Spatial and temporal distribution of algae in soil crusts in the Sahel of W Africa: Preliminary results

Authors: Hahn, Andrea, and Kusserow, Hannelore

Source: Willdenowia, 28(1/2) : 227-238

Published By: Botanic Garden and Botanical Museum Berlin (BGBM)

URL: https://doi.org/10.3372/wi.28.2819

ANDREA HAHN & HANNELORE KUSSEROW

Spatial and temporal distribution of algae in soil crusts in the Sahel of W Africa: Preliminary results

Abstract

Hahn, A. & Kusserow, H.: Spatial and temporal distribution of algae in soil crusts in the Sahel of W Africa: Preliminary results. – Willdenowia 28: 227-238. 1998. – ISSN 0511-9618.

As part of an international project dealing with genetic diversity in wild forage species of the Sahelian Zone, a preliminary investigation of soil algal crusts in highly degraded environments was made. Soil sealing and the formation of crusts belong to the complex mechanisms of desertification processes. The kinds of soil algae present in the crusts and their temporal dynamics through the seasons are of relevance for the understanding of these processes. Surface crust samples from two wet and two dry seasons were examined for their algal flora by culturing and microscopy, in order to assess the role of algae in such processes. At least two different types of crusts were distinguished: dark crusts with a high algal contribution, dominated by filamentous blue-green algae (cyanobacteria), and light crusts with a far lesser algal contribution. The development of cyanobacterial crusts over two years suggests a seasonality, with a codominance of coccal green algae during the dry seasons. On light soils, a gradient was also apparent in the algal flora from sealed to sandy patches. In long-term development of fast changing arid ecosystems such as the Sahel, soil algae might prove a useful bio-indicator in screening for desertification and revegetation.

Introduction

The preliminary results of a study of soil algae, which are presented here, were obtained within the frame of an international project conducted by the Botanic Garden und Botanical Museum Berlin-Dahlem (Prof. Greuter) in collaboration with the International Plant Genetic Resources Institute (IPGRI) Rome, the University of Giessen (Biometrics and Population Genetics), and the International Crop Research Institute for the Semi-Arid Tropics (ICRISAT) in Niamey (Kusserow 1997). The goal of this four-year project financed by the German National Ministry for Economic Cooperation and Development was to investigate genetic diversity of wild forage plants in the Sahel Zone. Additional aspects of this project included the complex mechanisms of desertification processes as limiting factors of genetic diversity in this rapidly changing environment. Within these processes the phenomenon of soil sealing and soil crust formation plays an important role that is not yet properly understood. According to some authors (e.g., Campell 1979, West 1990, Casenave & Valentin 1989) and to our own investigations, the process of soil sealing may protect the soil layer against erosion. However, our own observations also suggest that sealed surfaces obstruct seed germination.

Although algae are primarily known from aquatic habitats, they are also important contributors to the soil microflora. Studies on the ecology of soil algae have been summarized by, e.g., Metting (1981) and Starks & al. (1981). A phenomenon observed especially in arid and semiarid regions is the formation of surface crusts on soils. Such crusts, sometimes covering large areas, are often formed essentially by blue-green algae (cyanobacteria).

Three questions triggered the present study. Which algal groups can be found in soil crusts in the fast changing ecosystems of the Sahel? Are there different types of crusts? Are there differences between sealed surface crusts and neighbouring open, sandy patches regarding the algal flora? An additional aspect included the seasonal dynamics of algal populations, a question that had not been investigated in that region before.

Description of the sample sites

The Sahel of W Africa could be described as a region dominated by grasslands with scattered trees and bushes. According to a division into ecoclimatic zones after Le Houérou (1989) the Sahel can be divided into a Saharo-Sahelian subzone with 100-200 mm annual rainfall, the subzone of the Sahel proper with 200-400 mm annual rainfall, and a Sudano-Sahelian subzone with 400-600 mm annual rainfall. The soil samples with their algal communities described here were collected in the Sahel proper (sites 'Bandio', 'Tillabéri' and 'Tahoua', Fig. 1) and in the transitional Sudano-Sahelian zone adjacent to the south (sites T2 and T3).

The sample sites **T2** and **T3**, are situated in the so called "tiger bush" area. "Tiger Bush" or "brousse tigrée" is a special vegetation mosaic, where the woody vegetation cover is patterned in bands that alternate with open areas. Such vegetation mosaics develop commonly on lateritic plateaus. The woody vegetation consists of only a small number of species. Dominant are *Combretum micranthum, C. nigricans* and *Guiera senegalensis*, frequently associated with *Acacia macrostachya, A. pennata*, *A. ataxacantha*, *Boscia senegalensis* and *B. angustifolia*. The herbaceous layer consists of *Microchloa indica* and *Tripogon minimus* (typical for the egdes of the vegetation bands), in more degraded situations (as represented by T2) of *Cassia nigricans, Panicum laetum, Borreria scabra, Triumfetta pentandra* and *Zornia glochidiata*. The less degraded site T3 is characterized by *Borreria scabra, Triumfetta pentandra*, *Zornia glochidiata*, *Cyanotis lanata, Blepharis maderaspatensis* and *Brachiaria ramosa* (Kueppers in Kusserow 1997). A classification of the different types of crusts is given by Casenave & Valentin (1989).

T2 (13°13′54″N, 01°47′41″E) is situated on a lateritic plateau, 8.7 km WNW Kobadi (on the road from Niamey to Burkina Faso, Fig. 1). The soil samples were collected from an open area between two vegetation bands (collecting dates: 12.8.1993, 27.9.1994, 8.3.1995). The lateritic soil shows some well-developed crusts, characterized by a dark (brownish-black) colour. The site is characterized by high human impact (grazing and wood-cutting). The rain gauge in Torodi (13 km S of Kobadi) for the period 1981-95 (1984 is missing) shows a mean annual rainfall of 548 mm.

T3 (13°04′03″N, 02°13′34″E) is located near the small road from Say to Kobadi, 13 km W of the road junction in direction to Tamou. This site is less degraded than T2 and shows a higher content of woody plants. The samples (lateritic soil) were taken near a *Guiera senegalensis* bush at the edge of a stripe of woody vegetation (collecting dates: 17.8.1993, 2.2.1994, 19.9.1994, 7.3.1995). The rain gauge in Say (period 1982-95) shows a mean annual rainfall of 546 mm.

The site **'Tahoua'** is located 26 km (14°52′32″N, 05°03′51″E, collecting date 11.2.1994) and 18 km (14°52′15″N, 05°03′40″E, collecting date 23.9.1994) W of Tahoua along the small and sandy route to Edir. These places show highly degraded pale soils (perhaps seasonally flooded) with a thin topic crust layer and nearly no vegetation cover. The mean annual rainfall at the rain gauge in Tahoua, for the period 1981-95, is 332 mm.

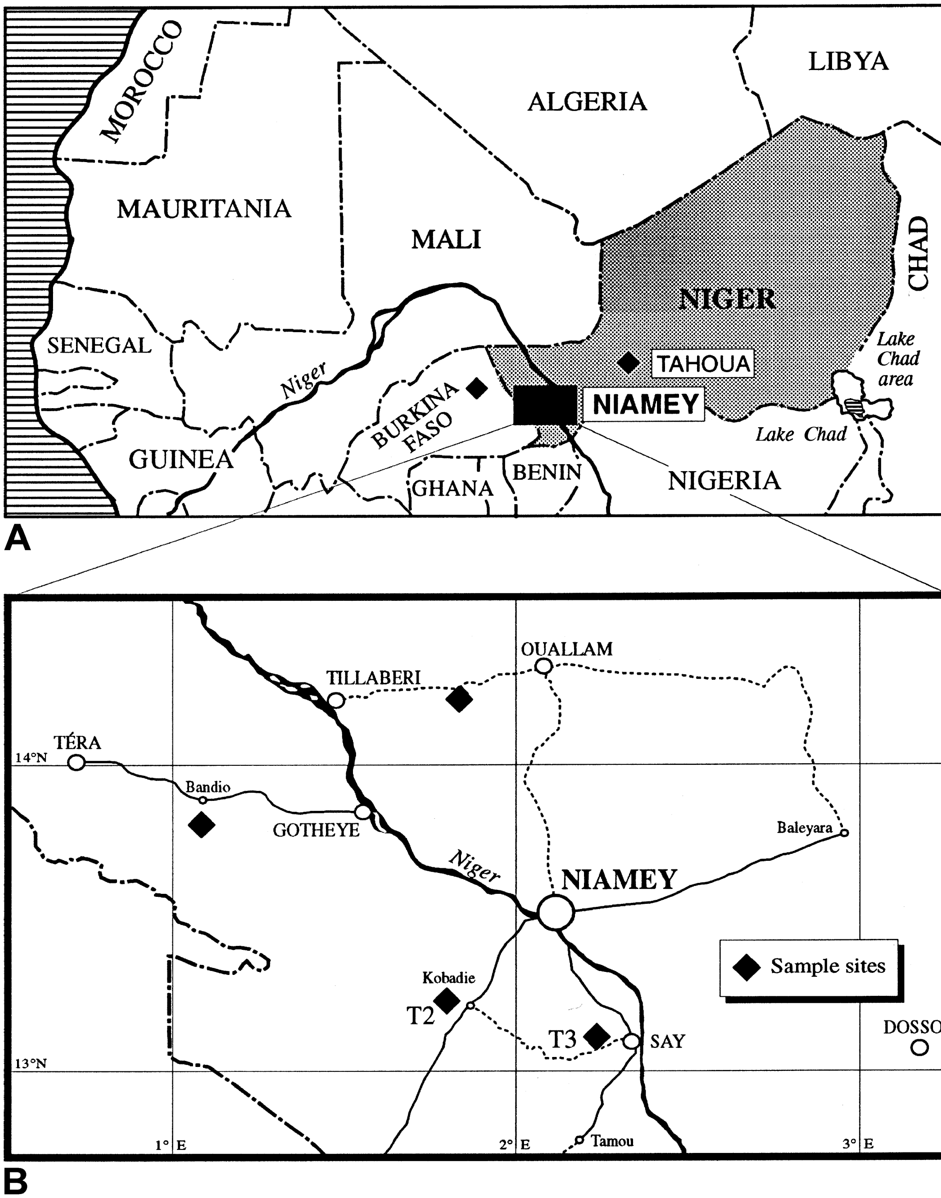

Fig. 1. Position of the sample sites – A: 'Tahoua' and 'Burkina'; B: T2, T3, 'Bandio' and 'Tillaberi'.

The site **'Tillabéri'** (46 km E of Tillabéri, 14°15′03″N, 01°51′32″E, collecting dates: 13. 9. 1994, 4.3.1995) on the small road from Tillabéri to Ouallam is located close to a millet field and shows a thin crust layer with a typical porous structure (0.5-0.8 mm thick) on top of red sandy soil with relics of roots. The mean annual rainfall for Tillabéri is 348 mm (period 1981-95).

The site **'Bandio'** c. 10 km S of the small village Bandio on the road from Gotheye to Tera is an open, highly degraded area devoid of higher vegetation (Fig. 2). Collections were made on

Fig. 2. Highly degraded area with sealed surfaces, S of Bandio (10.3.1995).

2.2.1994 and 10.3.1995. The coordinates are 13°48′43″N, 01°03′46″E and 13°48′35″N, 01°03′48″E. The predominant pale soil could be discriminated in paler and darker sections. The area is seasonally flooded. The mean annual rainfall (rain gauge Gotheye) is 377 mm for the period 1981-95. An example for dark crusts is given in Fig. 3.

The site **'Burkina'**, 14°11′32″N, 0°46′22″W is located in the northern part of Burkina Faso, on the road from Aribinda to Dori, 22 km E of Aribinda. The sample was collected on 1.9.1994 near a termite mound. Relics of a tree indicate the final stage of the termites' work.

Material and methods

Segments (approx. 1.5-3 × 1.5-3 cm) of soil crusts were sampled and subsequently stored under dry and dark conditions until further processing. Sampling took place during four periods between August 1993 and March 1995, including two dry and two wet seasons. The samples are stored in the Botanical Museum Berlin-Dahlem (B). For microscopical analyses, cultures were maintained in liquid medium (modified from Chu, as given in Ettl & Gärtner 1995 by adding 50 ml soil extract per 1000 ml) at 25 °C in a light-dark-cycle of 16L/8D at 60 µmol $m^{-2}s^{-1}$. Growth of algae and qualitative composition of the samples were screened at regular intervals using a microscope with reverse optics and a resulting total magnification of factor 160, thereby avoiding disturbance or contamination of the cultures. For each sampling period a sample of sterilized sand was similarly treated as a control and continuously screened during the culturing period in order to plot the possibility of a contamination.

Major taxonomic groups were identified during a culturing period of about six weeks. During the first two sampling periods, a rough estimate of the algal contribution to the crust composition was made. For the following two periods, algal diversity was assessed in more detail by recording morphological descriptions of the specimens observed in the raw cultures. The relative abundance was estimated in early stages of cultivation, whereas the qualitative composition of the samples was observed over several weeks.

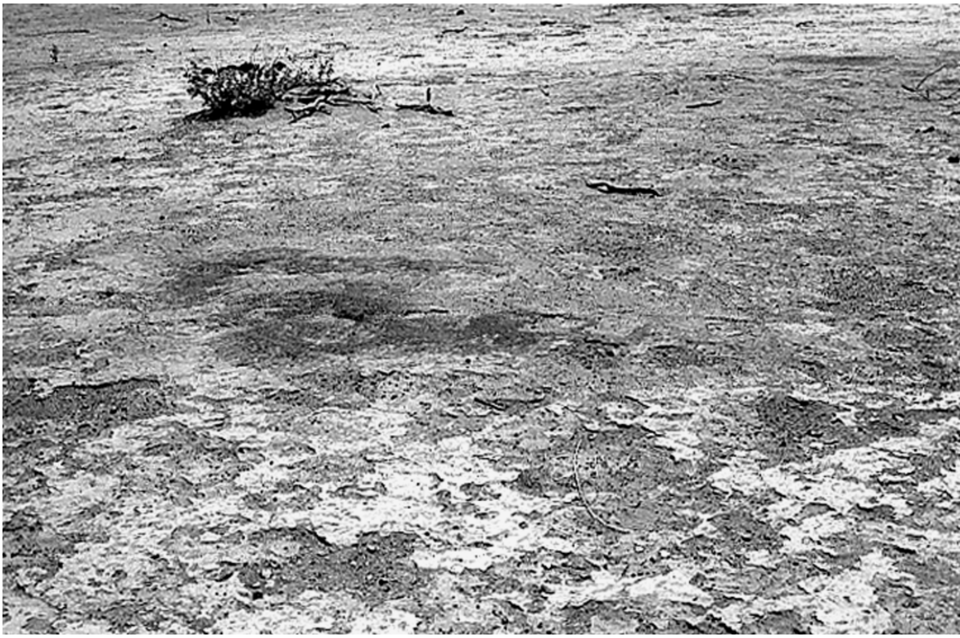

Fig. 3. Dark crusts, formed by blue-green algae, road Tillabéri - Quallam, 32 km before Quallam (18.4.1996).

Results

The pH of the soil samples (analysed by the Institute for Soil Survey, Technical University Berlin) had values between 6.3 and 6.9, a range most favourable for microorganism. The conductivity (µS/cm)1:2.5 is very low in Tillabéri (5.6-28.4) and T2 (21.8-36.2) and higher in T3 (147.1) and Tahoua (251). The low conductivity and a low content of salt (values between 0.045 and 0.183 % weight (1:5)), indicate no salinization problems. Analyses also showed that the crusts were not stabilized by carbonate.

In the material examined, the major groups of algae were (1) filamentous blue-green (cyanobacterial) taxa and (2) coccal green taxa (Tab. 1). Since many species of soil algae can only be determined by establishing clonal cultures, no determinations beyond genus level have been attempted. The 'coccal green taxa' are collectively termed so without further determination, as *Chlorophyceae* and *Tribophyceae* could not be separated. Two other groups, (3) coccal blue-greens and (4) diatoms, were of minor importance and are not taken into considerations for the purpose of this study.

The following filamentous blue-green (cyanobacterial) taxa were distinguished (descriptions are based on the samples studied).

Schizothrix sp.: Trichomes about 6.5 µm wide, cells cylindrical in shape and slightly drawn in at the margins, longer than wide, dark blue-green. Trichomes tapering towards the end, shorter trichomes thereby appearing lanceolate. One to three trichomes enclosed in a mucilaginous sheath, light brown in colour, appearing granular, though possibly through attached particles.

Aphanizomenon sp.: Thin (less than 6 µm wide) blue-green trichomes arranged in loose fascicles. Common mucilaginous sheath not visible. Single strands separated from fascicle, trichomes slightly tapering, cells longer than wide, trichomes motile (jerky lateral movements, presumably gliding longitudinal motion as well).

Tab. 1. Qualtitative composition and assessed algal abundance of examined soil samples. Descriptions of the sample sites are given in the text.

wet season 1993 (summer)	dry season 1994 (spring)	wet season 1994 (summer)	dry season 1995 (spring)
T3			
Rich. Filamentous blue-green algae dominating. Variability lower than in T2, but spectrum of algae similar. Two samples, one of a softer and one of a slightly harder layer, very similar in their algal composition.	Filamentous blue-green algae dominating over small coccal green forms, which are sometimes masked with red pigments. In total poor in algae. Spectrum similar to the wet season sample and T2. Soil very hard, crumbles readily.	Rich. Filamentous blue-green algae dominating. Additional various coccal green forms, though in lower abundances.	Rich. Filamentous blue-green algae dominating over coccal green forms. Large variability, similar to T2, but more green taxa. Two samples, one sligthly lighter from a small depression, one from a darker crust below a bush, very similar in their algal composition.
T2			
Rich. Filamentous blue-green algae heavily dominating.	(no samples)	Rich. Mostly filamentous blue-green algae in high abundance, variability not very large. Two samples, one from a dark crust somewhat higher, one from a light layer with some water, slightly lower. Both show high agreement in algal composition.	Rich. Mostly filamentous blue-green algae, some small coccal green forms (appearing later during cultivation), often masked red (carotinoids?). Some agreement with the samples of T3. More coccal green forms than at earlier dates, but less than in T3.
Tillabéri			
(no samples)	(no samples)	All samples not very rich. Three samples along a gradient towards an open, sealed surface, 2 m apart. The two more sealed samples are very similar to each other, with some coccal green forms and only a few thin filamentous and coccal blue-green ones. Diversity quite low. The third sample, a sandy surface near a millet stand, shows a similar spectrum of coccal algae, but additionally more filamentous blue-green forms (about 1:1), the overall algal density is higher than in the others, as is the diversity.	All samples very poor. Along the gradient the algal composition is: 1) sealed surface: few coccal green cells of several taxa, almost no filamentous blue-green algae; 2) small sandy patch with millet: very few small coccal green cells, masked red; 3) sandy hill: few filamentous blue-green algae (3 taxa), very few coccal green forms.
Tahoua			
(no samples)	Poor. Small coccal green cells in nestlike aggregates, often masked red. Single monadoid cells, no filamentous blue-green algae.	Poor. Few thin filaments of one blue-green taxon, some coccal green cells.	(no samples)
Bandio			
(no samples)	Poor. Mostly coccal green cells (masked red) in nestlike aggregates, few thin filaments of blue-green algae. Two samples very similar.	(no samples)	No algae detected.
Burkina			
(no samples)	(no samples)	Very poor. In one of the samples, no algae detected, in the other one small coccal green cells in very low abundance.	(no samples)

Fig. 4. Gallert-enclosed trichomes of *Nostoc* sp. (cyanobacteria) characteristic of the algal flora of the sandy surface of sampling site Tillabéri, collecting date 13.9.1994.

Scytonema sp.: Wide (10 µm) blue-green trichomes, cells cylindrical, only slightly longer than wide, end of trichome obtusely rounded. Cell content appearing granular. Red-brown mucilaginous sheath partly visible enveloping older trichomes. Flatly cylindrical heterocysts, hormogones and false branching visible in older cultures.

Nostoc sp.: Dark blue-green in colour, trichomes arranged in irregularly shaped mucilaginous aggregates. Single trichomes shaped like a string of beads. Width of trichome: 3 µm; diameter of aggregate: 13-45 µm (Fig. 4).

The different sampling sites show considerable differences in both the algal biomass and the heterogeneity of taxon composition. The macroscopical aspect of crusts in the examined area makes it possible to distinguish two types of soil crusts: dark (brown to black) crusts, and light crusts whose colour resembles that of unsealed, sandy patches nearby.

Dark soil crusts are characteristic of sites T2 and T3. They are dominated by filamentous blue-green algae, which is most evident in sampling series T2. During the dry season of 1995, taxa of the genera *Schizothrix* and *Aphanizomenon* were most prominent in the samples of T2 and T3, while during the preceding wet season *Scytonema* was also an important contributor to soil algal biomass in T2. Besides, in all samples of T2 and T3 coccal green taxa were evident (Fig. 5). Their relative abundance, although represented only by one to four taxa, was comparable to that of the blue-greens (two to eight taxa) in the dry season samples but considerably lower in the wet season samples. Other taxonomic groups (diatoms, coccal blue-greens) were of minor importance.

Light soil crusts were observed at the sampling sites Tillabéri, Tahoua, Bandio and Burkina. In those soils, filamentous blue-green algae were considerably less abundant than in the dark crusts of T3 and T2, while coccal green algae in some cases were more common and reached a higher diversity. The overall algal frequency in light soil crusts was quite low. It ranged from no

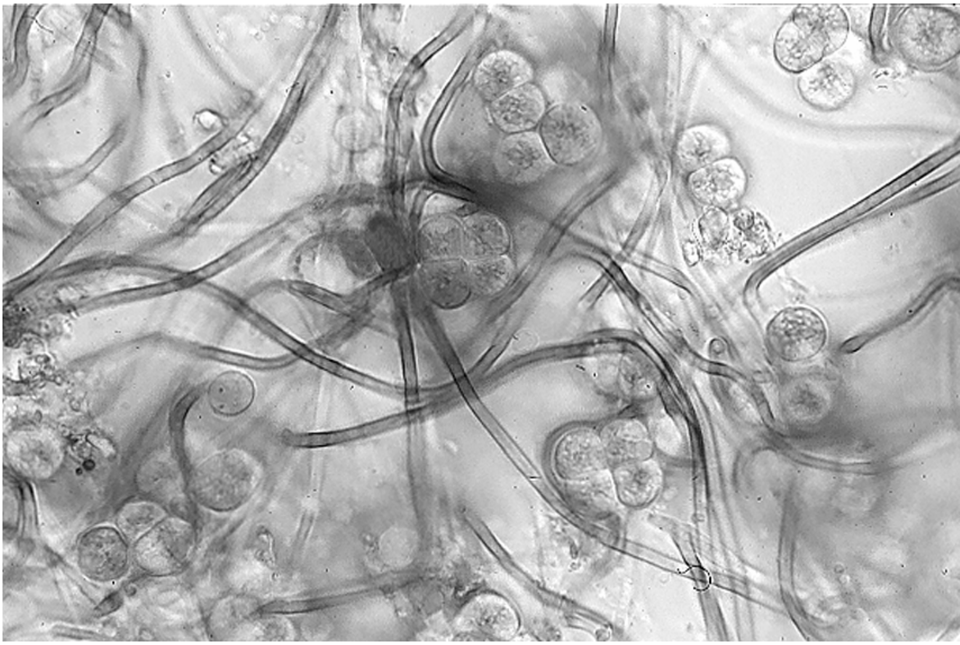

Fig. 5. Filamentous blue-green algae (cyanobacteria) and coccal green forms *(Tribophyceae* or *Chlorophyceae)* from site T3, collecting date 17.8.1993.

detectable algae in the dry season samples of 1995 from Bandio to very few algae in low diversities in the dry season sample of 1994 from Bandio, Burkina and both samples from Tahoua. Only the light soil crusts from Tillabéri were more diverse in their algal composition with one to four filamentous blue-green and three to six coccal green forms. Representatives of the blue-greens *Schizothrix, Scytonema* and *Aphanizomenon,* dominating the dark crusts of sites T2 and T3, were not present in the Tillabéri samples, where only one *Nostoc* species was detected.

In both sampling series from Tillabéri (three samples each), in spite of a relatively low frequency of algae when compared to the dark crusts of T3 and T2, the same tendency along the sealing gradient was observed. During the wet season of 1994 as well as the dry season of 1995, the samples from the sealed surface crusts were very poor in filamentous blue-green algae (one taxon each) but contained several coccal green taxa, though in low frequency. Towards the non-sealed, sandy patch nearby, a shift of algal composition was apparent at both dates with a slightly reduced diversity of coccal green taxa and an increasing number and abundance of filamentous blue-green taxa. As in the dark soil crusts, members of other taxonomic groups like diatoms and coccal blue-greens were of minor importance.

Discussion

In the examined area, at least two different types of crust formation are to be postulated, leading to (1) dark cyanobacterial crusts and (2) light crusts. Besides organic substances and amorphous sesquioxides, silica is cited in literature as a hardening agent in the form of amorphous silicic acid often forming viscose, gelatinous covers on mineral soils (Uehara & Jones 1974). Mechanical processes, too, have an important part in soil hardening, as in the compression of mineral substances dependent on grain size, grain form and water influence (Ewing & Gupta 1994). A finely grained mineral substance with temporarily high water saturation increases the surface consolidation during drying, through the effects of negative interstitial water pressure, which draws the particles towards one another. Cations and electrolytes of interstitial water also influence crust formation. Soils rich in sodium seem to form crusts more readily (Uehara & Jones 1974), which the authors attribute to easier particle dispersion during wet phases and subsequently stronger compaction during drying. Very often, however, biological and physico-chemical factors are not to be separated, as is the case in the incrustation of, e.g., *Microcoleus* trichomes with calcium carbonate, causing a substrate lithification (Campbell 1979). In our investigation, however, an effect of calcium carbonate could be excluded by physico-chemical soil sample analyses.

The sealing effects of surface crusts against the infiltration of rainwater, which were observed at the test sites, are caused by filamentous blue-green (cyanobacterial) taxa in the dark crusts. Even in the laboratory, cultures with a high density of blue-greens showed a conspicuously slowed water acceptance. On the other hand, crust formation seems to be independent of algal contribution in the light crusts, although water infiltration was slowed considerably on light crusts, too.

In the literature, the role of soil crusts is controversial. While the positive effect of reduced erosion is agreed (see, e.g., Campbell & al. 1989), the hindrance of penetration by both water and diaspores of higher plants found in some cases could not be confirmed in other cases. St. Clair & al. (1984) and Isichei (1980) observed better infiltration and decreased rainwater runoff, but Noy-Meir (1973) found higher runoff on clay and silty soils, especially when covered with soil crusts. Walker (1979, cit. in West 1990) suggests hydrophobicity, caused by microorganisms, as a reason. Additionally, the role of cyanobacteria in this context seems to be taxon specific, as Scherer & al. (1984) determined durations from 0.6 to 15.5 min for a rewetting of terrestrial cyanobacteria.

The effect on water infiltration and seed germination is still inconclusive. Reduced infiltration, usually judged negatively, might have the positive effect of decreased evaporation after a soaking, as Harper & Marble (1988) described for black cyanobacterial and lichen crusts in Utah. Complete crusts seem to inhibit seed germination by several mechanisms. Diaspores falling to the ground do not reach the soil, and the number of seedlings that are able to penetrate the crust from below seems to be reduced significantly. Soils with undisturbed crusts are usually poorer in both species and individuals of higher plants (Danin 1978). On the other hand, slight disturbance of the surface crust may lead to a stimulation of seed germination and seedling establishment (Harper & St. Clair 1985 and Eckert & al. 1986, both cit. in Harper & Marble 1988). In our study sites, which we have observed continuously during a period of four years (in one case, since 1989), there was no regrowth of vegetation in the open areas. Although the crusts were broken up from time to time by livestock, seedlings of woody pioneers did not establish. The evaluation of satellite data back to the early 1970s indicates no recovery of vegetation in the sites described above, but an increase of sealed surfaces (Kusserow 1997). This could be also documented for another research area in Mali, using multitemporal satellite data (Kusserow 1994).

The effects of surface-sealing discussed above are valid for crusts with and without algal contribution. The role of algae can be evaluated. Due to their ability to fix nitrogen from the atmosphere, blue-green algae (cyanobacteria) with heterocysts are usually thought to have an improving effect on soils and thereby on higher plants. This applies even more to arid and semiarid regions, since nitrogen-fixing bacteria here are rarer than in other climates (Loftis & Kurtz 1980). Shields & Durrell (1964) suggest soil algae as a first stage of succession on substrates poor in nutrients.

Algal communities show some regularities associated with climatic regions and soil conditions. Grain size and water capacity, in particular, have decisive influence on soil algae communities, apart from pH and salinity (Shields & Durrell 1964). In seven samples from T3, T2, Tahoua and Tillabéri, analysed for soil properties, the pH was found to be between 6.3 and 6.9, therefore not accounting for the differences in algal flora. Blue-green algae prefer alkaline habitats, although the main reason for this fact is presumably not so much the pH but rather the chemical processes in the substrate initiated (Shields & Durrell 1964). An increased concentration of sodium also seems to promote cyanobacterial development, while a higher content of nitrogen has negative effects (Shubert & Starks 1980). The latter is probably caused by the decreasing competitive advantage in relation to other groups of algae not capable of nitrogen fixation.

Shields & Durrell (1964) list predominantly filamentous blue-green algae for deserts in the southwestern USA, New South Wales (Australia), India and Algeria, including taxa of the genera *Microcoleus*, *Nostoc*, *Schizothrix* and *Scytonema*, often forming thick, almost continuous layers. In our examinations, too, taxa of the genera *Schizothrix*, *Nostoc* and *Scytonema* in some cases presented high percentages of the biomass. Shachak & Steinberger (1980) found filamentous blue-green taxa in the Negev (Israel) as well as some coccal chlorophyte taxa. Friedman & al. (1967, cit. in Starks & al. 1981), in contrast, found chlorophytes to be dominant in their examination sites in the Negev. Nevertheless, blue-green taxa seem to be the characteristic element of the soil algal flora of arid regions, and contradicting results might be due to fluctuations in the algal contribution during the annual cycle, as discussed below.

Species of the cyanobacterial genera cited above are highly resistant against desiccation (see Shields & Durrell 1964). Nevertheless, our observation of a cyanobacterial predominance during the moist season and a higher contribution of coccal green taxa during the drier periods seems to be common in arid regions, although it does not correlate with the temperature ranges cited in the literature (moist and warm versus dry and cool in India, see Shields & Durrell 1964). Seasonal effects have not often been examined (Metting 1981). For deserts and steppes, Grondin & Johansen (1993) found the qualitative seasonal fluctuation to be minimal, although quantitative differences in some cases were very large. Examinations in Utah (USA) showed that nitrogen fixation and primary production of crust-forming cyanobacteria reached their maximum during the wet season and under the influence of dew, especially while light intensity and temperatures were low (Skujins & Klubek 1978). During those wet periods, trichomes of some genera are able to reach the soil surface by fast gliding movement. *Microcoleus vaginatus*, for example, was found to move up to 48 mm in twelve hours, which equals five-hundred times its trichome length (Campbell 1979). For *Nostoc commune*, its ability to bind sand grains has been shown (Shubert & Starks 1979). Taxa such as *Scytonema*, *Nostoc* and *Rivularia* are characteristic of advanced stages of succession, following Shubert & Starks (1979), and these authors documented an increased diversity of unicellular green algae to be a sign for progressed stabilisation of soil conditions.

According to Campbell & al. (1989), land management should not be restricted to areas with an immediate economic significance, but should include the prevention of erosion by microbial crusts. This objective of a stable crust association as a means of erosion control and a protector for a seed repository of higher plants seems to be approached by our study sites with dark crusts (sites T2 and T3). Further taxonomic investigations and a more detailed differentiation especially in the group of coccal green taxa will be necessary in future examinations, but even from the data known so far, the large species variety of these two sites was obvious. For the other examination sites, the role of algae in crust formation seems to be negligible. The sealing effect of those physico-chemical soil crusts most probably works as an erosion control, but without the effect of a soil improvement by inducing nutrients.

The presence of soil algae at the sites we studied could be interpreted as the first, but also as the last stage of a succession. The sites demonstrating poor algal flora are all located in the Sahel Zone proper with a mean annual rainfall of 332-377 mm. All these sites (Tahoua, Tillabéri, Bandio and Burkina) could be classified as extremely degraded and their low content of algae might be seen as the last stage in colonization by living organisms. Characteristic for all these sites is the fact that they were covered with vegetation years ago (Kusserow 1997).

These preliminary results, mentioned above, indicate a possibility to measure different desertification levels, which can be described, more precisely, by the content and composition of their soil algae.

"Desertification" is a man-induced process in the fringes of the desert, which strengthens a natural aridification process and results in desertlike conditions in areas that do not form part of the desert ecosystem (modified after Mensching 1990). Excessive wood cutting in order to establish fields or for fuel is one major factor in reducing the vegetation cover. But less vegetation means less infiltration of precipitation and an increase in runoff. Furthermore the upper soil layer, no longer fixed by a vegetation cover, will be removed by wind and water erosion. This results in a formation of thin crusts, described above. Less vegetation cover also results in changes of the microclimate, influencing soil temperature and soil humidity.

The establishment of these crusts therefore plays an important role in the complex desertification process. It is all the more amazing that most of the research work in arid regions on soil algae has been restricted to the deserts proper.

The aspect of sealing and crust forming as a conservation method could be discussed as a good adaptation strategy in an environment characterized by tremendous climatic changes. Over the last 100 000 years there have been three main arid phases in the Sahel: one at 70 000 B.P., a second between 20 000 and 15 000 B.P., and a third that begun around 5000 to 3500 B.P. (Mainguet 1991). During the periods of dry climate in which the region we know today as the "Sahel" belonged to the desert, the sealing of the upper soil layer ensured the storage of seeds and therefore enabled the ecosystem to revert into a savanna-covered system during the humid stages.

Future studies will have to observe long-term development of the algal flora. Taxonomic and physiological examinations will have to be extended. These should include analyses of the role of other microorganisms (above all, bacteria) as well as physico-chemical processes (e.g., crack formation, physical and chemical soil properties). A continued screening of the future development of 'stable' crusts such as in sites T3 and T2 should be combined with an examination of possible colonization of sealed surfaces in the other regions.

Acknowledgements

The authors would like to thank Renate Erbas for producing the maps. We are especially grateful to Prof. Dr G. Kraepelin, Prof. Dr U. Geissler and to Dr R. Jahn for critical discussion of our results.

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Addresses of the authors:

Andrea Hahn, Institut für Systematische Botanik und Pflanzengeographie, Freie Universität Berlin, Altensteinstraße 6, D-14195 Berlin; e-mail: hahnandr@zedat.fu-berlin.de

Hannelore Kusserow, Botanischer Garten und Botanisches Museum Berlin-Dahlem, Freie Universität Berlin, Königin-Luise-Straße 6-8, D-14195 Berlin; fax: 0049 30 775 20 75.