The details of response to reviewers and Editor's comments:

Dear Editor and reviewers:

On behalf of my co-author, we thank you very much for giving us an opportunity to revise our manuscript, we appreciate editors and reviewers very much for their positive and constructive comments on our manuscript. We are glad to response all the comments, which would help to improve the message and the quality of our manuscript. The following is point-to-point responses to your comments. We have uploaded the revised version (including track changes) the final version (without track changes). We would like to submit for your kind consideration.

Response to Editor's comments

I received 2 reviewer comments and 3 short comments. All acknowledge the relevance of your study, however, there are some serious issues that needs to be tackled/clarified. First of all, your definition of the layer crust is not clear and should be improved. As well as the English language. I am not sure which version your editing serviced reviewed, but the current version has some issues as indicated by a native reviewer.

Response: thanks for your suggestions, we have revised our whole manuscript following 2 reviewer comments and 3 short comments. Our responses have uploaded to the Interactive Discussion. All the issues have been modified one by one and the language has been edited by an English language editing service for language check in the revised version.

Next to the 2 reviews and the short comments, I personally also had some suggestions for improvement:

- L20: what is meant by 'hydrological effectiveness"?

Response: thanks for your suggestions, the hydrological effectiveness in this study is the influence of the change of various crusts on the process of runoff, water infiltration, evaporation and interception. Of course, these are just local effects.

- L82-87: I found the objectives a bit vague. Can you please write them more explicit? (e.g. "determine the role of crust for soil properties (SUCH AS....?) and hydrological processes (LIKE..?)"; What dominant control factures..)

Response: thanks for your suggestions, we have revised the objectives of the study into "(1) to determine the role of litter crust for soil properties (soil water content, bulk density, soil total porosity, soil organic carbon) and hydrological processes reflected by(WHC, water interception capacity (WIC), water infiltration rate (WIR), and infiltration depth), and (2) to explore which is the dominant control factors of litter crust that affect water infiltration processes in sandy lands."

- L94-95: the unit of annual rainfall is mm/YEAR

Response: thanks for your suggestions, we have revised the unit of annual rainfall into "mm yr^{-1}".

- L164-168: what about the antecedent water content? This must have a big impact on the infiltration rate.

Response: thanks for your suggestions, the antecedent water content was listed in table 1. There is a significant difference in the water content of bare sandy land and biocrust, and litter crust. This difference is influenced by the different effects and characteristics of the crusts on the water transport in microenvironment. This also has an effect on the infiltration, and we have a more in-depth analysis in the discussion.

-L178-180: please convert units to similar once (so not using cm and mm and mL, but either do everything in mm or in m of in cm). Then you likely also don't need the conversion coefficient 10.

Response: thanks for your suggestions, there is descending powers of the unit in the calculation of this formula, so this coefficient 10 is necessary. Even if all units are of a uniform order of magnitude, there will be a coefficient of 10 in the result.

Hence, I advice the authors to take a serious look at the 2 reviewer comments and the 3 extra minor/technical comments, and improve the manuscript.

Response: thanks for your suggestions, we have revised our manuscript following 2 reviewer comments, 3 short comment and your comments. We thank you for your constructive comments on our manuscripts and for your efforts in our manuscripts.

Response to Reviewer's comments #1

It is an interesting and complex study to explore the hydrological impacts of litter crusts and biocrusts in desert ecosystems.

Response: Thanks for the reviewer's positive comment.

I am not a native speaker so I cannot judge whether the manuscript has reached the level of scientific writing in grammatical terms.

Response: Thanks for your suggestion, our manuscript have been edited by an English Language editing service for language check. Please see the certification at the Supplement information.

Some small suggestions:

Percentage (%) should be closer to the previous number (for example L29, L95 etc.).

Response: Thanks for your suggestion, we have deleted the spaces between % and the number throughout the manuscript.

L168 "stopwactch" => stopwatch

Response: Thanks for your suggestion, we have revised the word.

Some characters do not display correctly, but this is a typographically problem in preference (incompatible editing programs): ä, é and ℃ (for example L29, L62, L144 etc.).

Response: Thanks for your suggestion, we have unified the font of all the characters throughout the manuscript.

I suggest using the word "layer" instead of "crusts".

Response: Thanks for your suggestion, litter crust is a new concept that we put forward. We have given the definition of litter crust and the difference between it and litter layer in introduction. Unlike the common litter layer, litter crust is a hard shell formed by mixing litter and sand under external forces such as rain or wind. In this study, litter crust was defined as the crust formed by "all dead organic material made of both decomposed and undecomposed plant parts which are not incorporated into the mineral soil beneath".

L94-L95: minimum/maximum in which period?

Response: Thanks for your suggestion, we have added the period in the sentence as "minimum of 109 mm in winter and maximum of 891 mm in summer".

"Simulated rainfall (rainfall intensity was 20 mm h^{-1}) was applied to the quadrats for successive

30 minutes and then weighed to determine the Max WIC (g dm^{-2}). " How long after the simulation was the sample measured? If it was measured immediately then water still drips out of the crusts and it is not exact and should not be called interception (MIC), because a part of it would infiltrate into the soil (in field).

Response: Thanks for your suggestion, we have revised the sentence as "Simulated rainfall (rainfall intensity was 20 mm h^{-1}) was applied to the quadrats for 30 minutes continuously and then allowed to rest for 10 minutes in order for the moisture to stabilized before weighing to determine the Max WIC (g dm^{-2})".

L294-L295: "We immersed: : :weight gain." sentence is reduplication (Materials and methods). Is 24 hours enough to saturate the litter? After L289 WHC was 170%, but after L296 could it be 200%. The correct name would be WHC_24.

Response: Thanks for your suggestion, we have deleted the repetitive sentences. Soaking the litter in water for 24 hours can reach saturation, as we have confirmed in pre-test experiments before the experiment. I'm sorry we made a mistake here. The unit of Max WHC is g dm^{-2} not g water-g litter. The Max WHC corresponds to 200% of the litter weight. So we have revised the sentence as "In our study, Max WHC of litter crusts was 48.7 g dm^{-2}".

How did you measure the infiltration with crusts or without crusts on bare sand?

Response: Thanks for your suggestion, we measured infiltration used single-ring infiltrometry, which is a cylinder with an inner diameter of 15 cm and a height of 15 cm. Single-ring infiltrometry has been extensively applied as a basic infiltration measurement tool to measure the soil infiltration process. The method of measuring infiltration with crusts or without crusts on bare sand is the same.

Could cylinder edge cut the leaves or what about the leaves under the edge of the sampling device?

Response: Thanks for your suggestion, the cylinder edge is sharp and can easily cut off leaves during installation. Moreover, to prevent water leakage from the ring, the same soil materials were used to support the outside of the ring.

Is the sample number sufficient? (Did you make statistics e.g. based on standard deviation?)

Response: Thanks for your suggestion, for each crust type and bare sandy land, six experimental plots were selected. Five sample sites as replication was selected in each plot. Soil properties analyses in each site were repeated five times. The infiltration measurement of each water quantity was repeated 3 times in each site. We conducted analysis of variance (ANOVA) on the data. Tukey's honestly test was used to analyses the differences among variables. The results of statistical analysis are expressed as Mean and SE.

L465 (Figure 2.): Missing: BSL, bare sandy land;

Response: Thanks for your suggestion, we have added the note "BSL, bare sandy land" in the caption.

L478-L479 (Figure 4.) Is "ns" non-significant? You use different scale for the diagrams, please be consistent in all of them. The scale of diagram A goes to 40 mm/min, so it would be double size, and the others from 0 to 25 mm/min with original size. It helps the comparison.

Response: Thanks for your suggestion, we have added the note "ns, no significant difference" in the caption. We have unified the range of axes throughout the Figure 4.

Response to Reviewer's comments #2

Overall assessment – It would seem as though the methods used are sound as are the results obtained and the conclusions obtained from those results. However, the manuscript does require an English language edit. Some of the sentences are not comprehensible and as such it is very difficult to understand key aspects of this manuscript.

I fond it very difficult to understand what the authors meant but litter crusts as it is defined in some ways as a litter layer (leaves and other plant material on the ground) while at other times it seems that the leaves and other plant material formed a crust that is somehow adhered to the surface as a mat of vegetative material. As mentioned, a detailed re-write of this manuscript is required after which I would be glad to add further comment.

As a start, I would suggest that the authors begin by addressing the following:

Response: Thanks for your suggestion, our manuscript have been edited by an English Language editing service for language check. Please see the certification at the Supplement information.

Line 25 – the word "dangerous here seems too dramatic. Please consider changing.

Response: Thanks for your suggestion, we have changed "dangerous" to "serious".

Line 26 – "human" should be "humans" Line 25-26 – Overall this sentence is a little awkward. Please consider revising.

Response: Thanks for your suggestion, we have changed "human" to "humans" and have revised the sentence as "Desertification is one of the most serious and threatening environmental problems to humans in many areas of the word, and it leads to degradation of ecosystem functions and services".

Line 30 – Remove the word "the" before nutrients

Response: Thanks for your suggestion, we have deleted the word "the" in the sentence.

Line 32 – Are "flow dunes" an actual type of dune? Please elaborate.

Response: Thanks for your suggestion, it should be "mobile dunes", not "flow dunes", and we have revised the phrase as "mobile dunes".

Line 34-35– Remove this last sentence and simply put in your own words and reference Geist and Lambin.

Response: Thanks for your suggestion, we have revised the sentence as "Therefore, desertification is "one of the most threatening environmental problems in current society" (Geist & Lambin, 2004)."

Line 36-37 – I am not clear what is being stated here? Prevention and rehabilitation are being measured and if so how is that "applied continuously"? This is an awkward sentence.

Response: Thanks for your suggestion, we have revised the sentence as "With the increasing harm of desertification, many measurements have been implemented to prevent and combat desertification".

Line 37-40 – I have no idea what straw checkerboards are. Please provide a description.

Response: Thanks for your suggestion, the straw checkboard is to set straw on the surface of sand dunes forming a mesh structure. The straw checkerboard harrier is an innovative feature in China's long history of anti-desertification. It has been extensively studied and demonstrated to be a simple, feasible, and effective mechanical sand control measure. A specific introduction to the straw checkerboard can be found on the website: http://spd.cern.ac.cn/content?id=42752.

Line 44 – Please specialize what "groups" biocrusts belong to.

Response: Thanks for your suggestion, we have revised the sentence as "Biocrusts are highly specialized soil-surface plant-soil complex groups that are an important component of desert ecosystems, especially in arid and semiarid regions."
Line 50 – 51. "Deciduous trees: : :" This sentence needs a reference.
Response: Thanks for your suggestion, we have added a reference here "(Liu et al., 2018)".
Line54 " the phrase "are of care" does not make sense.
Response: Thanks for your suggestion, we have revised the sentence as "The interactions between precipitation, vegetation and litter crust are hot issues for hydrologists (Dunkerley, 2015)".
Line 54 – Do the authors mean "litter layer" instead of litter crust?
Response: Thanks for your suggestion, it is litter crust in the sentence.
Line 56-59 – I fail to see how interception and storage are transport processes? Please reword this sentence.
Response: Thanks for your suggestion, we have revised the sentence as "Previous studies have explored the interception of rainfall, the water-holding capacity (WHC) of litter materials, and the degree of retention within the litter (Makkonen et al., 2013; Dunkerley, 2015; Acharya et al., 2016)."
Line 63 – No need for a comma after reference.
Response: Thanks for your suggestion, we have deleted the comma after reference.
Line 66-67 – This sentence does not make sense – please consider rewording. I think the main issue is the words "which through two basic mechanisms.
Response: Thanks for your suggestion, we have revised the sentence as "On the other hand, litter crusts affect hydrological processes by serving as a barrier that prevents precipitation from directly reaching the soil and controls soil evaporation (Bulcock and Jewitt, 2012; Van Stan et al., 2017), attenuating both directions of ground radiation flux, and by increasing resistance to water flux from the ground (Juancamilo et al., 2010)".
Line 73-74. This sentence needs to be reworded or removed.
Response: Thanks for your suggestion, we have deleted the sentence.
Line 74-75 "The grain for Green Project: : :." This sentence needs a reference.
Response: Thanks for your suggestion, we have added a reference "(Chen et al., 2015)" for the sentence.
Line 75 - What is E.g? If this is supposed to be "For example" then write "for example"
Response: Thanks for your suggestion, we have deleted "E.g.".
Line 78: What kind of crusts? I am confused if we are talking about bio crusts or litter crusts.
Response: Thanks for your suggestion, the increase of the vegetation has the benefit of both the development of litter crust and biocrust. Therefore, we have revised the sentence as "the environmental conditions have improved and are suitable for the development and growth of biocrusts and litter crusts in the arid areas".
Line 86: I am sorry, but I am very confused. If this manuscript is only about litter layers, why does the introduction speak about biocrusts, which are not the same as litter layers.
Response: Thanks for your suggestion, litter crust is a new concept, and we introduced the more familiar biocrusts to make a comparison.
Line 91: I am not familiar with what a water-wind erosion crisscross section is. Please explain.
Response: Thanks for your suggestion, erosion zones in China are divided into water erosion,

wind erosion and freeze-thaw erosion according to their erosive force. The erosion area containing the two phases of water erosion and wind erosion is called the water-erosion and wind-erosion cross-zone.

Line 93 – 94 – Please write "monthly temperature" instead of just "temperature"

Response: Thanks for your suggestion, we have revised following the suggestion.

Line 98 – Please state percentages to the nearest 10th of a percent. These values are in no way significant figures.

Response: Thanks for your suggestion, we have revised the figures to keep one decimal place.

Line 99: Do the authors mean "erosion resistance" instead of "corrosion resistance"?

Response: Thanks for your suggestion, it should be "erosion resistance" here, and we have revised.

Line 102: I do not think the authors mean "removable" sand dunes. Please change.

Response: Thanks for your suggestion, we have changed "removable sand dunes" to "mobile sand dunes" in the sentence.

Line 109: I do not think Populus can prevent wind. Please reword to reduce wind speed at the surface or some other phrase.

Response: Thanks for your suggestion, we have revised the sentence to "*Populus simonii* was chosen as the main species for reduce wind speed at surface."

Line 112: Litters would not be the appropriate term here. Change to Litter layers.

Response: Thanks for your suggestion, we have revised the term as suggested.

Line 114-116 –There is a serious issue with what the authors mean by litter crusts – as described in the introduction they were speaking of litter layers, and in the introduction biocrusts were references considerably. How the authors define litter crusts here is completely different. This issue really needs to be addressed as there is no way for the reader to actually know what is being studied.

Response: Thanks for your suggestion, we have given a specific introduction to the litter crusts in the Introduction. "Unlike the common litter layer, litter crust is a hard shell formed by mixing litter and sand under external forces such as rain or wind. In this study, litter crust was defined as the crust formed by "all dead organic material made of both decomposed and undecomposed plant parts which are not incorporated into the mineral soil beneath" (Acharya et al., 2016)".

Line 122: replace "was" with "were" Line 127-128: So mosses are biocrusts? Again, very, very confused.

Response: Thanks for your suggestion, we have revised the sentence. Biocrust is an important surface-covered type in the desert. It is mainly divided into three types of algaes, lichens and mosses.

Line 131: All samples were collected at the same moment? Really? I do not understand how this could be accomplished. Within the same 10-minute time period, same hour, maybe, but the same moment (ie, second)?c

Response: Thanks for your suggestion, sorry for inaccurate use of phrase. We have revised the sentence as "Ten samples were collected for analysis in each sample site and all samples collected".

Line 161-": : :while avoiding produce leakage passages: : :"This part of the sentences does not make sense.

Response: Thanks for your suggestion, we have deleted the sentence.

Lines 199, 201,214, 215, etc –Please report numbers and percentages to the nearest decimal point.

Response: Thanks for your suggestion, we have kept one decimal place throughout the manuscript.

Line 240: Please reference some or all of the "few studies"

Response: Thanks for your suggestion, we have added the reference "(Jia et al., 2018)" in the sentence.

Line 245 – Remove comma after "ground"

Response: Thanks for your suggestion, we have deleted the comma after "ground".

Response to short comments #1

This manuscript reports on the positive effects of litter crusts on soil water holding capacity and water interception capacity by comparing between litter crusts, biocrusts and the bare soil. They synthesized multi hydrological-related properties of crust soils to give the whole picture of the hydrological processes differences between litter crust and biocrust in sandy lands. They found litter crusts significantly increased soil organic matter than biocrusts and bare sandy lands, and also increased soil porosity and decreased soil bulk density, which can help to maintain maximum infiltration rates. They also found the effect of crusts on water infiltration rate was depending on the level of water supply: significant different was only found at high water supply (>1000 mL) as the litter crusts increased the water infiltration. This research highlights the instrumental role for litter crusts in many hydrological processes, which is of great value under the context that national ecological programs in China improved vegetation recovery and developing litter crust intensively. In my opinion, this is an interesting and important study in understanding the ecohydrological functioning of litter crust and thus deserved to be published in HESS.

Response: Thanks for the reviewer's positive comment.

I also suggest several specific revisions as follows.

L52. Considering the term "litter crust" is not familiar to the reader, it is better to define what is "litter crust", and what is the difference between "litter crust" and more commonly "litter layers".

Response: Thank you for your comment, we have given the definition of litter crust and the difference between it and litter layer in introduction. Unlike the commonly litter layer, litter crust is a hard shell formed by the mixing of litter and sand under external forces such as rain, wind, etc. In this study, litter crust was defined as the crust formed by "all dead organic material made of both decomposed and undecomposed plant parts which are not incorporated into the mineral soil beneath".

L76. "(China)" is better to move upward to L74 when "Loess Plateau" is first appear.

Response: Thank you for your comment, following other referee, we have deleted the sentence "Preventing and controlling erosion in an urgent issue to require resolution on the Loess Plateau, China (Fu et al., 2011)".

L126. The unit "dm-2" is incorrect, please revise it.

Response: Thank you for your comment, we have revised the unit for "dm^2".

L126. The unit for biocrust evolution needs to be added.

Response: Thank you for your suggestion, we have added the unit "g dm^{-2}" for biocrust mass.
L129 and L130. As you've mentioned the unit for other factors you measured, it's better to address the unit of Max WIC and Max WHC here as well.
Response: Thank you for your suggestion, we have added the unit "g dm^{-2}" for Max WIC and Max WHC.
L132. ->"at depths of 0-3 cm, 3-5 cm, and 5-10 cm"
Response: Thank you for your suggestion, we have revised the sentence to "The samples in the soil layers were collected at depth of 0-3, 3-5, and 5-10 cm".
L134. ": : :was measured using a soil bulk sampler (100 cm3) stainless steel cutting ring: : :": the sentence is incorrectly phrased. Please revised it.
Response: Thank you for your suggestion, we have revised the sentence to "Bulk density (BD, g cm^{-3}) was measured using a soil bulk sampler (100 cm^3) stainless steel cutting ring".
L141." : : : and holding capacity of litter crust" ->" : : : and water holding capacity of litter crust"
Response: Thank you for your suggestion, we have revised the title to "Water interception and water holding capacity of litter crust".
L149 and L152. You can give the unit of Max WHC and MIC at their first appearance as suggested at L129 and L130. L154. The unit for SOM needs to be added.
Response: Thank you for your suggestion, we have added the units for Max WHC and MIC, and SOM in the sentences.
L169. "The time duration for the end of water infiltration : : :". I understand your point, but this expression is not correct.
Response: Thank you for your suggestion, we have revised the sentence as "The amount of time required for water to infiltrate in the ring was recorded to determine the water infiltration rate".
L203. Table 1, the data source for these changes of BD and TP, need to be cited here.
Response: Thank you for your suggestion, we have cited Table 1 in the sentence.
L207. The abbreviation "BSL" doesn't need to be explained again and placed in "()", as you have already explained it and used the "BSL" in the former passages.
Response: Thank you for your suggestion, we have deleted "bare sandy land" and the "()" in the sentence.
L213. Here comes the confusing that what does "crust mass" mean because you didn't mention such term in Methods. I suppose it refer to the same thing as "biocrust evolution" which you've mentioned in L126. If so, please be consistent through out the text.
Response: Thank you for your suggestion, we have changed "biocrust evolution" to "biocrust mass" throughout the manuscript.
L277. "Our study showed that the 5 cm litter crusts measured from 2-year and the 9 cm litter crusts measured from 4-year-old Populus simonii forests." This sentence is not complete. Please revised it.
Response: Thank you for your suggestion, we have revised the sentence to "Our study showed that litter crusts can reach 5 cm in 2-year-old and 9 cm litter crusts in 4-year-old *Populus simonii* forests".
L289. "maximum WHC of litter crust was 1.7 g water – g litter". You use the unit "g dm-2" for maximum WHC in previous text, please be consistent throughout the manuscript. "The maximum volume of litter crust was 1540 cm3". It is confusing here to use "maximum

volume": does "1540 cm3" indicate the volume for the whole crust sample, or the relative volume for the pores inside the crust sample? I guess you mean the later one, as you sampled the crust by the same volume.

Response: Thank you for your suggestion, we have revised the unit "g dm^{-2}" for Max WHC. "The maximum volume of litter crust was 1540 cm^{3}", it means the whole crust sample. Our sampled the litter crust by the same bottom area but the crusts have different thickness, so all samples have different volumes.

L460. The caption needs to provide the information of which statistic test was used. The significant level also needs to be noted in the footnote.

Response: Thank you for your suggestion, we have added the method of statistic test in the caption, "The results of GLM analysis for effects of crust types and the amount of water supply on the water infiltration time, infiltration depth and infiltration rate in the study.". The significant level was shown in the table by the value of p.

L464. Bare sandy land didn't have any crust. It is not appropriate to summarize the four sub-figure using" in different crusts".

Response: Thank you for your suggestion, we have revised the caption to "The vertical soil profiles in bare sandy land and different crusts in the study".

L465-. The meaning of the error bar needs to be given in the caption (eg. M+SE). The meaning of the abbreviation "BSL" is also need to be included in this caption (same as in figure 4 and figure 5).

Response: Thank you for your suggestion, we have revised as suggested.

Response to short comments #2

The effect of Litter crusts on hydrological process in dry sandy ecosystem in China has not been well illustrated till now. This manuscript suggested that litter crusts had a significant effect on soil water holding capacity, water interception capacity, and infiltration through changing soil organic matter, soil porosity and bulk density. The importance of litter crusts is confirmed in this study. The experiments were well designed and data was thorough analyzed and interpreted.

Response: Thanks for the reviewer's positive comment.

The specific comments and suggestions are listed as follows:

Line 14-15: Please keep the decimal number in one form.

Response: Thanks for your suggestion, we have revised the sentence and keep one decimal places.

Line 36-41: Please add more restoration techniques including afforestation that could result biocrusts in this paragraph.

Response: Thanks for your suggestion, we have added some measurements in this paragraph. "With the increasing harm of desertification, many measurements have been implemented to prevent and combat desertification, such as afforestation, establishment of sand barriers, or spraying reinforcing agents. One widely popular restoration technique establishes straw checkerboards on mobile sand dunes and eroded land."

Line 49-53: Please change the sentences as" Afforestation can not only produce biocrusts, but litter crusts, which form by the litter : : :" I think this may be easy to follow the logic.

Response: Thanks for your suggestion, we have revised the sentence as "In addition to biocrusts, afforestation also produces litter crusts, which form from the accumulation of litter that resulting from the common influences of wind and water (Jia et al., 2018)".

Line 78-79: Please use the same expression to describe the study area, i.e., arid areas, dry sandy, or wind-water crisscross erosion region. If use different expression, please give a clear explanation.

Response: Thanks for your suggestion, we have revised the sentence as "Consequently, the environmental conditions have improved and are suitable for the development and growth of biocrusts and litter crusts in the arid areas".

Line 114-116: Please move the definition to the place firstly used in the Introduction section.

Response: Thanks for your suggestion, we have moved the sentence to Introduction section.

Line 239-240: The phrases of "all these properties" and "all the changes" were not appropriate here. Please change them.

Response: Thanks for your suggestion, we have revised the sentence as "To our knowledge, few previous studies have reported how soil properties change in the litter crusts or how litter crust influences the hydrological processes in sandy lands (Jia et al., 2018)".

Line 298: what about other plant litter in the literatures, such as locust and pine? If possible, more information related to litter crusts could be discussed here.

Response: Thanks for your suggestion, the effects of the leaves of the pagodatree and the leaves of the pine needles on the water is not studied in this article, and the effects of the broadleaf forest is mainly discussed here.

Line 315: what is the relationship between percolate flux and rainfall intensity? Please make it clear.

Response: Thanks for your suggestion, following other reviewer's comments, we have deleted the sentence.

Table 1: Please add the difference note among different depth.

Response: Thanks for your suggestion, we have added the difference among different depth by different uppercase letters.

Table 2: Please give a clear description of crust types and amount of water supply in the caption or as notes.

Response: Thanks for your suggestion, we have added the crust types and amount of water supply in Table 2 caption.

Figure 1: Please provide the location in figure caption.

Response: Thanks for your suggestion, we have added the location in figure caption, "**Figure 1.** The vertical soil profiles in bare sandy land and different crusts in the southern Mu Us Desert".

Figure 4: What is the meaning of the ns in Figure A and B? It seemed that the dashed lines represent the average values or the changing pattern.

Response: Thanks for your suggestion, we have added the notes in the caption.

Response to short comments #3

Litter crusts significantly influenced the soil properties and hydrological functions. The paper quantified the ecohydrological effectiveness of litter crusts in desert ecosystems. The research is of great importance to understand the influence of litter crusts on desert ecosystems.

Response: Thanks for the reviewer's positive comment.

Some comments as below

1. Before infiltration measurement, how was the litter or soil surface treated? Was the single-ring installed directly on the surface? It may be better for clearly stating the procedure.

Response: Thanks for your suggestion. A single-ring infiltrometry was driven carefully to a depth of 5 cm by means of a plastic collar and a rubber hammer. Before infiltration measurement, the land surface remains intact and is as undisturbed as possible due to the surface did not grow any plant.

2. L172-174. "After the infiltration experiment, the ring was removed, and then, a vertical soil profile was quickly excavated and the infiltration depth was directly measured using a tape". Why was the profile quickly excavated as soon as the infiltration measure finished? After infiltration, the surface soil may be saturated and sticky, which may increase excavating difficulties.

Response: Very good comment! We quickly excavated a vertical soil profile and measured the infiltration depth. Because of water moves fast in the sand, if we wait a while for water to be stabilized in the sand and dig, the wetting area is not obvious or even visible. The measurement of infiltration depth by wetting front is very important.

3. L314-315 "which is affected by the rainfall intensity", infiltration rate was measured by single-ring infiltrometer, why did this sentence discuss the rainfall intensity?

Response: Thanks for your suggestion. The infiltration test of different water supply was carried out. The effects of different water supply on infiltration is similar to that of different rainfall intensity here. Following your comments, to better understand the content of the article, we have deleted this sentence.

Revised version including track changes：

Ecohydrological effectiveness of litter crusts in sandy ecosystem

Yu Liu[1,2], Zeng Cui[1], Ze Huang[1], Hai-Tao Miao[1,2], Gao-Lin Wu[1,2,3,*]

[1] *State Key Laboratory of Soil Erosion and Dryland Farming on the Loess Plateau, Northwest A&F University, Yangling, Shaanxi 712100, China;*

[2] *Institute of Soil and Water Conservation, Chinese Academy of Sciences and Ministry of Water Resource, Yangling, Shaanxi 712100, China;*

[3]*CAS Center for Excellence in Quaternary Science and Global Change，Xi'an, 710061, China;*

* *Corresponding author e-mail:* gaolinwu@gmail.com

phone: +86- (29) 87012884 fax: +86- (29) 87016082

Abstract

Litter crusts are integral components of the water budget in terrestrial ecosystems, especially in arid areas. This innovative study is designed to quantify the ecohydrological effectiveness of litter crusts in desert ecosystems. We focus on the positive effects of litter crusts on soil water holding capacity and water interception capacity compared with biocrusts. Litter crusts significantly increased soil organic matter compared to biocrusts and bare lands, ~~which was~~by 2.40 times ~~the content in biocrusts~~ and 3.84 times, respectively. ~~the content in bare sandy lands.~~ Higher organic matter content resulted in increased soil porosity and decreased soil bulk density. Meanwhile, soil organic matter can help to maintain maximum infiltration rates. Litter crusts significantly increased the water infiltration rate under high water supply. Our results suggested that litter crusts significantly improve soil properties, thereby influencing hydrological processes. Litter crusts play an important role in improving hydrological effectiveness and provide a microhabitat conducive to vegetation restoration in dry sandy ecosystems.

Keywords: litter crusts; water-holding capacity; water infiltration; interface habitats; sand restoration

1. Introduction

Desertification is one of the most serious~~dangerous~~ and threatening environmental problems to humans in many areas of the word, and it leads to ~~productivity reduction, biodiversity loss, and~~ degradation of ecosystem functions and services (Huenneke et al., 2010). Increasing external pressures from human activities or climate change can cause desertification and ~~influence~~ impact the livelihoods of more than 25~~ %~~% of the world's population (Kéfi et al., 2007). The occurrence of desertification, high air temperature, low soil humidity, and abundant solar radiation results in high potential evapotranspiration (Reynolds et al., 2007). Moreover, ~~the~~ soil nutrients are eroded by drastic water loss, and ~~the~~ soil fertility decreases with sand transport and dune burial, ~~which~~ consequently ~~impede~~ impeding vegetation growth. It is a challenge for ecologists to stabilize ~~the flow~~ mobile dunes and to transform them into ~~stable,~~ productive ecosystems. Therefore, desertification is "one of the most threatening environmental problems in current society~~serious problems of our age~~" (Geist & Lambin, 2004).

With the increasing harm of desertification, ~~some~~ many measurements ~~of prevention and rehabilitation~~ have been ~~applied~~ implemented to prevent and combat desertification~~continuously~~, such as afforestation, establishment of sand barriers, or spraying reinforc~~ementing~~ing agents. ~~It is o~~One ~~of the~~ widely popular restoration technique~~s to~~ establishes straw checkerboards on mobile sand dunes and eroded land. The straw checkerboards enhance~~ the entrapment of~~ dust entrapment on the surface of stabilized dunes, which facilitates topsoil development and makes it easier for biological soil crusts (biocrusts) to form (Li et al., 2006). Biocrusts are~~ a~~ soil surface ~~community~~ communities composed of microscopic and macroscopic poikilohydric organisms, are globally widespread~~,~~ and are an important component of the soil community in many desert ecosystems (Grote et al., 2010; Gao et al., 2017). Biocrusts are highly specialized soil-surface plant-soil complex groups that are an important component of desert ecosystems, especially in arid and semiarid regions. ~~The~~ Biocrusts provide important ecological functions ~~of biocrusts include~~ including increasing soil aggregation and stability, preventing soil loss, increasing the retention of topsoil nutrients ~~in the topsoil~~, and ~~increasing~~ improving soil fertility (Chamizo et al., 2012).

Large area afforestation is one effective measure used in the~~at~~ preventions~~s~~ and control~~s~~ of desertification in arid and semi-arid regions. Deciduous trees have been widely used in most of the sandy-land afforestation efforts (Liu et al., 2018). In addition to biocrusts, a~~A~~fforestation also ~~can easily not only~~ produces ~~both biocrusts, but and~~ litter crusts, which form ~~by~~ from the accumulation of litter that ~~accumulates ase a~~ resulting ~~o~~from the common influences of wind and water (Jia et al., 2018). Unlike the common litter layer, litter crust is a hard shell formed by mixing litter and sand under external forces such as rain or wind. In this study, litter crust was defined as the crust formed by “all dead organic material made of both decomposed and undecomposed plant parts which are not incorporated into the mineral soil beneath” (Acharya et al., 2016). That is, the litter crust formed by the mixing of litter organisms and soil. The interactions ~~among~~ between precipitation, vegetation and litter crust are ~~of care to~~hot issues for hydrologists (Dunkerley, 2015). Litter crusts have the capacity to store water on their surface, which is filled by rainfall and emptied by evaporation and drainage (Guevaraescobar et al., 2007; Gerrits et al., 2010; Li et al., 2013). Previous studies have explored ~~the transport processes of water in litter crusts, such as~~ the interception of rainfall, the water-holding capacity (WHC) of litter materials, and the degree of retention within the litter (Makkonen et al., 2013; Dunkerley, 2015; Acharya et al., 2016). The plant-litter input from above- and below-ground ~~composes~~ comprises the dominant source of energy and matter for a very diverse soil organism community that are linked by extremely complex interactions (Hättenschwiler et al., 2005). On one hand, litter crusts ~~could~~ can improve microhabitat conditions (Chomel et al., 2016)~~,~~ and form soil organic matter (SOM) through biochemical and physical pathways (Makkonen et al., 2013; Cotrufo et al., 2015). On the other hand, litter crusts affect hydrological processes by serving as a barrier that prevents precipitation from directly reaching the soil and controls soil evaporation (Bulcock and Jewitt, 2012; Van Stan et al., 2017), ~~which through two basic mechanisms: by the attenuation~~attenuating both directions of ground ~~of~~ radiation flux, ~~into and from the ground~~ and by ~~the~~ increasinge ~~in~~ resistance to water flux from the ground (Juancamilo et al., 2010). The combined effects of these ~~two~~ mechanisms produced by litter crusts provide strong controls ~~of~~ on water transport. Consequently, interception by litter crusts is a key component of the water budget in some vegetated ecosystems (Gerrits et al., 2007; Bulcock and Jewitt, 2012; Acharya et al., 2016).

~~Prevention and control of soil and water erosion is an urgent issue to require solution on the Loess Plateau (China).~~ The "Grain for Green Project" was implemented ~~for~~ to controlling soil erosion and improveing the ecological environment across a large portion of China (Chen et al., 2015). ~~E.g. t~~This project increased vegetation coverage on the Loess Plateau ~~(China)~~ from 31.6 ~~%~~% in 1999 to 59.6 ~~%~~% in 2013 (Chen et al., 2015). Consequently, the environmental conditions have improved and are suitable for the development and growth of biocrusts and litter crusts in the ~~wind-water erosion crisscross region~~arid areas. Litter crusts and biocrusts were important contributors for the improvement of the surface microhabitat conditions. Although the importance of biocrusts in water processes has been recognized, the effect of litter crusts on sandy lands has received little attention. Therefore, the objectives of the study ~~were~~ are (1) to determine the role of litter crust for soil properties (soil water content, bulk density, soil total porosity, soil organic carbon) and hydrological processes ~~reflected by~~(~~-~~WHC, water interception capacity (WIC), water infiltration rate (WIR), and infiltration depth), and (2) to explore which is the dominant control factors of litter crust that affect water infiltration processes in sandy lands. The results will clarify the impact exerted by crusts on hydrological process, which protect the soil against erosion and improve soil microhabitats in sandy lands.

2. Materials and methods

2.1. Study sites

The experimental site was located in the southern Mu Us Desert (110°21′–110°23′ E, 38°46′–38°51′ N, a.s.l. 1080-1270 m), which is ~~the~~ an intersection water-wind erosion ~~crisscross~~ region~~ of~~ China. ~~The climate is~~It has a continental semi-arid monsoon climate, with a mean annual temperature of 8.4 °C. The minimum monthly temperature is -9.7 °C in January and the maximum monthly temperature is 23.7 °C in July~~.~~ and t~~T~~he mean annual precipitation is 437 mm yr^{-1} (minimum of 109 mm in winter and maximum of 891 mm in summer), ~~accounting for~~with approximately 77~~ %~~% of the rainfall occurrings between June and September. ~~The~~ A mean of 16.2 days ha~~ve~~s wind ~~numbers of days that wind~~ speed exceeding Beaufort force 8, and they are predominantly during the spring~~ was 16.20, and~~

~~mainly in spring~~. The soils are~~type is~~ aeolian sandy soils, which ~~is~~ are prone to wind-water erosion~~. The~~ with sand, silt, and clay contents of the soil were 98.6~~4~~, 1.3~~2~~, and < 1.0~~0~~, respectively (Wu et al., 2016). The areas with sandy loess soil, loose structure, and poor ~~corrosion~~ erosion resistance were given priority. The Chinese government implemented several projects to reduce soil erosion and to prevent the drifting of sand as well as to improve the fragile ecosystem. Vegetation restoration has transformed the landscape from mobile~~removable~~ sand dunes to shrubby dunes, which are ~~was~~ composed of fixed and semi-fixed sand dunes. The dominant natural vegetation ~~was~~ is psammophytic shrubs and grasses (e.g., *Artemisia ordosica*, *Salix cheilophila*, *Lespedeza davurica*). In many of the sand dune~~s~~ sites, *Populus simonii* was chosen for sand fixation.

2.2. Experimental design and soil sampling

This study was conducted in the wind-water erosion ~~crisscross~~ intersection region, and *Populus simonii* was chosen as the main species for wind speed reduction ~~preventing wind and fixing sand~~~~reduce wind speed~~ at the surface. The region has suffered wind-water erosion in consecutive years due to its ~~special~~ unique geographical position, which has shaped its ~~unique~~ specific landscape characteristics. There is abundant plant litter gathered every year as a result of the interaction between wind transport and water erosion. Many ~~litters~~ litter layers were mixed with sand and eventually were fixed on the ground, this gradual process formed litter crusts. ~~In this study, litter crust was defined as the crust formed by “all dead organic material made of both decomposed and undecomposed plant parts which are not incorporated into the mineral soil beneath” (Acharya et al., 2016).~~ Soils covered by two types of crusts represented the most common crusts in this region. Biological soil crusts (biocrusts) were moss dominated, and ~~the~~ litter crusts were dominated by *Populus simonii* leaves. The litter crusts were divided into two groups: a 2-year ~~litter~~ crust ~~for 2 years~~ (covered by only litter, LC2) and ~~litter crust for~~ 4-year crusts (covered by litter and a semi-decomposed layer, LC4). For each crust type (LC2, LC4 and biocrusts) ~~and~~ as well as bare sandy land (BSL, as control, Fig. 1), six experimental plots (> 100 m^2) were selected. Five duplicate sample sites ~~as replication was~~ were selected in each experimental plot for repeatability.

After a sample site was selected, the crust thickness was measured using a tape. ~~The biocrust thickness was the total thickness of biocrust.~~ In each sample site, the undisturbed crust layer was sampled using a cylindrical container with a 15 cm diameter ~~of 15 cm~~ (with an area of 1.77 dm^{-2}). Moreover, biocrust ~~evolution~~ mass was represented by moss biomass per unit area (g dm^{-2}). The soil on the mosses was removed by wet-sieving, and the moss plants were used as the biocrust samples. Various types of crusts from each plot were collected to determine the maximum water interception capacity (Max WIC, g dm^{-2}) and maximum water-holding (storage) capacity (Max WHC, g dm^{-2}). Ten samples were collected for analysis in each sample site and all samples coll~~ec~~ated ~~at the same moment~~. Soil samples were collected using a soil drilling sample corer. The samples in the soil layers were collected at ~~intervals~~ depth of 0-3, 3-5, and 5-10 cm. Three replicates were taken from each sample site, and the same layer samples were mixed into one sample for each plot. ~~The b~~Bulk density (BD, g cm^{-3}) was measured using a soil bulk sampler (100 cm^3) stainless steel cutting ring~~, with three replicates in each plot. The~~ and soil total porosity (TP, ~~%~~%) was calculated by the (1-BD / PD) × 100, where BD represents soil bulk density (g cm^{-3}) and PD represents particle density (g cm^{-3}), which was assumed to be 2.65 g cm^{-3}. The samples were weighed and then oven-dried to a constant weight at 105 °C and then weighed to determine BD and soil water content (SWC, weight-%). The analyses in each sample site were repeated five times.

2.3. Water interception and water holding capacity of litter crust

Water interception was defined as the amount of rainfall temporarily stored in the litter after drainage ceased (Guevaraescobar et al. 2007; Acharya et al. 2016). In the laboratory, collected litter was air-dried (65 °C to constant weight) and weighed to obtain the dry weight. To measure the amount of water intercepted by litter, a circular quadrat with a permeable mesh bottom (diameter of 15 cm) was used in such a way that the quadrat area was equal to that of the soil corer. The collected litter was then distributed uniformly over the entire quadrat. Simulated rainfall (rainfall intensity was 20 mm h^{-1}) was applied to the quadrats for ~~successive~~ 30 minutes continuously and then ~~sit still~~allowed to rest for 10 minutes~~,~~ ~~water~~in order for the moisture to stabilized before ~~and~~ weighing~~ed~~ to determine the Max WIC (g dm^{-2}).

To determine the Max WHC, all crust samples were submerged in water for 24 hours. The samples were retrieved from the water and allowed to air dry and drain for approximately 30 minutes. Then, the samples were weighed to obtain~~as~~ the maximum weight. The Max WHC (g dm^{-2}) was calculated as the difference between the maximum weight and the dry weight. The soil organic matter content (SOM, g kg^{-1}) was determined by the dichromate oxidation method.

2.4. *Quantitative infiltration design*

To investigate the influence of crusts on water infiltration, infiltration experiments using five different amounts of water were conducted in each plot. A cylinder with an inner diameter of

15 cm and a height of 15 cm was used for single-ring infiltrometry. Single-ring infiltrometry has been extensively applied as a basic infiltration measurement tool to measure the soil infiltration process (Ries & Hirt, 2008). The infiltration device was driven carefully to a depth of 5 cm by means of a plastic collar and a rubber hammer~~ while avoiding produce leakage passages and guaranteeing the ring remains horizontal during installation~~. To prevent water leakage from the ring, the same soil materials were used to support the outside of the ring.

A paper board (5 × 5 cm) was placed in the ring above the crust and soil to ~~avoid the risk of~~ prevent scouring when the water was added into the ring. ~~The~~ Specific quantitative amounts of water (500 mL, 1000 mL, 1500 mL, 2000 mL and 2500 mL in the study) ~~was~~ were carefully poured on the paper board until, as quickly as possible, it was 3 cm deep (the depth of 500 mL of water in the ring is close to 3 cm)~~ as quickly as possible~~; this process was timed using a stopwa~~e~~tch. During the infiltration process, water was added by hand to maintain the water level within the ring. The amount of time ~~duration for the end of~~~~taken to~~ required for water to infiltrat~~e~~~~ion~~ in the ring was recorded to determine the water infiltration rate. The infiltration measurement of each water quantity was repeated 3 times in each sample site. After the infiltration experiment, the ring was removed, and then, a vertical soil profile was quickly excavated and the infiltration depth (cm) ~~was~~ measured directly ~~measured~~ using a tape.

Based on the water mass balance, the infiltration rate measured using the ring method was estimated from:

$$i = \frac{W}{A \times T} \times 10$$

where i represents the infiltration rate (mm min^{-1}), W is the amount of water supplied for infiltration (mL), *A* is the infiltration area (cm^2), *T* is the infiltration time (min), and 10 is the conversion coefficient.

2.5. Statistical analyses

Two types of crusts (biocrust and litter crusts) were selected to determine the impact of crust components on hydrological process. and f~~F~~ive BSL plots~~ of BSL~~ were selected as controls. The normality of the data and ~~the~~ its homoscedasticity were tested ~~by~~ using the Kolmogorov-Smirnov and Levene's tests. In these comparisons, we conducted analysis of variance (ANOVA) on the data. Tukey's honestly test was used to ~~analyse~~ analyze the differences in SWC, BD and TP in the different crust types at the different soil layers or within the same soil layer. ~~The d~~Differences in the crust thickness, Max WHC, and WIR of the crust types were also tested using Tukey's honestly test. The difference in the Max WIC of LC2 and LC4 was detected using an independent *t* test. All differences were tested at the level of $p < 0.05$. Generalized linear model (GLM) analysis was used to explain the interactions between crust types and water supply in determining the water infiltration time, depth and rate. Correlation analysis was performed to explore the ~~correlations~~ relationships among the different soil properties and the infiltration rates under different water supply-scenarios. All of these statistical analyses were completed using R statistical software v 3.4.2 (R Development Core Team 2017).

3. Results

3.1. Influence of crusts on soil properties

The contents of SOM were markedly higher in crust soils than in BSL (Fig. 2). The highest SOM content was in LC4 at the depth of 0-3 cm, ~~which~~ and was 3.84 times greater than the content in BSL and 2.4 times greater than the content found in biocrust. Compared to the BSL, t~~T~~he SOM contents in the subsurface layers (3-10 cm) were 63.6~~4~~-108.4~~4 %~~%, 18.~~18~~2-20.8~~3 %~~% and 48.~~18~~2-79.~~17~~2 ~~%~~% greater ~~under~~ in the biocrust groups, LC2 and LC4, respectively~~, than under BSL~~. Within each type of crust, the SOM content clearly decreased with increasing soil depth. Over the 4-year period, the litter significantly reduced soil BD in both in surface soil and~~or~~ subsurface soil (Table 1). With the decrease of BD, soil TP was significantly higher in LC4 than in the BSL and in biocrust.

Soil properties did show ~~There were~~ differences between crust types ~~in soil properties~~ (Table 1). Compared to the ~~bare sandy land (~~BSL~~)~~, both biocrusts and litter crusts significantly increased SWC in surface soil (0-5 cm). However, SWC showed a decreasing trend in crusts and showed an increasing trend in the BSL with increasing soil depth. The SWC in the BSL was 33 ~~%~~% higher in surface soil than in subsurface soil (5-10 cm), while the SWC in biocrusts and LC4 were 44 ~~%~~% and 18 ~~%~~% lower, respectively, in surface soil than in subsurface soil (5-10 cm).

3.2. Crusts improve hydrological effectiveness

The crust thickness, crust mass and Max WHC were ~~obvious~~clearly higher in the litter crust than in the biocrust (Fig. 3). Moreover, ~~the mass of~~ LC4 had a mass~~was~~ 1.6~~3~~ times higher than the mass of LC2 (Fig. 3B). The Max WHC values in LC4 and LC2 were 3.~~26~~ 2 and 2.0~~2~~ times that of biocrust (Fig. 3C), respectively. Meanwhile, the Max WIC in LC4 was 72.08 ~~%~~% higher than in LC2 (Fig. 3D). An~~The~~ analysis of ~~the~~ infiltration measurements showed that the effects of crust type and water supply on infiltration time, depth and rate were all significant (Table 2). While t~~T~~he water infiltration rate ~~of~~ with a 500 mL water supply in various crust types was ranked LC4 > biocrust > BSL > LC2,~~.~~ t~~T~~he ~~water~~ infiltration rates ~~of~~ with 1000 mL, 1500 mL, 2000 mL and 2500 mL water supplies in different crust types, which were ranked LC4 > LC2 > BSL > biocrust~~,~~ ; further~~and~~ the rates in litter crusts and biocrust were significantly different (Fig. 4). The water infiltration depth increased significantly with water supply, but the trend of water infiltration depths was BSL > LC2 > LC4 > biocrust among the different crust types (Fig. 5).

3.3. Soil properties affect infiltration rates of different water supplies

~~Pearson's correlation analysis showed that the i~~Infiltration rates of different water supplies were significantly correlated with soil and crust properties as shown by Pearson's correlation analysis (Fig. 6). Crust thickness and ~~crust~~ mass were significantly correlated with high water supply (> 1000 mL) ~~the~~ infiltration rates~~ of high water supply (> 1000 mL)~~. ~~The~~ An infiltration rate ~~of~~ with a 500 mL water supply was significantly positively correlated with TP in the 0-5 cm soil layer and SOM content in the 0-3 cm soil layer, ~~while the infiltration rate of 500 mL water supply was~~and significantly negatively correlated with BD in the 0-5 cm and 5-10 cm soil layers. The infiltration rates of the 1000 mL, 1500 mL, 2000 mL and 2500 mL water supplies were significantly correlated with the SWC in the 5-10 cm soil layer.

4. Discussion

Biocrusts influence many soil properties that are also impacted by other ~~influenced the~~ major ecosystem processes in dry lands, such as nutrient cycling and hydrological processes (Gao et al., 2017). Previous studies have separately reported an increase in water retention and SOM content due to the presence of biocrusts (Chamizo et al., 2016). To our knowledge, few previous studies ~~has~~ have reported how ~~all these~~soil properties change in the litter crusts or how litter crust influences the hydrological processes in sandy lands (Jia et al., 2018). We examined all the changes in soil properties and hydrological functions in contrasting biocrusts and litter crusts in a desert ecosystem. Our results will fill these gaps in knowledge and demonstrate that litter crusts significantly influence soil properties and hydrological processes in sandy lands.

4.1. Influence of litter crusts on soil properties

Plant As plant litter falls to the ground, and it forms an assemblyes to developing a porous barrier that is structured by wind and water; this is called litter crust. The litter crust modifies the bidirectional fluxes of liquid water and water vapor and affects water evaporation from the soil by insulating the soil surface from the atmosphere and by intercepting radiation (Dunkerley, 2015; Van Stan et al., 2017). Litter crusts play an important role in changing soil bulk density and porosity, and they serve as a major source of soil organic matter in surface soils. The present study showed that litter crusts decreased the soil bulk density and increased soil porosity and SOM contents. Litter decomposition is an important ecosystem process that is critical to maintaining available nutrients. The SOM is formed through the partial decomposition and transformation of plant litter by soil organisms (Cotrufo et al., 2015). The fragments Fragments produced during litter decomposition can promptly associate with the topsoil layer while. sSome brittle litter residues move to the surface soils by water and wind transfer, and then, they before forming coarse particulate organic matter in the soil. The addition of organic matter to the soil increases soil porosity and decreases soil bulk density. This study demonstrated that The SOM is significantly higher in LC4 than in LC2. The decomposition times of the two litter crusts are a powerful explanation for this result. Over time, the increasing quantity of litter input forms a new microclimatic and promotes SOM accumulation in ~~the~~ surface soils (Liu et al., 2017). The Max WHC also contributes to the higher SOM in LC4. In general, the higher water content enhanced the decomposition rate in litter monocultures (Makkonen et al., 2013).

In our study, litter crusts and biocrust significantly increased surface soil moisture. However, the biocrust showed obvious desiccation in the subsurface soil layer ~~and~~ not present in litter crusts ~~did not happen.~~. The higher moisture under biocrusts can be attributed to ~~the~~ biocrust-anchoring structures that bind soil particles and form mats on the soil surface; these properties strongly increase soil surface water retention ~~at the soil surface~~ (Chamizo et al., 2012). In arid and semi-arid regions during low-intensity rainfall, ~~which is predominant~~dominant in our study area, ~~the~~ rainfall is completely intercepted by biocrusts and cannot penetrate the crust to reach the subsurface soil. Moreover, ~~the~~ biocrusts decrease ~~the~~ subsurface soil water by consuming water during growth, which results in the desiccation of the subsurface soil layer. The change of soil properties (BD, porosity and SOM) caused by litter crust improved hydrological characteristics.

4.2. Effect of litter crusts on hydrological processes

The litter crusts can develop a significant thickness depending on wind, water and other factors. Our study showed that ~~the ~5 cm~~ litter crusts could reach 5 cm in ~~measured from~~ 2-year-old and ~~the ~~ 9 cm litter crusts ~~measured from~~in 4-year-old *Populus simonii* forests. Our study also demonstrated that there are significant differences in the porosity of different aged litter crusts ~~between different ages,~~ and that there are ~~also~~ differences in the interstitial spaces of litter crusts. These variations are major contributors that can cause the observed differences ~~observed~~ in the WIC of litter crusts. The WIC of litter crusts is an integral ~~fraction~~ factor impacting ~~for the effect of~~ litter ~~on~~ infiltration and the development of surface runoff (Gerrits et al., 2010; Dunkerley, 2015). This is because ~~the~~ litter interception ~~as~~ of a certain amount of water ~~could~~ can satisfy early stage infiltration and runoff ~~the~~ water requirements ~~in early stage of infiltration and runoff~~ (Gerrits et al., 2010). Litter crusts are continually broken down and decomposed by microbial activities.~~–~~ and t~~T~~herefore, the frequency of ~~–the~~ movement and recombination of ~~the~~ litter crusts and other organic components can also be considered to influence the porosity and hydrological characteristics of litter crusts (Dunkerley, 2015). In our study, ~~The m~~Max~~imum~~ WHC of litter crusts was ~~1.7~~48.71 g dm^{-2} ~~water – g litter~~. However, the maximum volume of litter crust was 1540 cm^3, and only approximately 5 ~~%~~% of the available void space in the litter was occupied by water. This result indicates that water is retained only in ~~only~~ smaller void spaces within the litter crusts and not in ~~very~~ large gaps, where gravity drainage is expected to dominate due to gravity and cohesive forces, which primarily control ~~would facilely arise because the dominant forces that contribute to water~~ interception ~~are gravity and cohesion~~ (Li et al., 2013; Dunkerley, 2015). ~~We immersed litter crusts in water for 24 hours and subsequently measured their weight gain.~~ The ~~results showed that the~~ litter crust could store water ~~which is~~ equal to 154-200 ~~%~~% of ~~their~~ its dry weight, so a large ~~part~~ proportion of this storage water is determined by the litter characteristics ~~of the litter~~. In our study, the dominant litter crusts were formed by broadleaf litter (*Populus simonii* leaves), which played an important role in determining the water dynamics of the litter crusts (Sato et al., 2004). According to the findings of Li et al. (2013), the Max WHC showed a strong linear relationship with litter mass whether the litter was a monoculture or a mixture. The maximum mass in LC4 was 28.3~~1~~ g dm^{-2}, ~~which~~ indicating~~ed~~ the possibility of high water storage levels ~~of water storage~~.

The high WIC of litter crusts and soil organic matter help to maintain maximum infiltration rates, ~~which~~ allowing ~~the~~ penetration of water into the soil profile, thereby slowing soil desiccation caused by evaporation (Sayer, 2005). The litter and SOM can increase soil porosity and aeration indirectly, thus increasing the WIR. Our results show~~ed~~ that the SOM content ~~was~~ is positively correlated with porosity and negatively correlated with BD. Meanwhile, compared to BSL, the litter crusts increased the WIR ~~under~~ with water supplies >1000 mL. The low water supply (500 and 1000 mL) was similar to low-intensity rainfall, and ~~water~~ soil or litter crusts~~was~~ quickly absorbed ~~by soil or litter crusts~~ water. This observation is believed to be related to the amount of available water ~~that is wetting up~~ and the empty storage ~~within the empty~~ spaces in soil or litter crusts that have~~are~~ not yet reached ~~at~~ their full water retention capacities (Dunkerley, 2015), as a result, there were no significant differences in the WIRs between different crust types. ~~In contrast, a high water supply (> 1000 mL) may result in an enlarged litter percolate flux, which is affected by the rainfall intensity.~~ When the affected soil layer was saturated and water was transported to ~~greater~~ deeper soil layers ~~depths~~, the WIR could be considered a soil characteristic that is dependent on the initial soil water content (Thompson et al., 2010). Therefore, the TP and SOM contents in the surface soil layer significantly influenced the WIR ~~of~~ with low water supplies, and BD and SWC significantly influenced the WIR with~~of~~ high water supply. The increased WHC and WIC in litter crusts and surface soil layers are the main reason the WIR in the litter crusts were slightly lower than in BSL. In addition, abundant SOM results in a soil structure that is

~~not~~ uncompacted, which can lead to the partitioning of water into lateral flows in litter crusts.

More diverse litter crusts can reasonably be assumed to be structurally richer than monospecific litter crusts (Hättenschwiler et al., 2005). Different litter sizes, litter shapes and litter colo~~u~~rs all contribute to distinct geometric organization, WIC, WHC and radiative-energy balance in a species-rich litter layer (Sato et al., 2004). In our study, ~~the~~ a monoculture litter was researched ~~when~~ to ~~analysing~~ analyze the impacts of litter crusts on ~~the~~ soil properties and hydrological functions. In the future, the effects of litter crusts mixed with different species not only on litter structure but also on the movement of water within the litter crusts should be considered. Moreover, ~~the~~ litter crusts affected vegetation properties, such as seed germination, seedling emergence, establishment, and survival (Jia et al., 2018), and this should receive more attention to improve the vegetation in desert ecosystems.

5. Conclusions

Litter crusts significantly influenced ~~the~~ soil properties and hydrological functions. The presence of litter crusts plays a critical role in soil fertility and hydrological functions in sandy lands. Litter crusts increased the soil water content in both the surface (0-5 cm) and subsurface (5-10 cm) soils, but biocrusts increased the soil water content in the surface soil and decreased ~~it~~ the content in the subsurface soil. Litter crusts significantly increased soil organic matter~~, which was~~ by 2.4~~0~~ times ~~the content in biocrusts~~ and 3.84 times the content in biocrusts and bare sandy lands, respectively. Higher organic matter content resulted in increased soil porosity and decreased soil bulk density. Meanwhile, soil organic matter can help to maintain maximum infiltration rates. Litter crusts significantly increased the water infiltration rates ~~under~~ with high water supplies (> 1000 mL). With low water supplies, ~~T~~the water infiltration rate was mainly determined by soil organic matter and soil porosity~~ under low water supplies~~. The water infiltration was mainly determined by soil water content and crust properties~~ under~~ when~~ high~~ water supplies were high. Our results suggested that litter crusts significantly improved the soil properties, thereby influencing the hydrological processes. A number of national ecological program~~me~~s have improved vegetation recovery and litter crust development extensively in China. The results indicate that litter crusts are instrumental in many hydrological processes because of their ability to increase organic matter and water infiltration. Therefore, it is necessary to consider the hydrological effectiveness of litter crusts. In the future, the effects of litter crusts mixed with different species not only on litter structure but also on the movement of water within the litter crusts should be considered. Moreover, the litter crusts effected vegetation properties, such as seed germination, seedling emergence, establishment, and survival, and these factors should receive more attention to improve the vegetation in desert ecosystems.

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Table 1. Soil water content and bulk density (Mean ± S.E.) at the 0-10 cm soil layer depth under with different crust types of crusts. SWC, soil water content; BD, bulk density; TP, soil total porosity; BSL, bare sandy land; Bio, moss crust; LC2, litter crust for 2 years; LC4, litter crust for 4 years. Different lowercase letters indicate significant differences among the various crust soils at the level of $p < 0.05$, and different uppercase letters indicate significant differences among different depth at the level of $p < 0.05$.

	Depth (cm)	BSL	Bio	LC2	LC4
SWC (%)	0-5	3.86 ± 0.22Bb	8.02 ± 1.42Aa	5.23 ± 0.28Aab	7.22 ± 0.60Aa
	5-10	5.13 ± 0.41Aa	4.49 ± 0.36Ba	5.74 ± 0.44Aa	5.92 ± 0.39Aa
BD (g cm^{-3})	0-5	1.52 ± 0.01Ba	1.53 ± 0.02Ba	1.55 ± 0.02Ba	1.33 ± 0.04Bb
	5-10	1.61 ± 0.02Aa	1.54 ± 0.03Aab	1.63 ± 0.01Aa	1.46 ± 0.03Ab
TP (%)	0-5	42.73 ± 0.30Ab	42.30 ± 1.50Ab	41.43 ± 0.75Ab	49.85 ± 1.66Aa
	5-10	39.38 ± 0.74Bb	42.04 ± 1.08Aab	38.64 ± 0.52Bb	44.82 ± 1.27Ba

Table 2. The results of GLM analysis for ~~E~~effects of crust types and the amount of water supply on the water infiltration time, infiltration depth and infiltration rate in the study. Note: type - bare sandy land, moss crust, litter crust for 2 years, litter crust for 4 years; water supply - 500 mL, 1000 mL, 1500 mL, 2000 mL and 2500 mL.

	Time		Depth		Rate	
	t	*p*	t	*p*	t	*p*
Type	-6.909	< 0.001	6.697	< 0.001	3.502	< 0.001
Water	20.496	< 0.001	24.918	< 0.001	-4.055	< 0.001

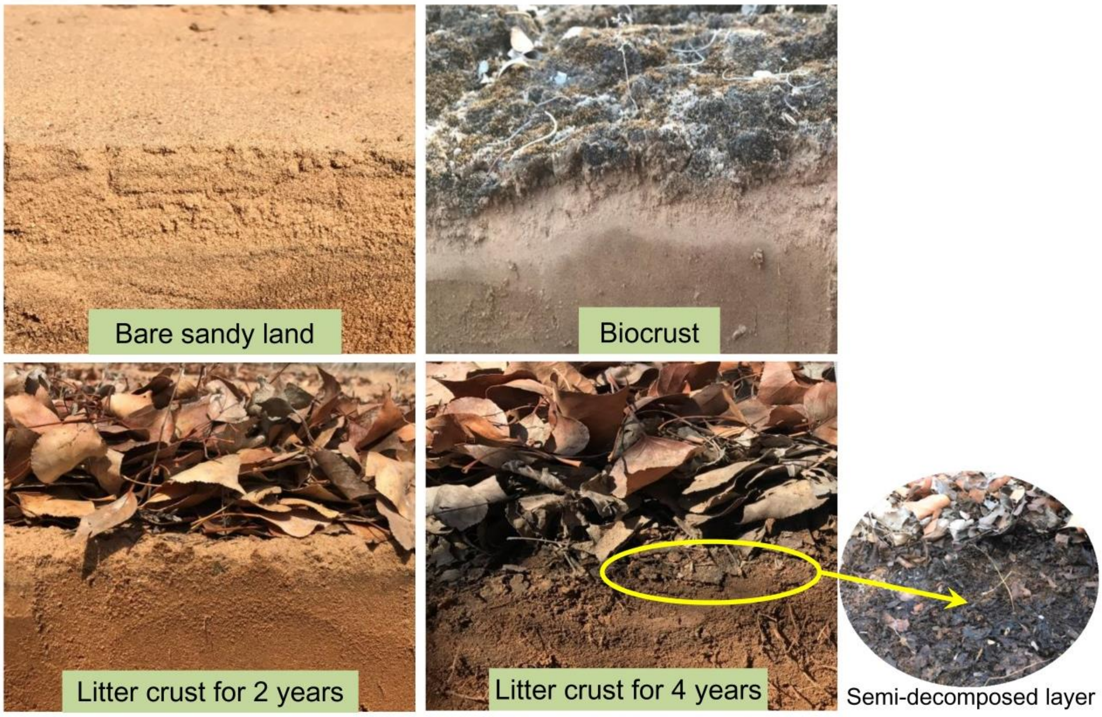


Figure 1. The vertical soil profiles in bare sandy land and different crusts in the southern Mu Us Desert~~study~~.

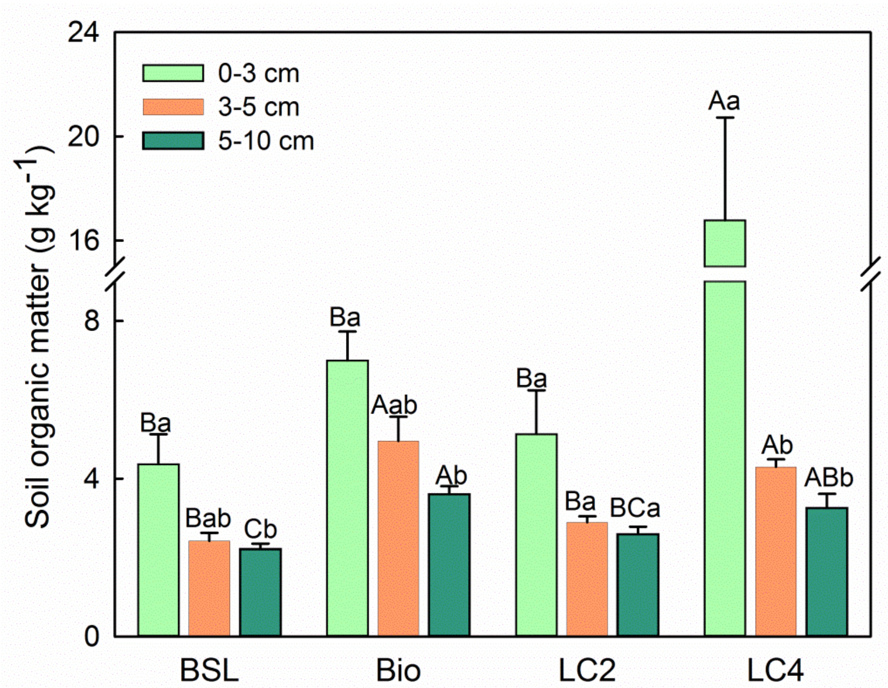


Figure 2. Soil organic matter content (0-10 cm soil depth) in bare sandy land and different crust soils (M±SE). Note: BSL, bare sandy land, Bio, moss crust; LC2, litter crust for 2 years; LC4, litter crust for 4 years. Different uppercase letters indicate significant differences among the various crust soils in the same soil layer at the level of $p < 0.05$, different lowercase letters indicate significant differences among the different soil layers at the level of $p < 0.05$.

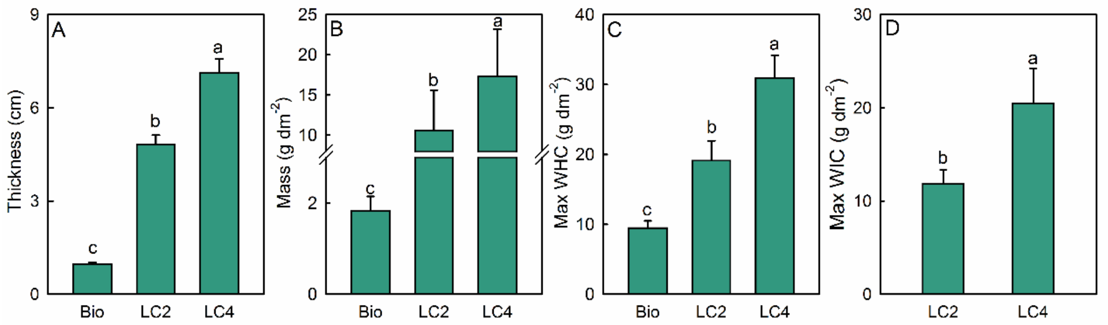
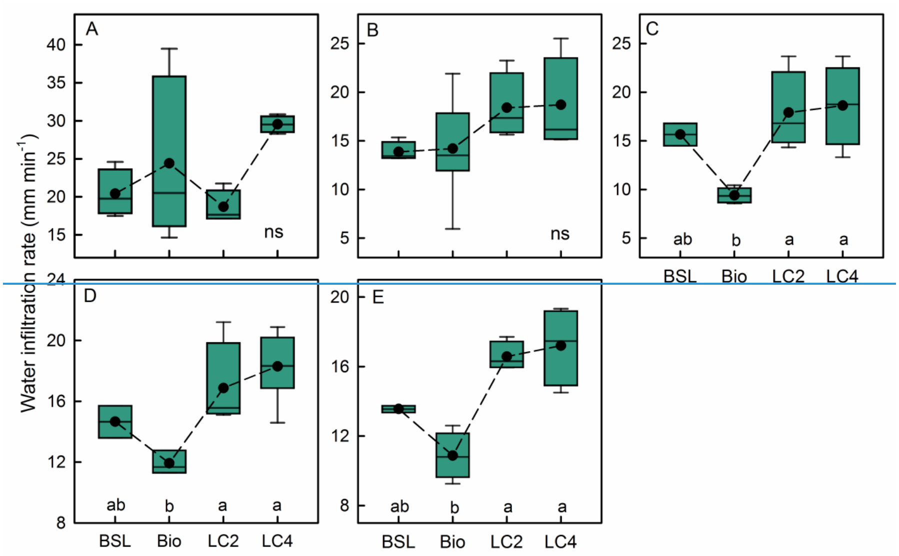


Figure 3. Thickness (A), mass (B), maximum water holding capacity (C) and maximum water holding rate (D) in the bare sandy land and different crust plots (M±SE). Note: BSL, bare sandy land, Bio, moss crust; LC2, litter crust for 2 years; LC4, litter crust for 4 years. Different lowercase letters indicate significant differences among the various crust plots at the level of $p < 0.05$.



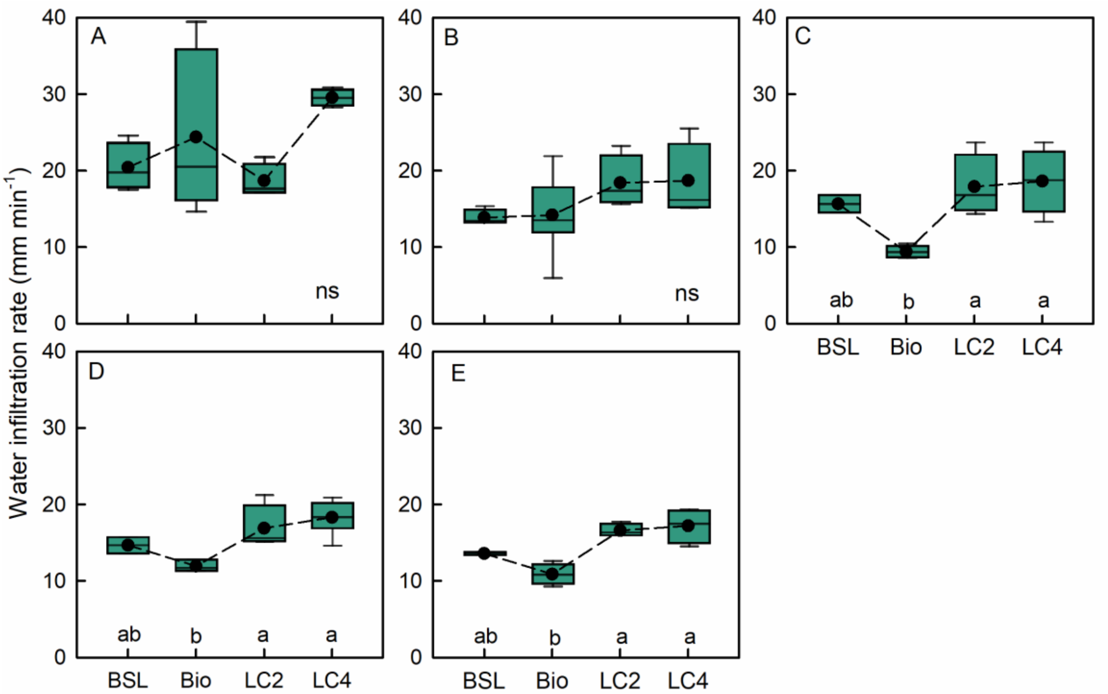


Figure 4. Water infiltration rates (M±SE) of different water ~~supplies~~ volumes (A-500 mL, B-1000 mL, C-1500 mL, D-2000 mL, E-2500 mL) among bare sandy land and crust types. Note: ns, no significant difference, BSL, bare sandy land, Bio, moss crust; LC2, litter crust for 2 years; LC4, litter crust for 4 years. Dashed lines represent the average values. Different lowercase letters indicate significant differences among the various crust plots at the level of $p < 0.05$.

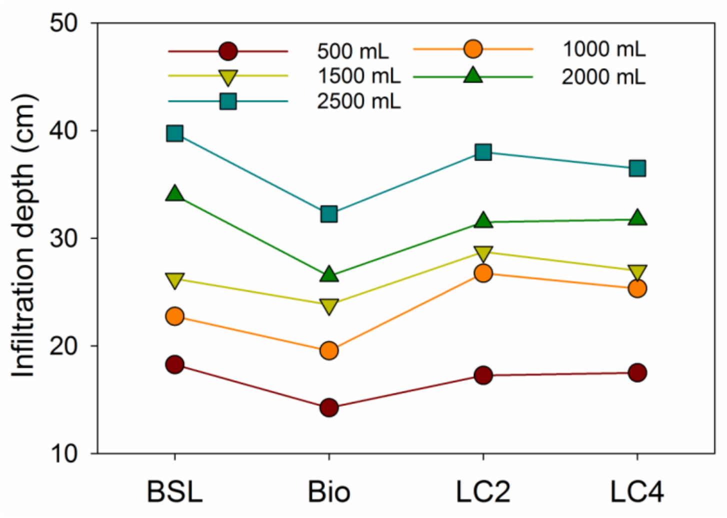


Figure 5. Water infiltration depth of different water supplies among bare sandy land and crust types. Note: BSL, bare sandy land, Bio, moss crust; LC2, litter crust for 2 years; LC4, litter crust for 4 years; 500 mL, 1000 mL, 1500 mL, 2000 mL, and 2500 mL represent the quantities of water supplied at different treatments.

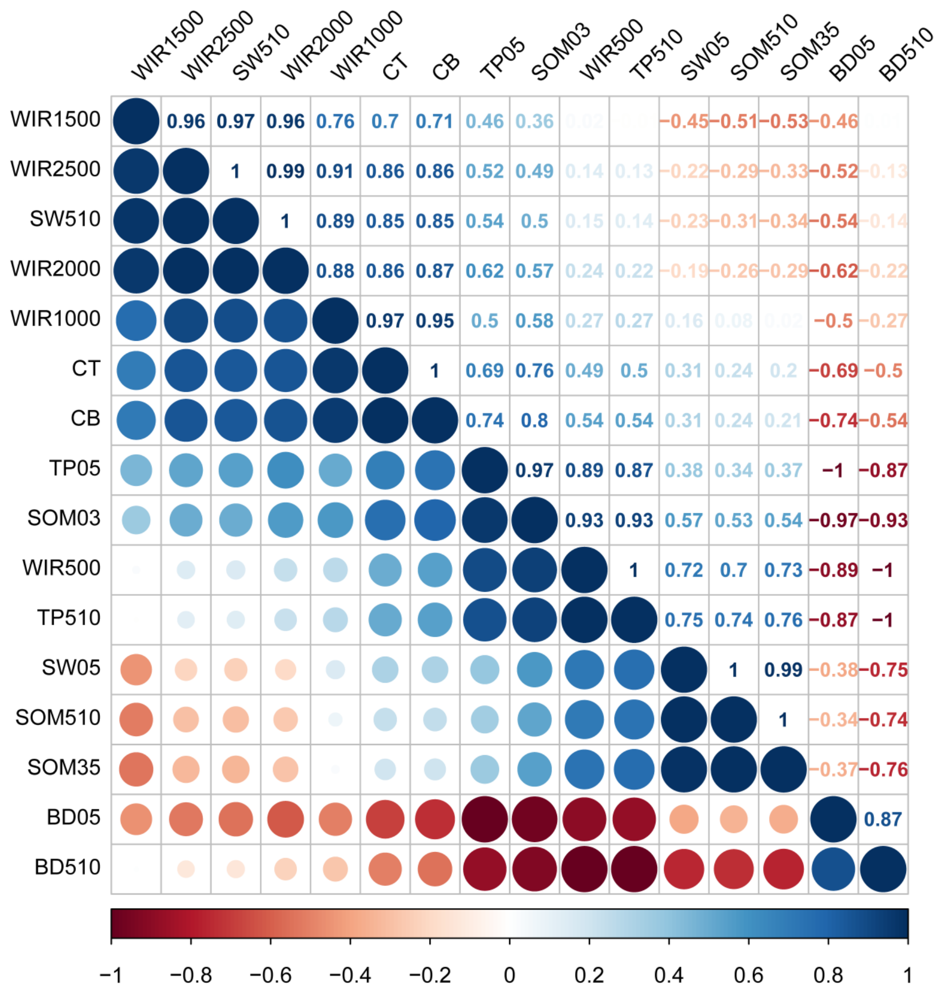


Figure 6. Correlation matrix among the different soil and crust properties and water infiltration rates. Note: blue indicates positive correlations and red indicates negative correlations; the numerical values represent correlation coefficients. WIR500, WIR1000, WIR1500, WIR2000, WIR2500 represent water infiltration rates (mm min^{-1}) of the 500 mL, 1000 mL, 1500 mL, 2000 mL, 2500 mL water supplies, respectively; CT and CB represent crust thickness (cm) and crust mass (g dm^{-2}); SW05 and SW510 represent soil water content in the 0-5 cm and 5-10 cm soil layers (%); SOM03, SOM35 and SOM510 represent soil organic matter content (g kg^{-1}) in the 0-3 cm, 3-5 cm, and 5-10 cm soil layer, respectively; BD05 and BD510 represent soil bulk density (g cm^{-3}) in the 0-5 cm and 5-10 cm soil layers; TP05 and TP510 represent soil total porosity (%) in the 0-5 cm and 5-10 cm soil layers.