A first record of biological soil crusts in the Cape Floristic Region

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To date, the biological soil crusts (BSCs) of southern Africa are thought to be dominated mainly by cyanobacteria, with the exception of the lichen fields of the Namib Desert. Because soil microorganisms can physically modify, maintain or create habitat for other organisms – including soil biota and plants – they have been considered ecosystem engineers. Therefore, the presence of BSCs may be a good indicator of ecosystem resilience. Although BSCs are found throughout the world, recent work has suggested that the absence of BSCs in the fynbos of South Africa may be as a result of the inherent acidity of soils. We surveyed one area within the fynbos biome for the presence of BSCs and determined the relative cover of vegetation and different crust types. We found a widespread presence (up to 80% of surface soil) of BSC communities in fynbos soils. We conclude that soil acidity may not be a constraining factor in the development of BSCs in fynbos soils and that previous reports on the absence of BSCs in fynbos soils may have been based on insufficient field observations. We encourage future studies in this region in order to determine the currently unexplored spatial distribution of soil microbial communities and the taxonomic composition of microorganisms in fynbos soils.

Introduction

Biological soil crusts (BSCs) are formed by an association of soil mineral particles and microorganisms which live in the top few millimetres of the soil.[1] The presence, distribution and characteristics of BSCs are controlled by the interactions between climate, geology, vegetation and the disturbance impact of livestock and game.[2,3] BSC formation is often initiated by filamentous cyanobacteria, such as *Microcoleus* spp., during episodic events of available moisture with the subsequent entrapment of mineral particles by a matrix of extracellular polysaccharides.[4] If undisturbed, the development of an appropriate substrate by filamentous cyanobacteria may lead to the establishment of fungal, lichen and moss populations, characterised by a slower growth rate.[5] Crust organisms have low moisture requirements and tolerate a wide range of temperatures, which enables them to exist even when moisture deficit limits vascular plant growth.[6] Once crust organisms have colonised gaps, the characteristics of the crust is then influenced by edaphic factors such as soil texture and topography.[7]

BSCs are found in almost every habitat in the world, including hot regions (e.g. Mojave Desert[8]), cool or semi-arid drylands (e.g. Colorado Plateau[6]), beneath rocks (hypolithic crusts[9]), continental and oceanic landscapes of the Arctic to Antarctic and the Polar desert,[10] savanna woodlands,[11] sub-humid regions,[12] subalpine and alpine areas[13] and sand dunes (e.g. Kalahari[14]). Although BSCs have colonised almost all soil types, finer textured soils tend to have higher BSC cover than unconsolidated sand and are found in areas with the lowest impact from wind forces, such as concave micro-depressions.[15]

A recent study[16] described the diversity and distribution patterns of BSCs from the Namibian–Angolan border down south to the Cape Peninsula (South Africa), reporting BSCs in six out of the seven different biomes covered along the transect. In the hyper-arid Namib Desert, BSCs are mostly lichen-dominated,[16,17] cover vast areas devoid of vascular plants and take most of their available moisture from fog. In the dry savannas of southern Africa, including on Kalahari Sand soils, BSCs are dominated by cyanobacteria.[16,18] Büdel et al.[16] reported that BSC formation was absent in the fynbos because of the acidity of the soil.

Fynbos vegetation occurs within the Cape Floristic Region (CFR) at the south-western tip of Africa, which is recognised as a global biodiversity hotspot.[19] Although the fynbos includes a range of soil types (e.g. Regosol, Podzol and Arenosol), which are typically acid to neutral (ranging from pH 4 to 7) and nutrient-poor,[20] the presence of microbial soil communities in these soil types remains poorly understood. Most studies in the fynbos have focused on soil factors (i.e. soil nutrients) that determine the distribution of vascular plants[21] or the diversity of microbial communities in soils.[22] We report the occurrence of BSCs in the CFR where previously reported as absent.[16]

Materials and methods

We surveyed an area within Table Mountain National Park, between October and December 2010. The site selected (34.14340 S, 18.24177 E) was located at Olifantsbosch in the Cape of Good Hope Nature Reserve portion of the Table Mountain National Park. The annual rainfall is about 650 mm, with maximum and minimum temperatures of 24 °C and 9 °C, respectively. The landscape (60 m to 80 m above sea level) is flat to moderately sloping (Figure 1a) on light-grey quartzite Table Mountain Sandstone. This site was selected based on the availability of its climatic, edaphic and botanical information, and because BSC formation was recently reported as absent.[16]

Four types of BSCs were used in this study from the classification given in Dougill and Thomas[23], and were selected based on crust form and morphology: unconsolidated, type 1, type 2 and type 3. This classification has previously enabled the study of different developmental stages of the BSC community within crust types.[24] To determine BSC distribution, the percentage of BSC cover was recorded on a 50 m x 50 m plot (divided into 2500 1 m x 1 m quadrats) and every plant species within the plot was identified. The diversity of vegetation was determined to correlate the spatial distribution of BSCs with soil nutrient levels and the presence of vegetation (data not shown here). The spatial arrangement of plant species and BSC was recorded on each 1 m x 1 m quadrat. BSCs were collected with a spade and carefully placed in Petri dishes between two layers of cotton wool to avoid rupture of the crust. Samples were transported back to the laboratory to determine pH levels and soil community composition. Soil pH was measured in a 1:2.5 solution of soil : water as suggested by Anderson and Ingram[25]. Identification of soil microorganisms was done by mounting portions of the BSC for microscopic examination as described by Alef and Nannipieri[26] at a magnification of 115 times with an Auto-Montage microscope (Leica MZ16A, Leica Microsystems, Wetzlar, Germany).

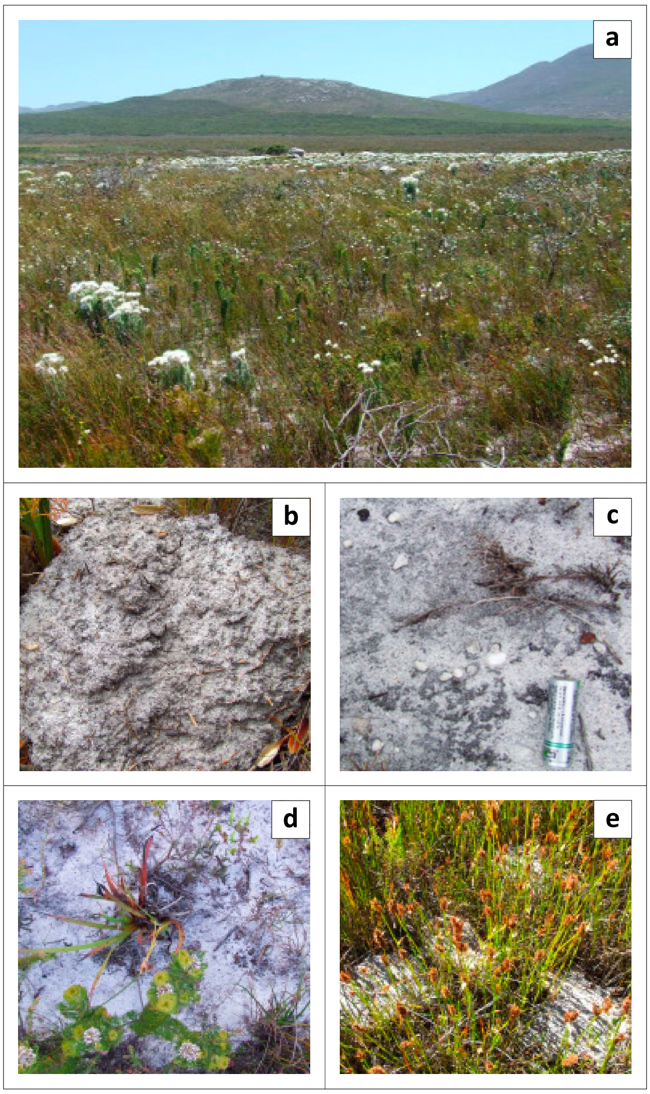

FIGURE 1: Different biological soil crust (BSC) formations in fynbos soils. BSCs were found in (a) flat to moderately undulating slopes at Olifantsbosch in Table Mountain National Park. Type 2 crusts formed (b) small coppices whilst (c) well-developed type 3 crusts were found in open spaces. (d) A combination of crust types 1 and 2 was usually found in plant interspaces (with *Dilatris pillansii* in the centre and *Serruria villosa* in the lower left corner). (e) The presence of coppices within the vegetation was also recorded.

Results

BSCs covered between 5% and 80% of the surface (when considering 1 m x 1 m quadrats). BSCs varied from a weakly consolidated crust with no obvious surface colouration to a dark well-consolidated surface with microtopography (Figure 1c and 1d), with crust types 1 and 2 as the most dominant types. Well-established BSCs were common and could be removed in large pieces with algal filaments visible within the sheath. The sheath is thought to be mostly composed of carbohydrates.[14] BSCs were also observed in plant interspaces and were most commonly found away from walking trails. The formation of small coppices (30 cm to 50 cm in diameter and up to 10 cm high) was commonly observed among wiry vegetation, composed mostly of crust type 2 (Figure 1b and 1e). These small coppices have, to our knowledge, never been described before. A widespread presence of lichens on rocks was also observed in the reserve. Algal patches (greening of the surface) were observed on the soil surface at several sites after summer rainfall showers or periods of increased humidity. Based on light microscopy, BSCs from the observed sites were mainly dominated by cyanobacteria and algae, but the identification of species was not possible at this magnification.

Soil texture was predominantly characterised by medium sand, with a pH ranging from 4.5 to 5.5. Plant cover ranged between 5% and 100% of the surface. The vegetation forms part of the Peninsula Sandstone Fynbos, dominated by a wide range of genera of Asteraceae, Ericaceae, Fabaceae, Proteaceae and Restionaceae. BSCs were commonly found under the protection of small shrubs such as *Metalasia* and were present despite the high cover of fynbos vegetation such as *Elegia cuspidata*.

Discussion

Soil microbial diversity and relative abundance are generally characterised after isolation of DNA followed by an analysis of the 16S rDNA sequence by amplification through polymerase chain reactions[22]; however, this procedure is expensive and time-consuming. Here, we report only on the presence of BSC formations on soils in the fynbos with low pH.

Among soil properties, soil pH is important for the establishment and diversity of microorganisms.[27] Büdel et al.[16] suggested that the absence of BSC formation, in particular of filamentous cyanobacteria, in the Fynbos Biome can be attributed to the low soil pH (below pH 4). The absence of BSCs on such acidic soils would thus be related to the physiology of soil microorganisms. In general, green algae seem to favour more acidic soils, whereas cyanobacteria are found preferentially on alkaline soils and are considered intolerant to low pH conditions,[28] and lichens seem to grow at pH levels across the gradient.[1] However, there are some apparently contradictory findings on the effect of soil pH on BSC distribution and on crusts dominated by mosses, lichens or cyanobacteria. For example, a positive correlation between lichens and soil pH was recently found in the Zapotitlán drylands of Mexico,[29] but no correlation was detected between soil pH and crusts dominated by mosses and lichens in the Mojave Desert.[8] Although infrequent, there are also scattered records of cyanobacteria in acidic environments at pH values just above 4,[30] which suggests that cyanobacteria can tolerate acidic soils.[31]

The reported absence of BSCs in the fynbos could also be related to a combination of several biotic and abiotic factors that affect the development of BSCs. BSCs can be present under all conditions of soil moisture and their cover is generally not reduced during droughts, as microorganisms can remain dormant throughout long drought periods.[3] The spatial and temporal distribution of BSCs can also change with time, for example, depending on the level of disturbance.[3]

We conclude that the previously reported[16] absence of BSCs within Table Mountain National Park may not have been related to low soil pH levels, but rather could have been based on insufficient field observations. BSCs are not always visible and can be difficult to identify in the field as the diversity of microorganisms in the crust can also induce different crust morphology and colouration at the surface. Given the widespread presence of BSCs found, we suggest that future studies should include extensive analyses of topsoil parameters and microbial diversity.

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Competing interests

We declare that we have no financial or personal relationships which may have inappropriately influenced us in writing this article.

Authors' contributions

D.M.M. was responsible for the experimental and project design. D.M.M. and C.H. wrote the manuscript.

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