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Biogeosciences Discussions

Interactive comment on "Microstructure and hydraulic properties of biological soil crusts on sand dunes: a comparison between arid and temperate climates" *by* T. Fischer et al.

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Comment #1 of Reviewer #1 Title: This is misleading/vague and it should be changed to something like: 'Comparison microstructure and hydraulic properties of sand dune Biological Soil Crusts from arid and temperate climates' (just an example only).

Response to comment #1: We renamed the title to "Comparing microstructure and hydraulic properties of smooth sand dune biological soil crusts from arid and temperate climates"

Comment #2 of Reviewer #1 Introduction: It is rather vague and confusing. It is missing key literature. For example Belnap (2006) has given a comprehensive review on the

problems investigated in this study. Another example is on microstructure studies by Menon et al (2011, J. Hydrology) using X-ray tomography. There is no detailed account on why this study was necessary and key idea of selecting these two sites? What is novel here has to be pointed out.

Response to comment #2: We rewrote the introduction. We replaced the text "Therefore, the aim of this study was to test the hypothesis that BSCs possess a mechanism of self-stabilization through water redirection under various environmental conditions. To address this aim, we hypothesize that the three components mentioned above contribute to different degrees, depending on the geological substrate, on the climate, and on the development of the BSCs, like BSC thickness, species composition and diversity, or physical crusting."

with

"Smooth BSCs were reported to possess low surface area infiltration and to have the potential to generate high surface runoff (Belnap, 2006), which was confirmed for the temperate study site by Fischer et al. (2010). We hypothesize, that BSCs may benefit from runoff generation when competing with higher plants under temperate conditions, and it may be favourable for their stabilization to develop water repellency and to control infiltration on sandy substrates. Under arid conditions, microphytes may require the water storage capabilities of a fine-textured soil to develop. BSCs would not benefit from developing water repellency or from controlling infiltration here. Instead, runoff generation would be dominated by physical factors coinciding with fine texture: fine pores and low infiltration. Hence, little infiltration may be required for stabilization under temperate conditions and may be controlled by the BSCs, but may have to be accepted under arid conditions.

The influence of BSC microstructure on infiltration was investigated by Menon et al. (2011). Instead of X-ray microtomography and Lattice Boltzmann flow simulation we studied cross sections of BSCs using scanning electron microscopy (SEM). Infiltration

was determined experimentally using microinfiltrometers, which allowed us also to account for the influence of EPS swelling and to record infiltration kinetics over time, wich offers us the opportunity to distinguish between physical and biogenic influences."

Comment #3 of Reviewer #1 1. Sampling was done different times (in Nizzana in 2009 and, Lieberose in 2010 and 2011). Any particular reasons? For sampling performed in 2010 and 2011, how do we make sure that conditions in the field are not changed?

Response to comment #3: It is well acknowledged that BSC establishment lasts from several years to decades. Both experimental sites remained undisturbed for at least 17 years. Hence, the year of sampling is irrelevant for the comparison of crust types. However, as a short term phenomenon, weather conditions may influence BSC activity. The Nizzana crusts are mostly dry and were sampled under dry conditions. We accounted for this by sampling the Lieberose crusts in the dry season (May 2010 and June 2011). All investigations were performed on the 2010 as well as the 2011 BSCs. The data did not differ significantly. We added to the Methods section for Lieberose: "We report mean values of the 2010 and 2011 samplings."

Comment #4 of Reviewer #1 2. Slope of these sampling sites not given. Looking at the images presented, it is really different. This is important factor for interpreting your results. Sites should be compared based on this.

Response to comment #4: We provide the slope angles in the site description section now.

Comment #5 of Reviewer #1 3. Prevailing weather conditions at the time of sampling? What is the prevailing wind direction? Any particular weather events occurred prior to the sampling?

Response to comment #5: Weather conditions: see our response to comment #3. The samples were taken at the lee side of both dunes. We added this information to the text.

Comment #6 of Reviewer #1 4. Why east-facing dune was selected for one site and north-facing slope for the other site? This is very critical in crust development. Inconsistency in sampling/method would lead to misinterpretation of the data.

Response to comment #6: We chose the lee side of both dunes to account for deflation at the dune crests and for sedimentation at the dune slopes and bases. In contrast, solar radiation will differ in any case under different climatic conditions. However, the north facing slope in Nizzana and the east facing slope in Lieberose almost equally correspond to the preferential east-northeast aspect in the northern hemisphere (Belnap, 2006). See also our response to comment #5.

Comment #7 of Reviewer #1 5. Some sentences are repeated for each site (e.g. the samples were cut into. . .. measurements).

Response to comment #7: We deleted this replication. The text now reads like: "Undisturbed samples of dry biological soil crusts were collected in 2 replicates (1 replicate only available for the dune base) near the crest (crust thickness ca. 1 mm), at the slope (crust thickness ca. 2 mm) and at the base (crust thickness 2-3 mm) of a carbonate-containing, siliceous north facing dune (lee side) in September 2009 following the same procedure as described for Lieberose."

Comment #8 of Reviewer #1 6. Replications are very few (at times only one!) as given in section 2.1 and this is one of my major concerns and considering the heterogeneity of BSCs, two replicates are absolutely not enough. It is not clear what these replicated samples were used for! I see variable number of replicates is used in each test (section 2.1, 2.2 and 2.3). Please make it clear in the manuscript.

Response to comment #8: The low amount of replicates is often criticized in hydrological studies of geomorphological units. However, in practice it is almost impossible to find two identical study objects which may serve as real replicates. In such cases the selection of two or more replicates inevitably results is criticism of comparability. Therefore, our approach was not based on a comparison of regions, but on a compari-

son of BSC types along two individual dune catenas under different climatic conditions. Based on this approach, we are well aware that we cannot give a comprehensive description of spatial heterogeneity of BSC types in two climatic regions – this would be a different task. In contrast, we propose mechanisms of crust stabilization on the two catenas studied.

On the scale of BSC habitats, the sampling size of a petri dish covers a variaty of surface structures, including BSC patches, within patch crevices and a between patch mineral surface interspace, offering the opportunity to perform replicate measurements when using appropriate, small-scale methods, like electron microspcopy, micro-infiltrometry etc. We are deeply convinced that spatial heterogeneity plays a crucial role for crust ecological functioning. In a previous study we used a geostatistical approach to characterize crust patches, and we found that the variogram range in Lieborose amounted to 4 mm or less (we refer to this publication in the manuscript: Fischer et al., 2012b), which is far bolow the size of the petri dishes used. Hence, a petri-dish sized sample covers all within patch spatial heterogeneity, and when talking about BSC stabilazation, we must be aware that in fact we talk about BSC patch stabilization.

Comment #9 of Reviewer #1 7. What was the average thickness of the crusts at different positions of the slope at these sites?

Response to comment #9: We added this information to the site description. See also response to comment #7.

Comment #10 of Reviewer #1 8. Why uncrusted areas were sampled/ not taken as control in each study site? Possibly you could explain difference you observed with this data. Again refer back to the issues raised by Belnap (2006) in doing hydrological observations.

Response to comment #10: We analysed the loose substrate in Lieberose as well (see also Figure 7). In Nizzana, the surface was always crusted, so loose surface substrate

could not be used as a full treatment in the 2-factorial design. Where indicated, we used the underlying mineral substrate for comparison.

Comment #11 of Reviewer #1 9. It is not clear where the micro-infiltration was done (field or lab?) and how it was possible to do this test on a fragile surface? Could you elaborate on this? In my experience, it was very difficult to do without breaking it.

Response to comment #11: The micro-infiltrometry was performed in the lab after equilibration of the samples with 60% r.h. at 20 °C. Gentle handling is required to avoid breaking, and data from broken sub-samples were excluded from the dataset. Once wetted, the samples were easier to handle for the swelling experiments.

Comment #12 of Reviewer #1 10. Statistical analysis. I am not familiar with some of the tests you have used here (Tukeys HSD, Shapiro-Wilk test etc). For the benefit majority of the readers, it would be nice to elaborate why these tests are used and what for. Some references may be provided as well.

Response to comment #12: All tests used are built into the R software suite, which was used for all statistical analysis. We added this information to the manuscript. As you know, R is free and widespread among scientists, so the reader may refer to the R manual.

Comment #13 of Reviewer #1 11. Micro-structure images are interesting and I wonder why you have not reported porosity from this data? Also insert a scale bar in those figures showing SEM images

Response to comment #13: The pixel resolution of the images was too little to resolve fine silt and clay, and, correspondingly, the pore space between fine silt and clay particles or within aggregates. It can be expected that a calculation of porosity (as the areal percentage of voids in the image) will give biased values. In contrast, the sand to medium silt particles/aggregates will be displayed correctly. Hence, we decided not to report porosities.

In addition, porosity will change aver time as EPS swell.

Comment #14 of Reviewer #1 12. Hot water extractable carbon (to measure EPS) would have helped to interpret some results

Response to comment #14: We strongly agree with the reviewer, but we feel that an in-depth discussion would go beyond the scope of the present article, which then would also lose its focus. We submitted a manuscript entitled "Hydraulic properties of biological soil crusts on sand dunes studied by 13C-CP/MAS-NMR: a comparison between an arid and a temperate site". We added the main conclusions from this study to the present manuscript.

Comment #15 of Reviewer #1 13. What was the rationale for measuring chlorophyll and plotting along with WHC data on figure 9? I recommend inserting a table for comparing site characteristics than given in the text format.

Response to comment #15: We tried to visually demonstrate the close relation between WHC and crust biomass.

We added a table with the site characteristics.

Comment #16 of Reviewer #1 Discussion: missing key literature here (see reported studies in Belnap 2006 review on the effect of slope, climate factors etc). I would focus the discussion on catena to start with and provide summary of key differences between two sites afterwards (again a table would help!). These two sites are too different (including crusts biodiversity) and without measurements on non-crusted controls at each location, I am not sure that a comparison of hydrological characteristics of these two sites giving us any valuable conclusions on the role of BSCs on hydraulic parameters.

Response to comment #16: We considered Belnap (2006) for the discussion now, and also point to the smoothness of the crusts in our title, because this was one of the main topics in her article. We further hypothesize in the introduction now that BSCs require finer texture in deserts due to higher water capacities, and that hydraulic properties are

a consequence of that requirement.

This, in turn, would mean that pure sand dunes in the desert would be impossible to be compared with pure sand dunes under temperate conditions, because such desert sand dunes would be too dry to support BSCs. Hence, the sites are different with respect to their dune characteristics, but we compare BSCs, not dunes (which is also reflected by the title).

We cannot expect identical species composition under such differing conditions. However, the mechanisms of water infiltration and retention are mostly influenced by the biotic components of the crusts, for smooth crusts namely by EPS. We fully agree with the reviewer that we need to provide more data on that, and we summarize the site characteristics in a table now.

We concluded that the biotic components of the crusts played a more prominent role for hydraulic properties under temperate conditions, whereas crust hydrology was dominated by its physical components.

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