Physico-chemical and spectral characteristics of soil crusts in semiarid areas. An ecosystem condition index?

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ABSTRACT

Physical and biological soil crusts occupy a wide extension in arid and semiarid areas all over the world. Numerous authors consider Biological Soil Crusts (BSC) as ecosystem engineers in arid lands because they control resource availability, through the regulation of the water balance, reduction of erosion and enhancement of soil fertility via nitrogen and carbon fixation. Evidences exist of the replacement of some types of BSC by other crust types over time and different types have different effects on resource availability. Therefore, the relative abundance and distribution of the different development stages of BSC can be considered as a soil quality indicator which includes information about the dynamic condition of the ecosystem, as well as its degree of maturity and conservation, as BSC extend slowly. The objective of this work is to verify if the physicochemical characteristics in the crust and the subjacent soil get better as BSC development increases, so the distribution of soil crusts (in different stages of development) in an ecosystem will be largely related to soil physicochemical conditions. Two semiarid areas in the province of Almeria were chosen: El Cautivo (Tabernas) and Amoladeras (Cabo de Gata) and the most representative physical and biological soil crusts were identified at both sites. The stage of development of BSC was considered. For each crust type, physical and chemical characteristics for the crust and the soil underneath were sampled and some spectral features of BSC were measured as an indicator of photosynthetic activity, using a portable spectroradiometer. Amoladeras appeared as an ecosystem with improved physicochemical characteristics in the two sampled fractions in comparison with El Cautivo (a badlands area), except water retention capacity, due to textural differences. Furthermore, the deepness of the absorption peak at 680 nm was higher in the BSC of Amoladeras than of El Cautivo. At both sites, water retention capacity, nitrogen and carbon content were higher in the BSC than in the physical crust both in the crust and the subjacent soil. These parameters, also at both sites, increased along with BSC development both in the crust and the in subjacent soil, except for the soil C and N content in Amoladeras.

Keywords: Biological soil crust, development, physicochemical characteristics.

INTRODUCTION

Physical soil crusts are thin layers on the top surface soil, more compact than the material just beneath. When climate and soil conditions are favorable, physical soil crusts are usually colonized by a series of organisms, generating Biological Soil Crusts (BSC) which consist of associations of soil particles with cyanobacteria, algae, microfungi, liverworts, bryophytes and lichens. BSC have a widespread distribution in arid and semiarid ecosystems all over the world and, although they constitute a minimal portion of the soil profile, play an important role in dryland ecosystems. BSC are considered as ecosystem engineers in arid lands (Bowker et al., 2006) because they control the water balance (Warren, 2001) by regulating infiltration and runoff (Belnap, 2006). They also increase soil moisture retention, maintain soil surface aggregates, decrease erosion (Eldridge *et al*., 2000), and strongly influence nutrient cycling (Eldridge and Greene, 1994) and vascular plant colonization (Belnap et al., 2003). They fix atmospheric N and increase soil organic matter content, they entrap soil particles and influence other parameters as soil texture, soil porosity, cracking, roughness and soil cohesion. When soil crust develops it extends until occupying all available surfaces but the development continues by replacing some species by others, e.g., the lichen-dominated crust is a late-successional stage with regard to the cyanobacterial crust (Lazaro et al., 2008). Therefore, the stage of development of BSC could be considered as an indicator of the soil quality, in its upper horizon and the BSC type would indicate the degree of maturity. The aim of this work is to verify the hypothesis that the higher the BSC development, the better the underlying soil physicochemical characteristics, so the distribution of different BSC in an ecosystem would be largely related to soil physicochemical conditions.

METHODOLOGY

Two semiarid ecosystems where soil crusts are well represented were selected, on silty and sandy soils and under different conditions of spatial distribution of soil crusts: “El Cautivo” and “Amoladeras”, both in Almeria (SE Spain). El Cautivo (Tabernas) is a badlands area developed on gypsiferous marls, where crusts appear as unique soil cover in many landforms, covering more than 80% of the soil surface. The most representative soil crust types identified in El Cautivo were: 1) structural crust over marls (S); 2) depositional crust with Incipient Cyanobacteria (IC); 3) Cyanobacteria-dominated crust (C), and 4) Lichen-dominated crust, (L). In Amoladeras (Cabo de Gata Natural Park), over an exhumed and dissected caliche area in the distal, flat part of an alluvial fan system, BSC appear in open areas among disperse shrubs and the most representative crust types were: 1) Cyanobacteria-dominated crust (C), 2) Lichen-dominated crust, (L) and 3) Moss-dominated crust (M). Four samples of each crust type and the soil below were collected in the field. Total nitrogen, organic carbon content and water retention capacity were analysed in the laboratory. The Kjeldhal method was applied for total nitrogen (N) determination. Organic carbon content (OC) was determined by wet oxidation using potassium dichromate as oxidant. Water retention capacity (WRC) was measured by the pressure-membrane method. Furthermore, in order to detect chlorophyll as a surrogate of photosynthetic activity and to distinguish physical from biological soil crusts, four plots for each crust type were selected and fifteen reflectance measurements were taken in the field on each plot using a GER 2600 portable spectroradiometer.

RESULTS AND DISCUSSION

In Amoladeras, the soil chemical characteristics show a higher quality as expected from sandy soils on a flat alluvial fan system with higher infiltration rates and lower erosion (Chamizo et al., 2008) than soils from El Cautivo, a badlands area with steep slopes and silty soils (Table 1). However, due to textural differences, water retention capacity is higher in El Cautivo than in Amoladeras. As can be seen in Table 1, the structural crust (physical crust) exhibits the lowest WRC, nitrogen and carbon content. Within BSC, total nitrogen, organic carbon content and WRC increase as crust development increases, at both sites, suggesting that BSC contribute organic carbon to soils in arid and semiarid ecosystems by carbon fixation and intensify biogeochemical activity responsible for a larger organic matter transformation (Danin and Ganor, 1991). According to Housman *et al*. (2006), the higher the biomass of cyanobacteria, the larger the fixed nitrogen in dryland soils. We observe that soil carbon and nitrogen content are higher under the most developed crusts in El Cautivo. However, in Amoladeras, soil under the cyanobacteria crust (the least developed crust at this site) presents higher carbon and nitrogen content. It can be due to a more accelerated decomposition of organic matter and a higher rate of denitrification under the most developed crusts. But it should be noticed that this result can also indicate that soil C and N content do not lineally increase from any given stage to the next one along BSC development, as the rate of photosynthetic organisms can be larger in some relatively earlier stages.

Tables 1 and 2. Total nitrogen, organic carbon content and water retention capacity (%) (average from four repetitions) and standard deviations, for each crust type and the soil under the crust, at both study areas. When differences are significant (p<0,1), they are annotated with a different letter before the value of the variable.

	Crust	C (g kg^{-1})	N (g kg^{-1})	WRC (-33 kPa) (%)	WRC (-1500 KPa) (%)
El Cautivo	S	^{a}4,83 ± 0,86	^{a}0,85 ± 0,05	^{a}23,23 ± 2,01	^{a}10,78 ± 1,00
	IC	^{a}5,98 ± 1,15	^{a}0,97 ± 0,27	^{a}23,55 ± 4,80	^{a}9,32 ± 0,09
	C	^{a}11,43± 4,98	^{b}1,71 ± 0,56	^{b}28,69 ± 2,15	^{a}11,21 ± 0,49
	L	^{b}24,58 ± 13,89	^{b}2,13 ± 0,32	^{b}27,87 ± 1,72	^{b}17,74 ± 8,04
Amoladeras	C	^{a}12,95 ± 0,82	^{a}1,61 ± 0,06	^{a}20,99 ± 5,93	^{a}8,91 ± 2,29
	L	^{b}28,43 ± 2,67	^{b}2,75 ± 0,21	^{ab}24,93 ± 2,45	^{b}17,23 ± 0,88
	M	^{b}27,70 ± 1,98	^{b}2,88 ± 0,94	^{b}28,36 ± 4,22	^{c}24,77± 3,60

	Soil under crust	C (g kg^{-1})	N (g kg^{-1})	WRC (-33 kPa) (%)	WRC (-1500 KPa) (%)
El Cautivo	S	4,95 ± 0,82	^{ab}0,84 ± 0,07	^{a}23,47± 0,69	12,16 ± 1,13
	IC	5,17 ± 1,60	^{a}0,73 ± 0,16	^{ab}24,92 ± 4,25	11,58 ± 1,62
	C	6,45 ± 1,42	^{ab}1,00 ± 0,28	^{bc}27,78 ± 3,70	11,91 ± 2,19
	L	7,33 ± 2,59	^{b}1,08 ± 0,17	^{c}28,88 ± 1,38	13,29 ± 1,11
Amoladeras	C	^{a}13,45 ± 1,25	^{a}1,49 ± 0,09	14,88 ± 1,95	^{a}6,76 ± 1,73
	L	^{b}11,02 ± 1,33	^{b}1,32 ± 0,09	16,92 ± 0,59	^{b}8,54 ± 0,65
	M	^{b}10,21 ± 0,19	^{b}1,20 ± 0,04	14,68 ± 1,39	^{a}6,41 ± 0,70

All BSC biota absorb water, but it is expected that as biomass increases, water absorption increases (Belnap, 2006). In our case, crust water retention capacity increases with crust development, though the differences of this variable decrease in the soils under the different crusts.

Figure 1 shows the spectral curves of different crusts in El Cautivo and Amoladeras.

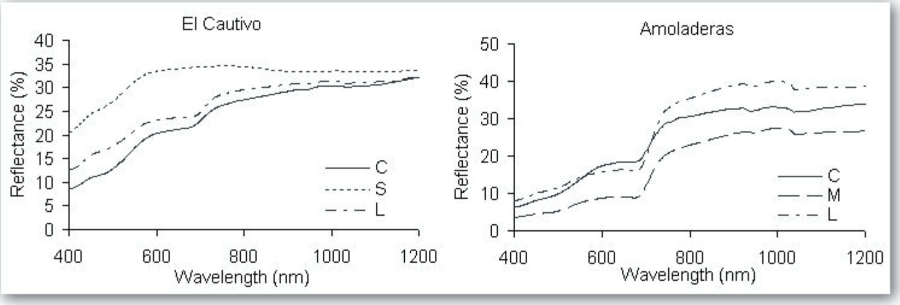

Figure 1. Mean reflectance spectra of different crusts at both sites.

BSC present the common absorption peak around 680 nm (due to chlorophyll *a*), which is absent in the physical crust. As cyanobacterial biomass increases, the amount of chlorophyll a, and thus soil coloration, increases as well (Belnap et al, 2008). The absorption feature at 680 nm is higher in the BSC from Amoladeras than those from El Cautivo and this absorption increases with crust development. However, the average reflectance in the lichen crust is higher than in the cyanobacteria and the moss crusts due to its lighter colour because it is mainly formed by white lichens.

CONCLUSIONS

BSC retain more water, maintain better soil moisture of the surface horizon and fix more carbon and nitrogen in the crust and in the subjacent soil than the physical crusts. The higher the BSC development, the higher their water retention capacity and carbon and nitrogen fixation and also higher their contribution of carbon and nitrogen to soils underneath. The absorption feature due to chlorophyll *a* is also higher in the most developed crusts, suggesting that the photosynthetic activity is also higher. Therefore, BSC distribution can be related to soil physicochemical conditions and the presence of well-developed BSC can be considered as an index of ecosystem health.

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