How development and disturbance of biological soil crust do affect runoff and erosion in drylands?

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ABSTRACT

Deserts and semiarid ecosystems (shrublands and grasslands) are the largest terrestrial biome, covering more than 40% of the Earth's terrestrial surface and Biological Soil Crusts (BSCs) are the predominant surface type in most of those ecosystems covering up to 70% of its surface. BSCs have been demonstrated to be very vulnerable to disturbance due to human activities and their loss has been implicated as a factor leading to accelerate soil erosion and other forms of land degradation. Incorporation of the response of different type of soil crusts and the effects of their disturbance is likely to improve the prediction of runoff and water erosion models in arid and semi-arid catchments. The aim of this work is to analyse the influence of BSC development and the impact of crust disturbance on infiltration and erosion. Extreme rainfall simulations at microplots scale were performed in two semiarid ecosystems with different lithology and conditions of occurrence of BSCs: El Cautivo and Amoladeras. Moreover, open plots were set in the field to examine the response under natural rainfall, and contributing area was estimated from a 1 centimetre resolution DEM built from laser scan height records. Our results demonstrated that the stage of development of the undisturbed BSCs affects infiltration and erosion with an increase in the infiltration rate and a decrease in erosion as crust development is higher. Crust disturbance affected infiltration and erosion: trampling caused the highest runoff rates and crust removal the highest erosion, nevertheless, the effects of crust disturbance on erosion were lower for Amoladeras, an area with a flat topography and a coarser soil texture. At both sites, under extreme rainfalls, although crust removal enhanced infiltration at the beginning of the rain, the early development of a new physical crust increases runoff until reaching similar runoff rates as undisturbed crusts. The responses of BSCs to extreme simulated rainfall and to natural rains were compared to evaluate when the differences among BSCs in different degree of development are more accentuated in order to identify critical thresholds to incorporate in runoff and erosion models.

Keywords: Biological soil crust, rainfall simulation, natural rainfall, runoff, erosion.

INTRODUCTION

In arid and semiarid lands, the open areas between vascular plants are usually covered by a complex community formed by cyanobacteria, microfungi, algae, lichens, and bryophytes known as Biological Soil Crusts (BSCs). BSCs influence many soil surface characteristics like soil texture, porosity, cracking, water retention, roughness or cohesiveness and, by this way, they can affect hydrological cycles at a specific site (Belnap, 2006). Several studies have been carried out about the influence of BSCs on runoff and infiltration at plot scale, with controversial results. Some works indicate that the presence of BSCs increase infiltration and consequently decrease runoff (e.g., Greene and Tongway, 1989; Eldridge, 1993). However, other works indicate that BSC decrease infiltration and increase runoff (e.g., Greene *et al*., 1990; Solé *et al*., 1997), or have no effect on these processes (Eldridge *et al*., 1997). The differences found can be attributed to the different type of crusts and stage of development involved in the different works. Besides, BSCs are quite vulnerable to disturbance and activities like cattle grazing, off-road vehicles and trampling that cause the loss of BSCs or in many cases convert late successional BSCs to early ones. Disturbance of BSCs may decrease infiltration capacity, thus increasing runoff and sediment loss (Barger et al., 2006). The objective of this work is to analyse the influence of BSC development and the impact of crust disturbance on infiltration and erosion. This paper constitutes the first results of a project concerning the incorporation of soil crusting dynamics into runoff and erosion modelling at catchment scale in semiarid ecosystems in which the hydrological responses of crusts just after crust disruption and later during crust reconstitution, colonization and succession processes are being analysed.

METHODOLOGY

Two semiarid ecosystems with different topography and lithology were chosen: El Cautivo, a badlands catchment with steep slopes and a silty substrate (gypsipherous marl), and Amoladeras, a flat caliche area with sandy soils, both in the province of Almeria (SE Spain). Round plots of 0.25 m^2 on the main crusts identified at each site were selected and delimited by steel rings. In El Cautivo, the crust types identified were: 1) structural crust over marls (S) (a physical crust); and three BSCs, which in order of development stage were: 2) depositional crust with incipient cyanobacteria (IC); 3) cyanobacteria-dominated crust (C), and 4) lichen-dominated crust. In Amoladeras, three BSCs were identified as the most representative soil crust types: 1) cyanobacteria-dominated crust (C), 2) lichen-dominated crust, (L) and 3) moss-dominated crust (M). Three disturbance treatments were applied for each crust type: a) no disturbance of crust; b) crust trampling, stepping 100 times over the plot, and c) scraping. At both sites, four plots for each crust type and treatment were selected. Then, two consecutive 30 minutes rainfall simulations were carried out on each plot, the first one on dry soil and the second one, 30 minutes later, on wet soil. Rainfall intensity was approximately 50 mm h^{-1} (5 years return period). Moreover, with the aim of examining the response under natural rainfall, open plots of about 1 m^2 size on cyanobacteria and lichen crusts were set in El Cautivo (Fig 1b). Contributing area was estimated from a 1 centimetre resolution DEM built from laser scan height records.

1a 1b

Figure 1.- 1a: the three rainfall simulators. 1b: open plot over a cyanobacteria-dominated crust and DEM of this plot.

RESULTS

As can be observed in table 1, runoff and erosion were higher in El Cautivo, a badlands area, than in Amoladeras, a flat area with more developed soils with coarser texture. In general, BSC showed lower runoff coefficient and much lower erosion rates than the structural crust (physical crust). Lichens and mosses promote higher soil surface roughness than cyanobacteria and algae (Danin *et al*., 1998), thus favoring infiltration. Furthermore, cyanobacteria filaments and the anchoring structures of mosses and lichens provide soils with a large resistance to water erosion (Belnap, 2006). According to our results, runoff and erosion decreased with crust development, except for the lichen crust in El Cautivo (the most developed crust in this area) which showed higher runoff coefficient than the other BSCs and similar to the structural crust. This can be due to the steeper slopes where this crust is located in El Cautivo and specially to the higher water repellency of this crust (Chamizo, 2009). Lichens can also cover soil pores completely and reduce soil porosity (Belnap, 2006), thus reducing infiltration. In Amoladeras, lichens are usually broken due to the frequent grazing in the site explaining the higher infiltration rate respect the cyanobacteria crust, which is less fractured.

Table 1. Total runoff coefficient (%) and total erosion rate (g m^{-2}) (average from 4 repetitions) and standard deviations for each crust type and treatment after 1 hour rainfall simulation.

		Runoff coefficient (%)			Erosion rate (g m^{-2})		
Site	Crust type	Undisturbed	Trampled	Scraped	Undisturbed	Trampled	Scraped
Cautivo	S	67.30± 9.5	73.42 ± 6.4	57.95± 10.4	647.75 ± 230.5	386.2 ± 137.1	334.07 ± 177.7
	IC	60.63 ± 11.8	59.85 ± 11.8	53.51 ± 11.3	150.60 ± 136.2	118.25 ± 109.4	274.77 ± 182.3
	C	57.95 ± 15.4	65.8 ± 7.1	47.88 ± 8.4	25.97 ± 23.4	108.33 ± 67.7	128.76 ± 92.48
	L	71.3 ± 7.8	74.37 ± 5.0	70.09 ± 6.5	10.72 ± 3.1	222.11 ± 157.5	744.60 ± 19.3
Amoladeras	C	58.62 ± 11.2	55.34 ± 11.2	36.90 ± 7.2	15.34 ± 12.9	52.48 ± 44.3	79.42 ± 41.2
	L	35.14 ± 18.9	35.82 ± 2.6	33.15 ± 10.9	1.98 ± 1.5	5.50 ± 3.9	14.61 ± 4.0
	M	11.22 ± 5.9	17.38 ± 6.4	27.31 ± 22.0	6.30 ± 9.5	2.01 ± 1.0	35.43 ± 41.7

Regarding to the disturbance treatments, under simulated extreme rainfall, although trampling induced the highest runoff rates as consequence of the induced soil compaction, runoff increase was lower than what found by other authors with similar treatments (Barger et al., 2006), specially in Amoladeras where the soil was already very compacted as consequence of the high grazing load in the site. The removal of the crust increased infiltration, except on M (due to the high absorption capacity of this crust), but after some minutes of rain, runoff rate in the scraped plots approached the values recorded on undisturbed crusts, because of the new surface sealing caused by raindrop impact. Scraping and trampling promoted significant higher erosion rates than undisturbed crusts.

Table 2. Runoff coefficient and erosion rate resulting from the rainfall simulation (50 mm) and two natural rains (22 mm and 9 mm, respectively), in plots (with slope gradients about 12º) on cyanobacteria and lichen crust from El Cautivo area.

		Cyanobacteria crust		**Lichen crust**	
		Runoff coefficient (%)	Erosion (g m^{-2})	Runoff coefficient (%)	Erosion (g m^{-2})
Extreme rainfall	Rainfall simulation	47.54	19.50	78.12	13.75
	Natural rainfall (I_5=36.5 mm h^{-1})	27.67	15.76	40.62	3.73
Low intensity rainfall	Natural rainfall (I_5=8.3 mm h^{-1})	7.07	1.90	12.86	1.86

The comparison of runoff and erosion rates in undisturbed plots on cyanobacteria and lichen-dominated crusts under natural and simulated rainfall (Table 2), shows how the lichen crust promoted higher runoff rates than the cyanobacteria crust for both extreme and small rainfalls, and this when plots with similar slope gradients are compared. The reasons for such differences are: the higher hidrophobicity and pore clogging in lichens crusts as a consequence of their more complex multi-layered structure and filament migration to the surface (Chamizo, 2009, Kidron et al., 1999). However, erosion was higher in the cyanobacteria than in the lichen crust under extreme rainfalls, nevertheless, under a small and low intensity rainfall, erosion was low and there were little differences in erosion rates between both crust types.

CONCLUSIONS

The influence of different parent material and topography explains the contrasted runoff and erosion rates in El Cautivo and Amoladeras. Runoff and erosion are much higher in El Cautivo, a badlands area with a silty substrate, than in Amoladeras, an area with a flat topography and a coarser soil texture. Infiltration increases and erosion decreases with BSC development. However, the higher water repellency and lower porosity in the lichen crust can be the cause of its lower infiltration rate in El Cautivo. On the contrary, the llichen crust in Amoladeras shows higher infiltration than the cyanobacteria crust, explained by the frequent cracks and crust discontinuity as a consequence of grazing. Trampling over soil crusts causes not only crust disruption but also soil compaction and induces the highest runoff rates, being this effect less accentuated in Amoladeras because the soil had been previously compacted. The removal of the crust, though inducing the highest infiltration rates, increases erosion dramatically. The same runoff and erosion patterns among BSCs appear under natural rain. Given the protection against soil erosion, BSCs play an important role in arid and semiarid areas, and although the production of runoff from biologically-encrusted soils is high, in many cases water flows towards adjacent soils, assuring the survival of nearby vascular plants in drylands. Nevertheless, the effects of this additional runoff water has to be analysed at hillslope and catchment scale in these ecosystems.

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