Authors response

Reviewer #2

Reviewers comment #1:
The abstract, the introduction and the aims of the paper sound very promising, but the presented results and analysis actually do not completely show neither the hypothesized delay in water saturation involved in the dew deposition on developed BSCs in relation to less developed (no data showing this delay are presented) nor an adequate statistical analysis of all the possible factors influencing this delay to identify the most relevant ones. Respect the delay, probably a continuous monitoring of the weight of the Petri dishes, containing the BSCs samples, together with a shorter time step in the prediction of dewfall would have provided valuable information for the paper. Respect the factors, others crust characteristics such as crust roughness or hydrophobicity should be included in the analysis of influencing factors.

Response to reviewers comment #1: We now included into the paper a second measuring campaign where we determined dewfall rates in 1.5 to 2.75 hour intervals after installation (21:30 CEST). We also added a figure (now Figure 3) which depicts the course of the dewfall rate over time and the respective model response, we also provide the root mean square errors (RSME) of the prediction. Summarizing both field campaigns, we replaced figure 2 by a new figure depicting measured versus predicted total dewfall values including respective statistical data.

We now point to the fact that „the thermodynamic and meteorological datasets used for the modeling were identical for all crusts", and point to relevant factors by stating that "it can be deduced that dew formation depended on [BSC] water retention properties, and that it increased with BSC thickness and coverage."

We further introduced crust coverage into the model and added to the text: "We found previously patchy distributions of the BSCs over the soil surface (Fischer et al., 2012). Soil water retention functions, however, were determined in steel rings, which had an inner diameter of 30 mm (see section 2.3) and which were taken at locations with dense crust cover (crust 1) or from within individual BSC patches (crusts 2 and 3). The petri dishes, which were used for determination of dewfall, had a diameter of 10 cm and were not covered entirely with BSCs. Assuming sandy substrate in the crust patch interspaces, we accounted for incomplete crust coverage by weighing individual contributions of BSCs and substrate to total dewfall using equation 7.

$$D_w = c_{BSC} D_{BSC} + (1 - c_{BSC}) D_{Substrate} \quad (7)$$

where D_w is the weighed hourly dewfall, c_{BSC} is the crust coverage (0.2, 0.4 and 0.7 for crusts 1, 2 and 3, respectively), D_{BSC} and $D_{Substrate}$ are hourly dewfall values for BSC patches and for the substrate, respectively. Cumulative dewfall was determined as the sum of hourly dewfall values."

We now considered crust roughness and water repellency. We added to the crust description (M&M section): „All crusts were smooth and were characterized by immediate wetting when getting in contact with water drops. The repellency indices of the crusts, which were determined using water and ethanol infiltration rates, amounted to median values of 1.01, 4,89, 9,21 and 4,98 for the substrate and for crusts 1, 2 and 3, respectively, where a theoretical value of 1 characterizes totally non-repellent soils (Hallet and Young, 1999) and exceeds 50 for highly repellent soils (Urbanek et al., 2007).“

Further, we added to the discussion, that „we did not observe an influence of elevated repellency indices on dew formation. Water repellency typically occurs on very dry surfaces. It well might be that a slow increase of the relative humidity near the ground and in soil pores, which is typical before dew starts to form after sunset, causes molecular interaction between hydrophobic surfaces and water molecules from the gas phase, thus preconditioning the surface for liquid water adsorption. However, this possible mechanism should be subject to future research.”

Reviewers comment #2: In relation with my suggestion of predicting dewfall at higher temporal resolution, I recommend to calculate G instead of using a fixed value, because G is also a dynamic factor and it could have different values for the different developmental stages of BSCs and also it changes during the dew event. Consequently, assuming a constant value of -2 Wm-2 for all period and crusts could introduce an additional bias. Calculating G, at a shorter time step could be applied to predict and analyse the pattern of dewfall deposition. Moreover, dew is not a constant process and there may even be small evaporation events during a dew event, that could be detected with the appropriate temporal resolution and provide interesting information to the paper.

Response to reviewers comment #2: We followed this recommendation and included the variation of G, but also of the soil heat capacity (which increases with water content) into the model. By reprocessing the data set, also the model fit for the first campaign was improved. We added an appendix to the manuscript, where we explain the thermal properties of the crusts. This appendix reads like:

“The soil heat flux G over time was described as a sine wave (Horton and Wierenga, 1983) using equation 9.

$$G(z,t) = A_T C\sqrt{\omega\alpha_{STC}} \cdot \exp(-z\sqrt{\frac{\omega}{2\alpha_{STC}}}) \cdot \sin(\omega t + \phi + \frac{\pi}{4} - z\sqrt{\frac{\omega}{2\alpha_{STC}}}) \qquad (9)$$

where A_T is the amplitude of the soil surface temperature (K), C is the volumetric heat capacity (J m^{-3} K^{-1}), ω is the angular frequency, α_{STC} is the soil thermal conductivity (W m^{-1} K^{-1}), Φ is the phase angle and z is the soil depth (5 mm). ω and Φ were fit numerically to generate a G(t) maximum at 13:00 CEST and a period of 24 hours.

The de Vries model, which has attracted considerable attention to describe the soil thermal conductivity, is based on the assumption that soil particles and air are immersed in a continuous medium: water (de Vries, 1963). Because this assumption does not apply to dry soils, we calculated the soil thermal conductivity of the dry samples using equation 10 (Johansen, 1975).

$$\alpha_{STC} = \frac{0.135\rho_d + 64.7}{\rho_s - 0.947\rho_d} \qquad (10)$$

where ρ_d is the bulk density of the crust and ρ_s is the density of quartz (kg m^{-3}).

The soil heat capacity C was determined according to de Vries (1963) using equation 11.

$$C = 2.0 \cdot x_s + 2.51 \cdot x_o + 4.19 \cdot \Theta(t_i) \qquad (11)$$

where x_s, x_o and $\Theta(t_i)$ are the volumetric contributions of mineral (derived from the water retention curve) and organic components (as loss on ignition; 0,42, 0.90 and 3.08% for crusts 1, 2 and 3, respectively), and the volumetric moisture content after i hours ($m^3\ m^{-3}$), which was derived from the model output."

Reviewers comment #3: I worry very much about the presented conclusions which are in many cases based on speculations as can be see for example in the first sentences of conclusions: "The results support. . .. improving their water supply by dew collection". The paper does not provide results supporting all these statements. The same apply to ". . .which may be compensated by ecophysiological . . .. . .or hinder mosses from taking over".

Response to reviewers comment #3: We removed these speculative statements and completely rewrote the conclusions. Now the conclusions read like: „The proposed mechanism of dew formation involves later water saturation in near-surface soil pores and EPS where the crusts are thicker and where the water capacity is high, resulting in elevated vapor flux towards the surface. This applies to both the free atmosphere as well as to the deeper soil, possibly also resulting in some extraction of moisture from the rooting zone of higher plants and its capture in BSCs. Unlike vascular plants, it can be hypothesized that BSCs gain benefit from improving their water supply by dew collection. Despite higher amounts of dew, the water availability to the crust community decreases with crust development. It can be concluded that under constant further conditions organic matter accumulation, crust thickness and coverage were the main factors of dew formation."

Reviewers comment #4: Section 2.1: Authors describe different degree of pores occupation by filamentous cyanobacteria and filamentous and coccoid green algae and they cite Fischer et al (2010). However, additional information, such as some quantification of this occupation for each developmental stage should be included.

Response to reviewers comment #4: We welcome this remark and see that the volumetric proportion of organic matter influences both hydrological and thermal soil properties. In addition to the soil water retention curve, which clearly reflects the influence of organic matter and which was already discussed in the first version of the manuscript, we now incorporated the influence of organic matter on the soil heat capacity into the model using equation 11 (see our response #2). The contribution of soil organic matter is reflected by the variable x_o, which was determined as loss on ignition. We provide these data in the text now.

Reviewers comment #5: Section 2.3: It would be interesting to specify better the calculation of aerodynamic resistances (ra), how were they parametrized?

Response to reviewers comment #5: We used the FAO method and determined wind speeds in 5 min intervals in 2 m height (u_2). Wind data were averaged to hourly values, and r_a values were calculated using the function r_a=208/u_2. We refer to Allen et al. (1988) in that regard.

Anyway, we put particular emphasis on the differences between the crusts. For the crust behavior it was important for us to use an identical meteorological dataset for all crusts (see our response #1). So even if there was some bias in r_a (and in other meteorological recordings as well), this would be the same for all crusts.

Reviewers comment #6: Section 2.4: In equation 3, G was assumed to a fixed value of -2 Wm-2. As authors know G is also a dynamic factor and I think assuming a fix values can introduce an important bias

Response to reviewers comment #6: See our response #2.

Reviewers comment #7: Section 3: I think subsections are no needed in this case.

Response to reviewers comment #7: We removed the subsections in section 3.

Reviewers comment #8: The acronym EPS should be defined the firs time it is introduced.

Response to reviewers comment #8: Done.

Literature cited

Allen, R.G., Pereira, L.S., Raes, D., Smith, M.: Crop evapotranspiration - Guidelines for computing crop water requirements - FAO Irrigation and drainage paper 56, FAO - Food and Agriculture Organization of the United Nations, Rome, 1988.

De Vries, D.A.: Thermal properties of soils. In: Van Wijk, W.R. (ed.) Physics of plant environment. North Holland Publishing Company, Amsterdam, pp. 210-235, 1963.

Hallet, P. D. and Young, I. M.: Changes to water repellence of soil aggregates caused by substrate-induced microbial activity, Eur. J. Soil Sci., 50, 35–40, 1999.

Horton, R., Wierenga, P.J.: Estimating the soil heat flux from observations of soil temperature near the surface. Soil Sci. Soc. Am. J. 47, 14-20, 1983.

Johansen, O.: Thermal conductivity of soils. Ph. D. thesis, Trondheim, Norway, 1975. CRREL TL 637 (retrieved 03.09.2012 from http://www.dtic.mil/), 1975

Urbanek, E., Hallett, P., Feeney, D., and Horn, R.: Water repellency and distribution of hydrophilic and hydrophobic compounds in soil aggregates from different tillage systems. Geoderma, 140, 147–155, 2007.