

1 **Title:** Biocrust reduced soil water retention and soil infiltration in the alpine *Kobresia* meadow

2 **Running title:** Biocrust reduced soil water retention and soil infiltration

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13

14 **Abstract**

15 Biocrust is a key component of ecosystems and plays a vital role in altering hydrological processes
16 in terrestrial ecosystems. The ~~role-effect~~[impacts](#) of biocrust on hydrological processes in arid and
17 semi-arid ecosystems has been widely documented;~~;~~ ~~however~~[However](#), the effects and mechanisms
18 of biocrust on soil hydrological processes in alpine ecosystems are still poorly understood. In this
19 study, we selected two meadow types from the northern Qinghai-Tibet Plateau: normal *Kobresia*
20 meadow (NM) and biocrust meadow (BM). Both the soil hydrological and physicochemical
21 properties were examined. We found that in the 0–30 cm soil layer, soil water retention and soil
22 water content in NM were higher than those in BM, whereas the 30–40 cm layer's soil water

23 retention and soil water content in NM were lower than those in BM. The topsoil infiltration rate in
24 BM was lower than that in NM. Furthermore, the physicochemical properties were different
25 between NM and BM. The 0–10 cm soil layer’s clay content in BM was 9% higher than that in NM,
26 whereas the 0–30 cm layer’s soil capillary porosity in NM was higher than that in BM. In addition,
27 the 0–20 cm layer’s soil total nitrogen (TN) and soil organic matter (SOM) in NM were higher than
28 those in BM, implying that the presence of biocrust ~~did may~~ not favor the formation of soil nutrients
29 owing to its lower soil microbial biomass carbon and microbial biomass nitrogen. Overall, soil water
30 retention was determined by SOM by altering soil capillary porosity and bulk density. Our findings
31 ~~may suggested revealed~~ that the establishment of cyanobacteria crust biocrust ~~did may~~ not improve
32 soil water retention and infiltration, and the soil in cyanobacteria crust bioerust meadows ~~may could~~
33 be more vulnerable to runoff generation and consequent soil erosion. These results provide a
34 systematic and comprehensive understanding of the ~~role effects~~ of biocrust in the soil hydrology of
35 alpine ecosystems.

36 **Keywords:** Alpine meadow; biocrust; soil-soil water retention; soil water infiltration;
37 physicochemical properties

38 1 Introduction

39 Biocrusts are composed of living non-vascular plants (mosses, lichen and green algae) and
40 microorganisms (such as cyanobacteria, fungi and bacteria) associated with their bonding soil
41 particles that occur in the uppermost few millimeters ~~or even centimeters of surface soil~~ (Belnap et
42 al., 2016, Sun et al., 2022). As a crucial part of soil surface, biocrusts ~~are widely distributed in arid~~
43 ~~and semiarid regions throughout the world, and it~~ plays a vital role in regulating biogeochemical
44 processes, hydrology processes, and surface energy balance, ~~such as improving soil aggregation~~

45 ~~and stability, increasing the soil fertility and, reducing soil erosion and thus maintaining water~~
46 ~~availability~~ (Li et al., 2016), which can serve as “ecological engineers” in soil systems. However, to
47 our knowledge, the controlling mechanism of biocrust on soil hydrological processes is still unclear.
48 Most previous studies were conducted in arid and semi-arid ecosystems, such as the Tengger Desert,
49 Negev Deserts, and Loess Plateau hydrological processes where plant are limited by soil moisture.
50 Very few studies have focused on the role of biocrust on hydrological processes (i.e., soil water
51 content, soil water retention, and soil infiltration) in alpine ecosystems where plant are limited by
52 soil temperature, ~~and the mechanisms are poorly understood~~. Thus, examining the impact of biocrust
53 on hydrological processes ~~could provide insight could have substantial effects~~ on water balance in
54 alpine ecosystems and grassland management policies for maintaining the sustainability of meadow
55 ecosystems.

56 The alpine meadow is an important ecosystem in the Qinghai-Tibet Plateau (QTP), which plays
57 an important role in water retention (Dai et al., 2019), ~~in~~ preventing soil erosion (Qian et al., 2021)
58 and ~~in~~ regulating energy exchange (Zhu et al., 2020) by altering soil surface features (i.e. —such as
59 roughness, soil texture, porosity, and aggregation) (Li et al., 2016) ~~thereby modifying evaporation,~~
60 ~~soil water retention, and water infiltration processes~~. However, the formation of biocrust in alpine
61 meadows is different from that in arid areas, where the biocrust is formed from intensive land use
62 such as overgrazing. Overgrazing could reduce vegetation coverage, thereby increase soil light
63 condition, which favor the photosynthesis of cyanobacteria crust. Previous study have-d found a
64 well relationship between biocrust and vegetation coverage, i.e. the occurrence frequency of
65 cyanobacteria crust also increased with reducing vegetation coverage owing to overgrazing. ~~—(Li et~~
66 al., 2015). Moreover, and the biocrust types vary with the succession stage of alpine meadows (Li

67 et al., 2016b). For instance, as the degree of degradation increases, the moss-dominated crust is
68 transformed into cyanobacteria-dominated crust, followed by lichen-dominated crust from
69 *Graminoid*-dominated vegetation degradation to *Kobresia humilis* meadow (light degradation) and
70 then to *K. pygmaea* meadow (moderate degradation) (Li et al., 2016). Thus, we suggest that the
71 impact of biocrust on hydrologic processes in alpine meadows may differ from that in arid areas,
72 and vice versa.

73 To date, although numerous studies have pointed out that biocrust has substantial effects on
74 soil water retention and soil moisture infiltration processes by altering soil microenvironments, such
75 as soil roughness, soil porosity, and aggregation, no consensus has been reached. For instance, some
76 studies have found that biocrust could increase soil water infiltration and reduce runoff by increasing
77 soil porosity and aggregate stability compared with bare soil in cool desert ecosystems (Kidron and
78 Benenson, 2014; Wei et al., 2015). In contrast, other studies ~~found~~reported that soil water infiltration
79 was significantly reduced in crusted areas compared with non-crusted areas in arid ecosystems (Li
80 et al., 2010; Xiao and Hu, 2017). These discrepancies highlight the necessity to further explore the
81 effects of biocrust on hydrological processes, such as exploring the specific hydrological processes
82 by conducting soil infiltration experiments and soil water retention curve measurements.
83 Furthermore, most previous studies were mainly conducted in arid and semi-arid ecosystems, and
84 very few studies have focused on the effects of biocrust on the soil's hydrological processes in alpine
85 ecosystems. Therefore, it is crucial to assess the role of biocrust in soil water retention and
86 infiltration in alpine meadows.

87 To address these knowledge gaps, In this study, normal *Kobresia* meadow and biocrust
88 meadow in QTP were selected. ~~Both~~Both soil and hydrological features were measured, with the aim

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89 of exploring the role of biocrust in hydrological processes in alpine ecosystems. Specifically, the
90 objectives of this study were to explore the effect of biocrust on soil-hydrological features in alpine
91 ecosystems, to reveal how biocrust affects soil water retention by altering soil and vegetation
92 properties. ~~Our results, and could~~ provide insights into the management of biocrust in alpine
93 meadows.

94 **2 Materials and methods**

95 **2.1 Site description**

96 The field test sites were located in the northeastern Qinghai-Tibet Plateau (101° 19' E, 37° 37'
97 N), in Qinghai Province, China (Fig.1a). The area has a continental plateau climate with a mean air
98 temperature of -1.7°C and a mean annual precipitation of approximately 562 mm (Dai et al., 2020).
99 It should be noted that approximately 80% of the precipitation occurs during the growing season
100 (between May and September), and the other 20% occurs during the non-growing season. The main
101 vegetation type in this region is the *Kobresia* meadow, which is dominated by *Kobresia humilis*
102 (Fig.1b). The soil type in the study area is silt loam according to the in the USDA soil taxonomy
103 system of classification (Cusack and others 2018), with a soil thickness of approximately 60–80 cm.
104 The pH and EC is 7.5 m s m⁻¹ and 6.7 in the study area, respectively. (Li et al., 2016).

105 **2.2 Experimental design and soil sampling**

106 In August 2020, we choose two study sites on the northeastern Qinghai-Tibet Plateau to avoid
107 pseudoreplication, and two types of soil surfaces were selected in each study site, i.e. normal
108 *Kobresia* meadow (NM, Fig. 1b) and biocrust meadow (BM, Fig. 1c). To reduce the differences
109 caused by spatial heterogeneity, the BM was selected adjacent to the NM ~~to ensure~~ the soil type
110 and topographic condition was same. The vegetation cover in BMs is usually less than 20% with a

111 thick turf but no litter layer in topsoil, and the BM type is dominated by cyanobacteria crust (ca.
112 80%) (Li et al., 2016). In contrast, NM has a dense vegetation cover and is mainly dominated by
113 *Kobresia pygmaea*, with average plant heights of 1–3 cm. Furthermore, a clear typical turf horizon
114 and litter layer was observed within the topsoil in NM, that is, the Afe horizon. BM had a higher
115 root biomass than that of NM, owing to its thick turf (Table 1).

116 We obtained the disturbed soil samples (i.e. non-ring knife soil sample) in NM and BM, and
117 four quadrats (1 × 1 m) were randomly selected for soil sampling with a depth of 10 cm in each
118 treatment using an earth boring auger, and then brought back to the laboratory to measure and
119 analyze soil organic matter (SOM), soil microbial biomass carbon (MBC), microbial biomass
120 nitrogen (MBN), total carbon (TC), total nitrogen (TN), and soil particle size distribution/soil texture
121 (PSD). Undisturbed cylindrical ring samples (i.e. ring knife soil sample) were also obtained in each
122 treatment to determine the soil bulk density (BD), soil porosity, and soil hydraulic properties (i.e.,
123 soil water retention and soil water supply capacity). The soil infiltration rates were measured using
124 a double-ring infiltrometer for each treatment.

125 2.3 Laboratory measurements and analyses

126 First, the disturbed soil samples were sieved through 0.25 mm and 2-mm soil sieves to remove
127 debris and roots for the analysis of soil properties. SOM was measured based on the Walkley &
128 Black procedure (Nelson and Sommers, 1982), MBC and MBN were measured by the chloroform
129 fumigation-direct extraction method (Vance et al., 1987), and TC and TN were measured using an
130 element analyzer (Elementar Vario EL III, Hanau, Germany). PSD was determined using a
131 Mastersizer 2000 (Malvern Instruments, UK). BD was measured as the ratio of the oven-dry soil
132 mass to the core volume (100 cm³). The soil total porosity, soil capillary porosity, and soil non-

133 capillary were measured using the following equation (Dai et al., 2020):

$$134 \quad TP = \left(1 - \frac{BD}{d_s}\right) \times 100\% \quad (1),$$

$$135 \quad CP = CWC \times BD \quad (2),$$

$$136 \quad NCP = TP - CP \quad (3),$$

137 where TP, CP, and NCP represent soil total porosity (%), soil capillary porosity (%), and soil non-
138 capillary porosity (%), respectively; CWC represents soil capillary water capacity; d_s is the soil
139 particle density, which was assumed to be 2.65 (g cm⁻³).

140 The soil water retention curves (SWRCs) were measured using a pressure plate apparatus (1500
141 F1, Soil Moisture Equipment Corp., SEC, USA), and the relationship between soil water content
142 and matric potential was fitted by the Gardner model. The formula of the Gardner model is as
143 follows (Gardner et al., 1970):

$$144 \quad h = A\theta^B,$$

145 where h is the soil water content (%), θ is the matric potential (kPa), and A and B are the fitting
146 parameters. Higher values of $A \cdot B$ and A indicate a higher soil water supply capacity and soil water
147 retention capacity, respectively.

148

149 2.4 Statistical analysis

150 In this study, to compare the differences between BM and NM on soil water retention and soil
151 properties, we conducted one-way analysis of variance (ANOVA) statistical tests to determine
152 differences in plant and soil properties for the same soil layers between the BM and NM, and a least-
153 significant-difference test ($P < 0.05$) was conducted when significant differences were detected by
154 ANOVA. To explore the relationship between soil properties and soil soil water retention, and

155 quantitative evaluation of the effects of soil properties on soil-soil water retention, Pearson's
156 correlation and variance partition in the analysis were used by R software version 3.4.3 (R
157 Development Core Team, 2006) with the "hier.part" and "corrplot" packages. Furthermore,
158 structural equation modeling was used to examine the soil properties' direct and indirect effects on
159 soil water retention.

160

161 3 Results

162 3.1 Soil texture~~Soil particle size distribution~~Soil texture among two surface soil types

163 Silt content dominated the ~~soil particle size distribution~~soil texture in the 0–40 cm soil layer
164 across the two surface soil types (mean 61.69%), followed by sand (mean 30.13%), and clay (mean
165 8.18%) (Fig. 2). Specifically, the 0–10 cm ~~soil layer's~~ clay content in BM was 9% higher than that
166 in NM, whereas the 10–40 cm ~~soil layer's~~ clay content in BM was 16% lower than that in NM,
167 especially for the 10–20 cm soil layer ($P<0.001$). In contrast, the 0–40 cm ~~soil layer's~~ silt content
168 in BM was higher than that in NM, especially for the 20–30 cm soil layer ($P<0.05$). However, no
169 clear pattern was observed for the sand content between BM and NM. Overall, ~~in the 0-40 cm soil~~
170 ~~layer,~~ clay content (8.62%) in NM was 11% higher than that in BM (7.69%), whereas in the 0–40
171 cm ~~soil layer,~~ silt content (61.24%) in NM was nearly equal to that in BM (62.13%).

172 3.2 Soil physicochemical properties among two surface soil types

173 There were no significant differences for 0–40 cm BD, 0–40 cm TP, 0–40 cm CP and 0–40 cm
174 NCP ($P>0.05$) (Fig.3), but the 0–20 cm BD in NM was 13% lower than that of BM, and the TP and
175 CP in NM were 7% and 5% higher than that of BM. No clear pattern was observed for NCP in NM
176 and BM (Fig.3). Furthermore, the 0–20 cm TN and SOM in NM were much higher than those in

177 BM and reached a significant level at 0–10 cm ($P<0.05$), whereas the 30–40 cm TN and SOM in
178 NM were lower than those in BM (Fig.3). Similarly, the 0–10 cm soil layer's TC and C: N ratio in
179 NM were significantly higher than those in BM, whereas the 30–40 cm soil layer's TC and C: N
180 ratio in NM were lower than those in BM (Fig.3). Additionally, the 0–40 cm soil layer's MBC and
181 MBN in NM were higher than those in BM and reached a significant level at 0–10 cm ($P<0.05$)
182 (Fig. 4).

183 3.3 Soil hydrological processes among two surface soil types

184 The soil hydrological processes varied between crust BM and NM (Fig.5 and Table 1). Given
185 that parameter A fitted by the Gardner model represents the soil water retention (a higher A value
186 indicates higher soil water retention), the soil water content was reduced with decreasing matric
187 potential and reduced sharply at high matric potential, but remained stable at low matric potential
188 (Fig. 5). The 0–30 cm layer's soil water content and soil water retention in NM were higher
189 than those in BM, whereas the 30–40 cm layer's soil water content and soil water retention in NM
190 were lower than those in BM (Table 1 and Fig. 6b). Similarly, the 0–10 and 20–30 cm layers' soil
191 water supply capacity (i.e., $A*B$ fitted by the Gardner model) in NM was higher than that in BM,
192 while the 10–20 and 30–40 cm layers' soil water supply capacity in NM was lower than that in BM
193 (Fig. 6a). Furthermore, the surface infiltration rate in the BM was significantly lower than that in
194 the NM (Table 1).

195 3.4 Dominated factors affecting soil-soil water retention

196 Pearson correlation analysis showed that soil water retention was significantly negatively
197 related to BD, but significantly positively related to TP, CP, and SOM (Fig.7a), whereas soil particle
198 size distribution soil texture exerted weak soil water retention (Fig.7a). Furthermore, the variance

199 partition showed that SOM explained the greatest variability in soil-soil water retention (24.40%),
200 followed by CP (21.24%), BD (18.22), and TP (18.22%) (Fig. 8b), and structural equation modeling
201 showed that the effect of SOM on soil water retention was achieved by altering CP and BD (Fig. 8).

202 **4 Discussion**

203 **4.1 Effect of biocrust on soil properties**

204 The effects of biocrust on soil properties have been widely explored in previous studies (Guo
205 et al., 2008; Liu et al., 2019). Compared with non-biocrust and most studies conducted in arid
206 regions, ~~we have found that~~ the presence of biocrust could improve soil aggregation and stability (Wu
207 et al., 2020), increase soil fertility (Zhou et al., 2020), and reduce soil erosion (Chamizo et al., 2017).
208 In this study, however, we found that the presence of cyanobacteria crust could improve topsoil
209 texture compared with normal meadow, but not that of deep soil. The 0–10 cm ~~soil layer's~~ clay
210 content in cyanobacteria crust meadow was higher than that for normal meadow, whereas the 10–
211 40 cm ~~soil layer's~~ clay content in cyanobacteria crust meadow was lower than that for normal
212 meadow, which is in line with previous studies conducted in arid and semi-arid regions (Liu et al.,
213 2016; Wu et al., 2020). The higher clay content in cyanobacteria crust meadow was attributed to the
214 exudation and cohesiveness of the biocrust, which promoted clay and silt formation and reduced
215 sand content (Wang et al., 2021). Furthermore, we found that the 0–20 cm ~~soil layer's~~ soil bulk
216 density in normal meadow was lower than that in cyanobacteria crust meadow, thereby leading to
217 higher soil porosity and total capillary porosity in normal meadow. Such higher soil capillary
218 porosity in normal meadow was attributed to its higher soil organic matter content, which was also
219 confirmed by the significant positive relationship between soil organic matter and soil capillary
220 porosity (Fig. 7). ~~Because it~~ has been well documented that a higher soil organic matter could

221 improve soil aggregation and stability and subsequently increase soil capillary porosity (Cui et al.,
222 2021).

223 Moreover, ~~more-most~~ previous ~~found-indicated~~ that the presence of cyanobacteria crust can
224 also improve soil nutrient conditions in the process of mobile sand fixation (Belnap et al., 2004;
225 Guo et al., 2008; Li et al., 2005a). However, we found that the presence of cyanobacteria crust
226 reduces the 0–10 cm ~~layer's~~ soil total carbon, total nitrogen, and C: N ratio compared with normal
227 meadow, which is in contrast to most previous studies conducted in arid and semi-arid regions
228 (Chamizo et al., 2012b; Zhao et al., 2010). A ~~probable-possible~~ reason for these differences may
229 ascribe to the environmental differences. It is well ~~documenteddoumeted~~ that the formation of
230 biocrust is a changing process from simple to complex in its morphology, the early cyanobacteria
231 crust was formed only under favorable hydrothermal conditions such as temperature, soil water,
232 solar radiation, and nutrient content (Belnap et al., 2004; Li et al., 2005b). For instance, biocrust is
233 metabolically active when the external environment is wet, and its metabolically active environment
234 is sensitive to temperature (Belnap et al., 2004; Li et al., 2005b), otherwise the biocrust may choose
235 to enter the dormant stage when the external environment is under unfavorable conditions. Therefore,
236 compared to the higher soil temperatures in arid and semi-arid lands, the biocrust in alpine
237 ecosystems may be in a dormant stage owing to its lower temperature and less available nutrients.
238 Moreover, the biocrust in our study was mostly dominated by cyanobacteria crust, which was
239 vulnerable to external disturbances such as grazing activity; ~~thus~~ Thus, the biocrust may choose
240 dormancy when it is subjected to grazing pressure, ~~which-this evidence~~ was also confirmed by the
241 significantly lower microbial soil carbon and microbial soil nitrogen content in cyanobacteria crust
242 meadow compared with normal meadow (Fig. 4).

243 **4.2 Effect of biocrust on soil hydrology and their underlying mechanisms**

244 We found that soil water infiltration was greatly reduced in cyanobacteria crust meadow
245 compared with that in normal meadow, which was consistent with the results of a previous study
246 conducted in alpine meadows (Li et al., 2016b). However, it is in contrast to other studies conducted
247 in cool desert ecosystems where biocrust increased soil water infiltration and reduced runoff by
248 increasing soil porosity and aggregate stability compared with physical crusts and non-crusts bare
249 soils (Kidron and Benenson, 2014; Wei et al., 2015). These discrepancies were associated with soil
250 texture and biocrust developmental stage. In general, soil water infiltration in coarse-textured soils
251 is higher than that in fine-textured soils owing to its large pores compared with the narrow pores in
252 fine-textured soils, which reduces the movement of water into the soil (Belnap, 2006). However, we
253 found that the establishment of cyanobacteria crust increased clay content and subsequently reduced
254 soil macropores, which hindered soil water infiltration. Therefore, we conclude that the soil in the
255 cyanobacteria crust meadow may be more vulnerable to runoff generation and consequent soil
256 erosion, owing to its lower soil water infiltration and soil water retention capacity. On the other hand,
257 biocrust can reduce available pore spaces for water to infiltrate by clogging the soil surface
258 conductive pores owing to its higher water absorption and swelling of biocrust (Fischer et al., 2010),
259 and consequently reduce soil infiltration. In addition, soil water infiltration was ~~also affected~~
260 by the developmental stage of the biocrust in homogeneous soil. A previous study ~~indicated~~
261 that soil hydraulic parameters differed significantly between cyanobacterial biocrust and moss
262 biocrust (Wang et al., 2017). For instance, Chamizo et al. (2012a) reported that the incipient-
263 cyanobacterial crust had a lower soil infiltration rate than that of the cyanobacterial crust, whereas
264 the dark-colored mosses' crust had higher surface soil infiltration capacity by increasing

265 macroporosity and unsaturated hydraulic conductivity in the grasslands [dominated by *A. splendens*](#)
266 (Jiang et al., 2018). In our study, the biocrust was dominated by incipient-cyanobacterial crust,
267 which had low biological activity and low porosity owing to the predominance of vesicle pores,
268 thereby leading to a lower soil infiltration rate.

269 Furthermore, the soil water retention and soil water supply capacity varied significantly
270 between the biocrust and normal meadows. We found that in the 0–10 cm soil water retention and
271 soil water supply capacity in normal meadow were higher than that in cyanobacteria crust meadow,
272 which was not in line with previous studies conducting in drylands in which biocrusts enhanced
273 surface soil water retention capacity and water availability (Sun et al., 2022). We speculate that the
274 lower soil water retention in the cyanobacteria crust meadow was related to its lower soil organic
275 matter; this evidence was also confirmed the lower microbial biomass carbon (Fig. 4a). Furthermore,
276 the structural equation model indicated that the effect of soil organic matter on water retention was
277 mainly achieved by altering soil bulk density and soil porosity (Fig. 8) because higher soil organic
278 matter could reduce soil bulk density and thereby increase soil porosity (Liu et al., 2019), leading
279 to higher soil water retention. This result was also confirmed by the significant positive relationship
280 between soil organic matter and soil water retention (Fig. 7). [Considering soil organic matter was](#)

281 derived from vegetation litter and root biomass, whereas the vegetation litter in cyanobacteria crust
282 meadow was lower than that in normal meadow owing to its lower aboveground biomass and
283 vegetation coverage, ultimately resulting in lower soil organic matter in cyanobacteria crust meadow.

284 4.3 Implications for the [effect role](#) of biocrust in alpine meadows

285 Grassland ecosystems cover more than 60% of the QTP and provide important ecosystem
286 services, such as biodiversity conservation, carbon storage, and water conservation (Dong et al.

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287 2020). However, in recent decades, grasslands in the QTP have suffered from serious degradation
288 due to increasing human activity (Cao et al. 2019). Biocrust is an important surface feature of the
289 degraded alpine meadows. It is acknowledged that biocrust has a positive effect on soil nutrient and
290 soil water content retention in arid regions. In contrast, we found that the presence of cyanobacteria
291 crust decreased soil water retention and soil infiltration rate, which did not improve water
292 conservation in alpine meadows. Therefore, the soil in the [cyanobacteria crust biocrust](#) region may
293 be more vulnerable to runoff generation and consequent soil erosion. Moreover, soil nutrients, such
294 as SOM, TC, and TN, were reduced significantly in the cyanobacteria crust meadow, suggesting
295 that the growth of vegetation in the cyanobacteria crust meadow may be limited by soil nutrients.
296 Considering the negative effects of biocrust on alpine meadows, some steps should be taken to
297 reduce the formation of [cyanobacteria crust biocrust](#) in degraded alpine meadows, such as reducing
298 grazing intensity ~~and~~. [Nevertheless, our study results were only obtained only by conducting ed-in](#)
299 [site scale, which may not sufficiently to extrapolate the whole QTP owing to its high spatial](#)
300 [heterogeneity. Thus, a](#)
301 [it is necessary larger scale or more study sites is necessary to have a generalizability conclusion](#)
302 [regarding the effects of biocrust on hydrological processes in alpine meadow of QTP owing to](#)
303 [its considering the high spatial heterogeneity in QTP. –](#)

304 5 Conclusions

305 Soil hydrological processes were significantly affected by the establishment of [cyanobacteria](#)
306 [crust biocrust](#), and we found that the [cyanobacteria crust biocrust](#) could reduce topsoil water and
307 infiltrate topsoil, which suggested that the establishment of [cyanobacteria crust biocrust](#) ~~did~~ [may](#) not
308 favor soil hydrological processes in alpine meadows. Furthermore, the presence of [cyanobacteria](#)

309 ~~crustbioerust~~ increased topsoil clay content, while the 0–30 cm layer’s soil capillary porosity in NM
310 was higher than that in BM, indicating that the presence of ~~cyanobacteria crustbioerust~~ reduced soil
311 porosity and thereby reduced topsoil water infiltration. This suggested that the discrepancies in soil
312 water retention and topsoil infiltration were close to physicochemical properties, and that SOM
313 plays a role in soil water retention by affecting CP and BD. Our study ~~aremay helpful provides~~
314 ~~insight into the role of for making reasonable management policies to maintaining the sustainability~~
315 ~~of meadow ecosystems in the long run, especially under intensives dramatic human activity and~~
316 ~~climate change in QTP.elimate changes during the anthropocenebioerust in soil hydrological~~
317 ~~processes in alpine ecosystems.~~

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321 **Author contribution**

322 Licong Dai: Investigation, Data curation, Writing – original draft, Formal analysis. Ruiyu Fu :
323 Investigation, Data curation, Writing – original draft, Formal analysis, Visualization. Xiaowei Guo
324 and Zhongmin Hu: Investigation, Data curation, Project administration, Supervision. Yangong Du:
325 Writing – original draft, review & editing. Guangmin Cao and Huakun Zhou: Conceptualization,
326 Methodology, Funding acquisition, Supervision.

327 **Declaration of competing interest**

328 The authors declare that they have no known competing financial interests or personal
329 relationships that could have appeared to influence the work reported in this paper

330 **Data availability statement**

331 The data that support the findings of this study are available from the corresponding author
332 upon reasonable request.

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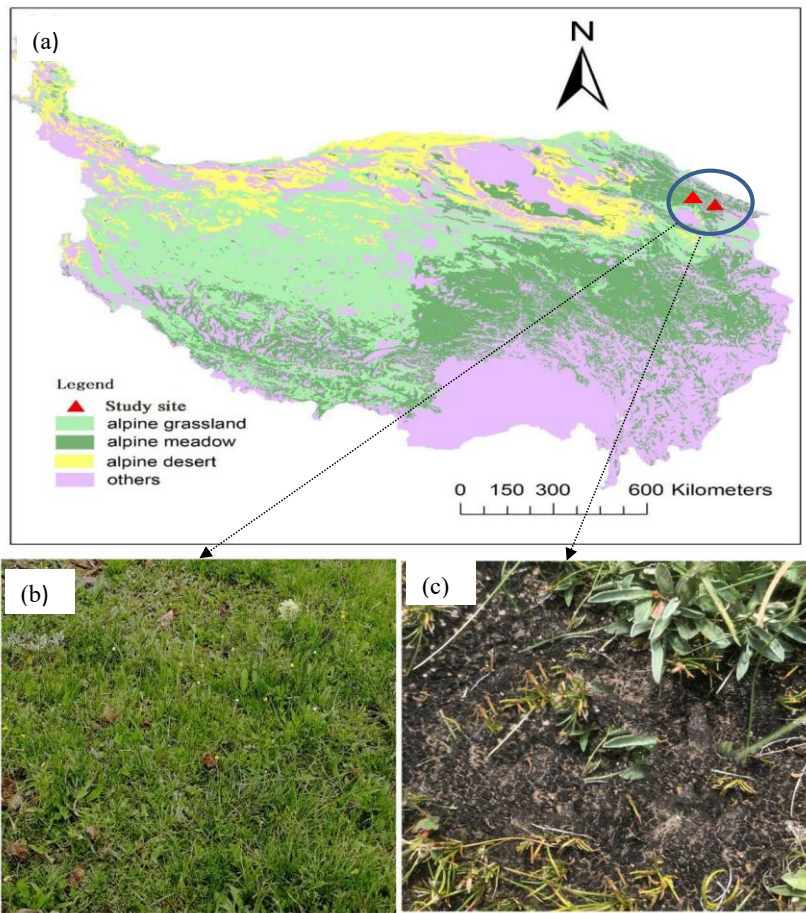
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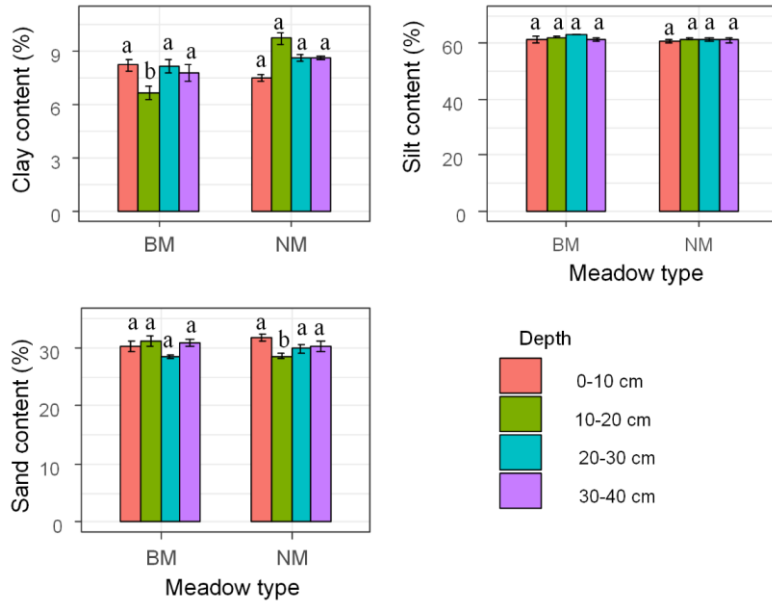
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445 Fig.1 The study site (a) and two type meadows in this study: normal *Kobresia* meadow (b) and
446 biocrust meadow (c)

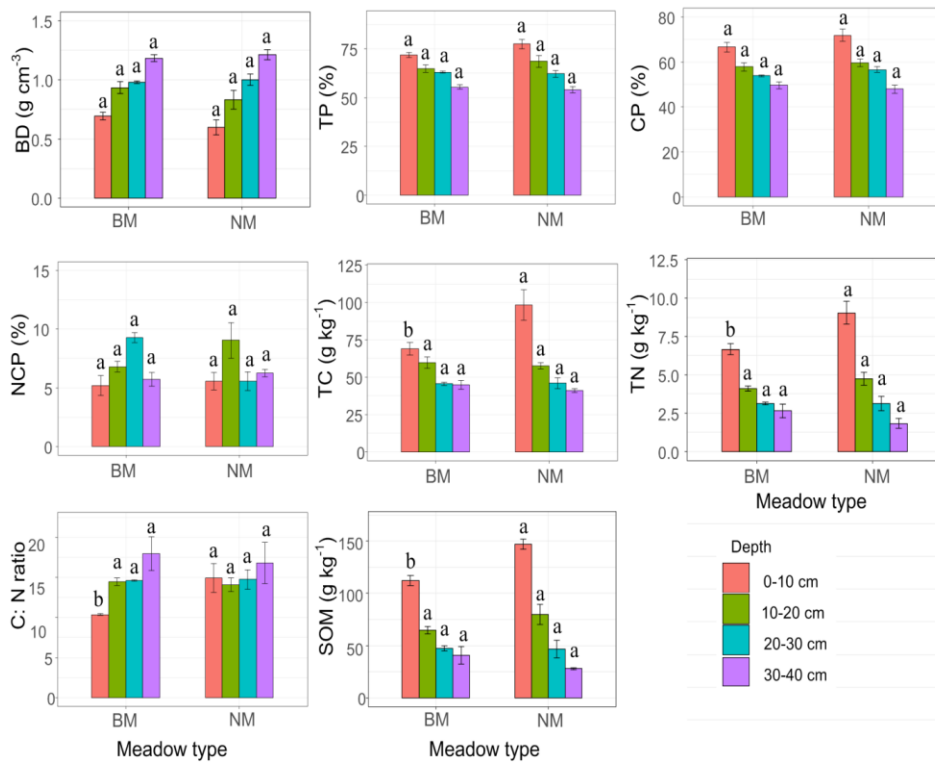
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455 Fig.2 Soil textureSoil-particle size distributionSoil-texture among two surface soil types. Note: NM,
456 normal *Kobresia* meadow; BM, biocrusts meadow, the different letters mean significant differences
457 ($P < 0.05$) between normal *Kobresia* meadow and crust meadow at the same soil layer.



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459 Fig.3 The soil physicochemical among two surface soil types, BD: soil bulk density, TP: soil total

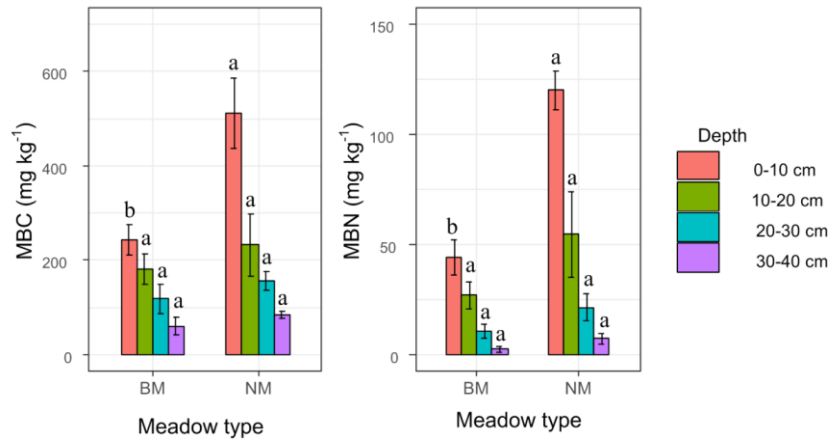
460 porosity, CP: soil capillary porosity, NCP: non-capillary porosity, TN: soil total nitrogen, TC: soil

461 total carbon, C:N: soil C: N ratio, SOM: soil organic matter, the different letters mean significant

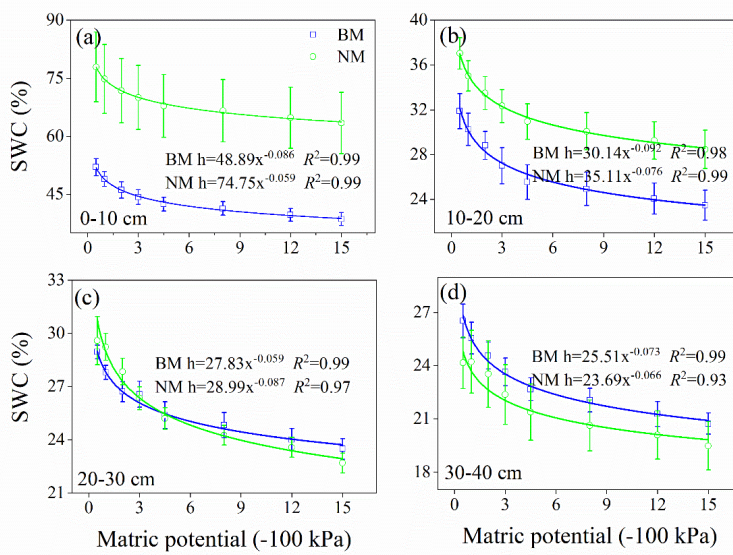
462 differences ($P < 0.05$) between normal *Kobresia* meadow and crust meadow at the same soil layer

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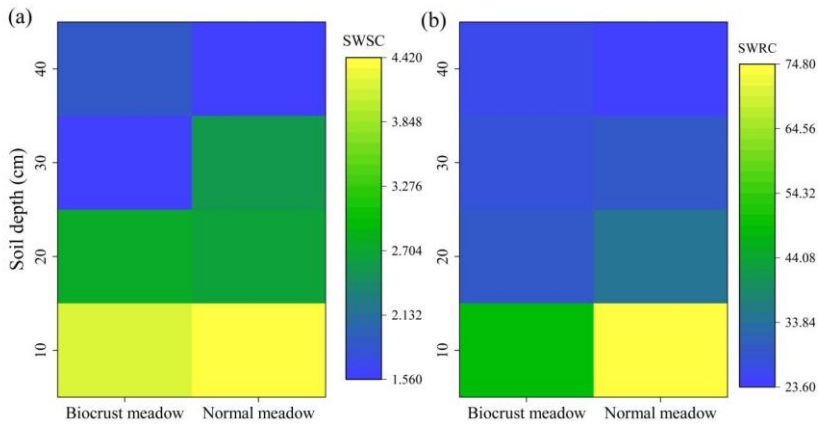


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 466 Fig. 4 Soil microbial biomass carbon (MBC) and microbial biomass nitrogen (MBN) among two
 467 surface soil types, the different letters mean significant differences ($P < 0.05$) between normal
 468 *Kobresia* meadow and crust meadow at the same soil layer
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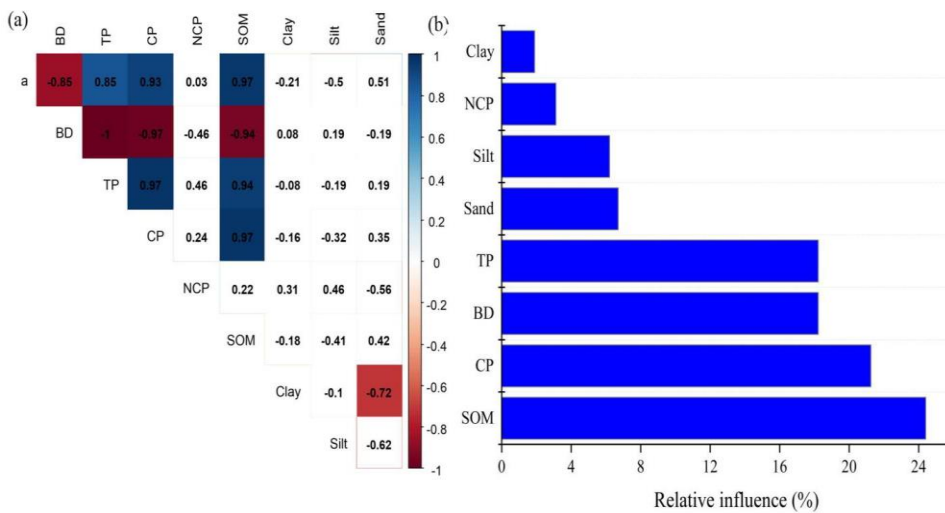


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 471 Fig.5 Soil water retention curve of different soil layer (a: 0-10 cm, b: 10-20 cm, c: 20-30 cm, d: 30-
 472 40 cm) among two surface soil types between soil water content (SWC) and matric potential. Note:
 473 NM, normal *Kobresia* meadow; BM, biocrusts meadow, the soil water retention curve was fitted by
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474 Gardner model (i.e. $h = A\theta^B$), A and B are the fitting parameters; a higher value of A indicated a
 475 higher soil water-holding capacity.
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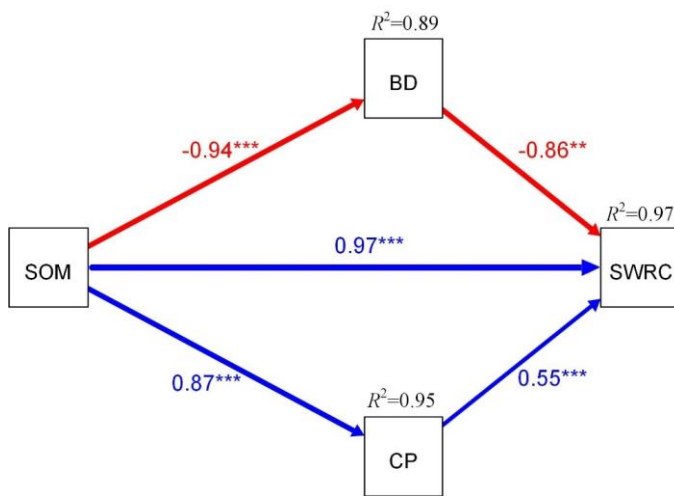
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 478 Fig.6 Soil water supply capacity (SWSC) (a) and soil water retention capacity (SWRC) (b)of
 479 different soil layer among two surface soil types, the SWSC was represent the A*B from Gardner
 480 model, the SWRC represent the A from Gardner model, a higher value of A*B and A indicated a
 481 higher soil water supply capacity and soil water retention capacity, respectively.
 482



483
 484 Fig. 7 Pearson correlation between soil water retention and soil properties (a) among two surface
 25

485 soil types, and the relative influence of soil properties on soil water retention (b). Note: the “*”,
 486 “***” and “****” indicated significant at 0.05, 0.01 and 0.001 level, respectively. Note: a: the
 487 parameter fitted by Gardner model, BD: soil bulk density, TP: soil total porosity, CP: capillary
 488 porosity, NCP: non-capillary porosity, SOM: soil organic matter.

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491
 492 Fig. 8 Structural equation modeling of the direct and indirect effects of soil properties on soil water
 493 retention capacity (SWRC) among two surface soil types. Standardized path coefficients, adjacent
 494 to arrows, are analogous to partial correlation coefficients, and indicative of the effect size of the
 495 relationship. Continuous blue and red lines represent positive and negative correlations, respectively.
 496 Model fit: Fisher.C=5.48, $df=2$, P -value=0.065.

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505 Table 1 The soil saturated hydraulic conductivity, soil water content and root density across two
 506 type meadow
 507

	NM	BM
K_s (mm min ⁻¹)	1.36	0.80
Soil water content (%)		
0-10 cm	41.58	18.77
10-20 cm	41.88	27.70
20-30 cm	35.93	29.45
30-40 cm	29.34	29.59
Root density (g m ⁻²)		
0-10 cm	3012.62	4917.89
10-20 cm	622.63	1431.53
20-30 cm	154.18	194.25
30-40 cm	93.01	142.02

508 Note: NM, normal Kobresia meadow; BM, biocrusts meadow

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