figure 1. Crust types at site 1: (a) no crust , (b) packing crust, (c) pavement crust and (d) erosion crust. Images of polished blocks, UV.

Relationship of crust morphology with fine sediment generation
At site 1, crust types clearly discriminated between $Sed_{30} > 0.7$ g/L (*erosion crusts*) and $Sed_{30} < 0.7$ g/L (*no crust, packing crusts and pavement crusts*). At site 2, *erosion crusts* were also > 0.7 g/L, with the exception of one plot, where the cryptogam cover present might account for the lower sediment concentration. The statistical analysis of the relationships between crust types and sediment concentration (Student's T-test) shows that *erosion crusts* are significantly different from every other crust type (Table 2).

Table 2. Crust types and sediment concentration. Probability level of significance P(T <= 1) from unpaired, two tailed Student's T-test run after comparison of variances using a F-test.

	No crust	Packing	Pavement	Erosion
No crust	-	0.537	0.124	0.003
Packing	-	-	0.133	0.003
Pavement	-	-	-	0.005
Erosion	-	-	-	-

Conclusion

Overall, the micromorphology of the soil surface crusts from grazed soils in north-eastern Australia studied here is in good agreement with the typology suggested by Valentin and Bresson (1992). Structural crusts developed on these soils through compaction by raindrop impact (*packing crusts*) as well as through vertical sorting of soil particles by winnowing and sieving (*sieving crusts* and also *pavement crusts*). Most *erosion crusts* formed through erosion of the top sandy layer of *sieving crusts*, but some *erosion crusts* were transitional with *packing crusts*, as evidenced by a very thin surface plasmic layer without any vesicles. The crust micromorphology is also in good agreement with the soil surface conditions suggested by Roth (2004).

Below the crusted layers, the soil matrix showed signs of an intense bioturbation, as evidenced by the abundance of channels, either empty or filled in with pellets and/or microaggregates. However, there appears to be no clear relationship between bioturbation intensity and crust type. Even though there is no clear evidence of the relict or active character of the empty and filled in channels, the high degree of bioturbation points to ability of degraded grazed surfaces to recover and regain hydrological function.

There was no clear differentiation of crust types by infiltration rate. Several reasons might be invoked. First, at site 2, crusts were sampled 6 months after the rainfall simulation instead of 1 day at site 1. Second, it appears that the infiltration rates of many of the well covered plots were controlled by the underlying soil, i.e. a dense matrix (site 1) or a buried plasmic layer (site 2), rather than by the surface crust. Therefore, some form of matrix characterization might be required for relating surface condition assessment and soil hydrological properties. Sediment concentration appears to be more related to crust types than infiltration rate, especially when the ground cover was low. In such conditions, *erosion crusts* generated a sediment concentration much higher than *sieving crusts* and *pavement crusts* did.

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