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Micromorphology of microbiotic crusts from Niger soils. Influence on soil-water dynamics
Micromorphologie de croûtes microbiotiques de sols du Niger. Comportement vis-à-vis de l'eau

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Microbiotic crusts are formed by colonization of soil surface by communities of micro-organisms. In arid environments like Sahel, microbiotic crusts cover wide areas.

Microbiotic crusts were studied in Western Niger sahelian areas.

Micromorphology was observed by scanning electron microscopy. The microbiotic crusts studied are mainly formed by cyanobacterial filaments (5-20 µm in diameter). The filaments form a dense network on soil surface, delimitating pores up to 60 µm in diameter. This network traps and binds mineral particles. Porous organic areas with individual pore size of a few micrometers are observed below the crust surface. The organic matter probably derives from microbial extracellular secretions.

Run off and erosion were measured in field parcels with varying microbial cover and compared with those in bare areas. Field measurements do not permit to unravel the influence of microbial cover on run off. Erosion measurements show that soil particles, in particular sand particles, are stabilized by the microbial cover.

Keywords : micromorphology, microbiotic crust, erosion, run off, Sahel
Mots clés : micromorphologie, croût microbiotique, ruissellement de surface, Sahel

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Introduction

Microbiotic crusts are formed by colonization of soil surface by communities of micro-organisms (cyanobacteria and lichens, essentially). They are a common feature of arid and semi-arid environments, as for example on the Colorado Plateau (USA), or areas in Eastern Australia, or in Negev Desert (Israel). In some of these regions, like African Sahel, the stability and conservation of soils have a great importance for agricultural sustainability.

Microbiotic crusts affect properties of soils such as structure, water retention, and nutrient supply. Both field observations and experiments show a positive role of microbiotic crusts in soil stabilization and preservation against water and wind erosion (Eldridge and Greene, 1994). On the contrary, the role of microbiotic crusts in water infiltration and run off remains controversial, the reported results being often contradictory: for Eldridge (1993), microbiotic crusts favour water infiltration, whereas for Verrecchia et al. (1995), microbiotic crusts enhance run off.

Microbiotic crusts occuring in the western part of Niger (Sahel), at 70 km NE of Niamey, near the village of Banizoumbou, have been studied in order to examine their microstructure and their influence on run off and erosion.

Materials and methods

Two types of sites have been studied, open natural areas and parcels protected from animal circulation and human activities. Samples of dry crusts have been taken in each site, at the end of the rainy season, for scanning electron microscopy (SEM) of surface, thin sections of vertical soil profile, and microbial determination.

Measurements of run off and erosion have been performed in the enclosed parcels during two rainy seasons, from 17 July to 14 October 1996 (run off only), and from 6 May to 29 September 1997. Daily average rainfall was 12.0 mm for 33 rainy days in 1996, vs. 15.8 mm for 30 days in 1997.

The parcels (1 m^2) are of three types:

(1) 3 parcels lied fallow since 4 years, with a microbiotic crust covering 57-68% of the surface in 1996 (referred to as densely covered parcels in table 1). In 1997, the microbial cover fell to 7-13% of the surface (referred to as moderately covered parcels in table 1).

(2) 4 parcels lied fallow since 1 year, with a microbiotic crust cover of 6-26%. Two of these parcels were treated by an herbicide at the beginning of the rainy season in 1996. The other two were treated by an herbicide and by sodium hypochlorite in order to destroy and prevent development of any biological cover. In all treated parcels the percentage of microbial cover fell to 3-12% of the surface (referred to as moderately covered parcels in table 1); in 1997, the four parcels were almost devoid of any microbial cover.

(3) 1 parcel devoid of any microbial cover since 1996.

The parcels were connected with a collector which catches water run off and removed soil particles. Measurements were effected after each rain. Collected particles were sieved to separate sand (> 50 µm) and finer particles, and weighed after drying.

Results and discussion

Surface observations

All microbiotic crusts studied are essentially formed by a superficial network of cyanobacterial filaments 5-20 µm in diameter (Figs. 1, 3-5). The principal genera represented in the areas studied are Schizothrix, Scytonema and Microcoleus. Sand particles are entrapped by the network (Figs. 1, 3), whereas fine particles stick on filament surfaces (Figs. 1, 3). The sticking effect of cyanobacterial filaments is well known (Pentecost and Riding, 1986). In some places, the network also comprises filaments and organic membranes which probably derive from extracellular polymer secretions (EPS) of the microbes (Fig. 2). Cyanobacteria commonly produce EPS which reorganize in three-dimensional networks (Défarge et al., 1996). Organo-mineral aggregates can also be observed at the surface of some crusts (Fig. 5). They are composed of fine mineral particles, filaments, and organic membranes (Fig. 6). Aggregate cohesion seems to be assured by the membranes (Fig. 6). Thus, the trapping and binding effects of the cyanobacterial filaments and their organic remains probably play a positive role in stabilization of the crusts.

The three-dimensional reticular organization of cyanobacterial filaments and organic membranes results in the formation of pores up to 60 µm in diameter (Figs. 1, 2, 4, 5). This superficial porosity adds to the original porosity of soil.

Soil profile observations

SEM observations of thin sections of vertical profiles in microbiotic crusts reveal the presence of bodies of organic matter at depth (Fig. 7). These organic bodies have an internal spongy structure with pores of a few micrometers in diameter (Fig. 8). The organic matter probably derives from microbial EPS (compare Figs. 8 and 6).

Run off measurements

In all parcels, there is no run off for rainfalls below 4-5 mm. Over this intensity run off increases with rainfall. Run off ratio ranges and averages are similar in bare parcels and in moderately microbially-covered parcels (Table 1). A dense microbial cover seems to enhance run off: in 1996, average run off was 37% on densely microbially-covered parcels, vs. 27% in the other parcels (Table 1). However, the same high values are observed in the bare and moderately microbially-covered parcels in 1997 (Table 1; there was no more parcel with a dense cover in 1997). The higher run off ratios observed on bare and moderately covered parcels in 1997, compared to 1996 (Table 1), could be ascribed to higher daily rainfall average (see § materials and methods).

However, laboratory measurements seem to indicate that microbial cover enhances water retention capacity of these soils: at pF 2.5, water retention was 6.8-36% for microbially-covered samples, vs 2.1-3.8% for bare samples (Malam Issa, unpubl.results). The higher water retention capacity of covered parcels is probably due to the additional porosity caused by the filament network and the organic areas (Figs. 1, 2, 4, 8).

Thus, these results do not permit to unravel the role of microbial cover in water infiltration and run off. The microbiotic crusts studied appear to have a significant water retention capacity, which, however, is unsufficient to reduce run off. On the contrary, run off seems to be globally enhanced by a dense microbial cover.

Erosion measurements

As in the case of run off, there is no soil particle removal for rainfalls below 5 mm. Then, in all parcels, both fine and sand particles removal globally increase with rainfall, although some high rainfalls do not induce any sand removal. The results confirm the trapping and binding effect of the network of cyanobacterial filaments and organic membranes inferred from microscopic observations (Figs. 1-6): removal of soil mineral particles is reduced in microbially-covered parcels by comparison to bare parcels (Table 1); in particular, sand particles appear to be significantly retained by the microbial cover, with an average removal of 144 $g.m^{-2}$, vs. 219 $g.m^{-2}$ in bare parcels (Table 1).

Conclusions

The results presented show the influence of a microbial cover on the structure and the stabilization of soils. The microbiotic crusts from Niger are formed by a superficial network of cyanobacterial filaments and organic membranes which traps sand particles and binds finer mineral particles. Resistance to water erosion of sand, and, to a lesser extent, of fine particles, is enhanced by this network. Soil porosity is also affected by the microbial cover, with the additional presence of pores delimitated by the filament network at the surface of the crusts, and of spongy organic bodies probably derived from microbial remains at depth. Further studies remain necessary to unravel the influence of microbial cover on run off.

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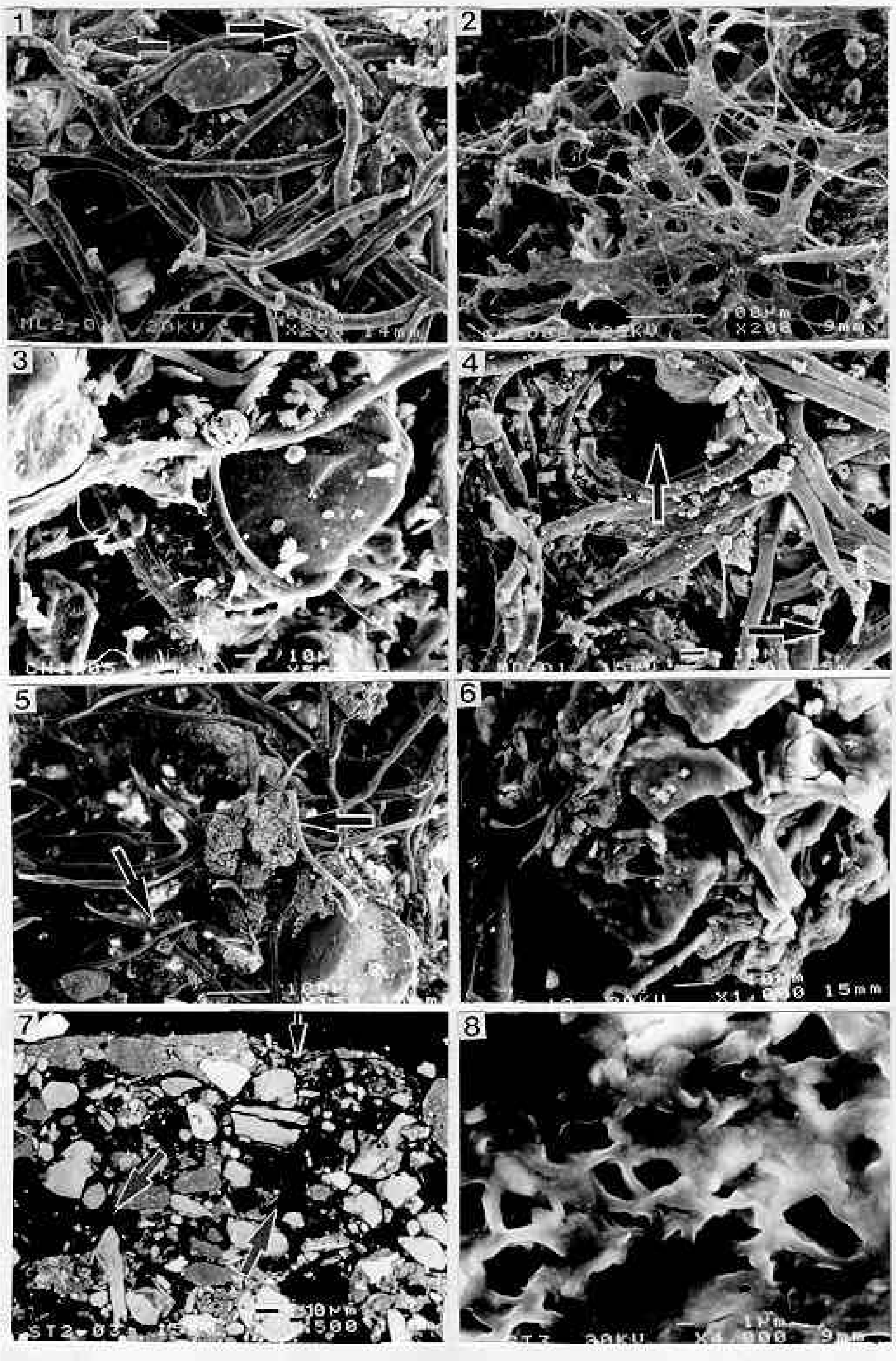
Figure captions

Figs. 1-6: SEM micrographs of the surface of microbiotic crusts from Niger. 1. Network of cyanobacterial filaments enclosing sand particles. Note fine particles sticking at the surface of filaments (arrows). 2. Network of filaments and organic membranes probably derived from extracellular secretion products. 3. Enlarged view of the filament network, showing close tightening of a sand grain and sticking of fine particles on filament surfaces. 4. View showing fine particles sticking on filament surfaces, and superficial pores (25-60 µm) formed by the intertwingling of filaments (arrows). 5. View showing the filament network, and aggregates 100-120 µm in diameter (arrows). 6. Blow-up of an aggregate in Fig. 5, showing the detailed structure formed by fine mineral particles, filaments, and organic membranes. Figs. 7, 8: SEM micrographs of thin section of vertical profile in a microbiotic crust. 7. The crust is essentially composed of quartz particles and organic bodies (arrow). The soil surface is shown at the top of the photograph. 8. Blow-up of an organic body in Fig. 7, showing the internal porous structure.

Table 1: Results of field run off and erosion measurements. (Average values from 20 values).

	Bare parcels	Moderately (3-13%) microbially-covered parcels	Densely (57-68%) microbially-covered parcels
Run off ratio (range, %) 17.07.96-14.10.96	0-76	0-94	0-94
Run off ratio (average, %) 17.07.96-14.10.96	27	27	37
Run off ratio (range, %) 06.05.97-29.09.97	0-76	0-72	-
Run off ratio (average, %) 06.05.97-29.09.97	38	39	-
Fine particle removal (range, $g.m^{-2}$) 06.05.97-29.09.97	0-92	0-56	-
Fine particle removal (average, $g.m^{-2}$) 06.05.97-29.09.97	14	12	-
Sand removal (range, $g.m^{-2}$) 06.05.97-29.09.97	0-662	0-510	-
Sand removal (average, $g.m^{-2}$) 06.05.97-29.09.97	219	144	-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