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

3 **Authors:** Licong Dai [1], Ruiyu Fu[1], Xiaowei Guo[2*], Yangong Du[2], Guangmin Cao[2], Zhongmin Hu[1*]

4 **Affiliations:**

5 [1]Key Laboratory of Agro-Forestry Environmental Processes and Ecological Regulation of Hainan

6 Province, Hainan University, Haikou, 570228, China

7 [2] Qinghai Provincial Key Laboratory of Restoration Ecology for Cold Region, Northwest Institute

8 of Plateau Biology, Chinese Academy of Sciences, Xining 810001, China

9 * Corresponding author: Xiaowe Guo and Zhongmin Hu; **E-mail:** xwguo1206@163.com for

10 Xiaowei Guo and huzm@hainanu.edu.cn for Zhongmin Hu

11 **Postal address:** Renmin Road No 56, Haikou 570228, China

13 **Abstract**

14 Biocrust is a key component of ecosystems and plays a vital role in altering hydrological processes

15 in terrestrial ecosystems. The ~~role~~ ~~effect~~impacts of biocrust on hydrological processes in arid and

16 semi-arid ecosystems has been widely documented~~.~~~~;~~ ~~however~~However, the effects and mechanisms

17 of biocrust on soil hydrological processes in alpine ecosystems are still poorly understood. In this

18 study, we selected two meadow types from the northern Qinghai-Tibet Plateau: normal *Kobresia*

19 meadow (NM) and biocrust meadow (BM). Both the soil hydrological and physicochemical

20 properties were examined. We found that in the 0–30 cm soil layer, soil water retention and soil

21 water content in NM were higher than those in BM, whereas the 30–40 cm layer's soil water

22 retention and soil water content in NM were lower than those in BM. The topsoil infiltration rate in

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

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

1 Introduction

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

45 availability (Li et al., 2016), which can serve as "ecological engineers" in soil systems. However, to

46 our knowledge, the controlling mechanism of biocrust on soil hydrological processes is still unclear.

47 Most previous studies were conducted in arid and semi-arid ecosystems, such as the Tengger Desert,

48 Negev Deserts, and Loess Plateau hydrological processes where plant are limited by soil moisture.

49 Very few studies have focused on the role of biocrust on hydrological processes (i.e., soil water

50 content, soil water retention, and soil infiltration) in alpine ecosystems where plant are limited by

51 soil temperature, and the mechanisms are poorly understood. Thus, examining the impact of biocrust

52 on hydrological processes could provide insight could have substantial effects on water balance in

53 alpine ecosystems and grassland management policies for maintaining the sustainability of meadow

54 ecosystems.

55   The alpine meadow is an important ecosystem in the Qinghai-Tibet Plateau (QTP), which plays

56 an important role in water retention (Dai et al., 2019), in preventing soil erosion (Qian et al., 2021)

57 and in regulating energy exchange (Zhu et al., 2020) by altering soil surface features (i.e. —.such as

58 roughness, soil texture, porosity, and aggregation) (Li et al., 2016), thereby modifying evaporation,

59 soil water retention, and water infiltration processes. However, the formation of biocrust in alpine

60 meadows is different from that in arid areas, where the biocrust is formed from intensive land use

61 such as overgrazing. Overgrazing could reduce vegetation coverage, thereby increase soil light

62 condition, which favor the photosynthesis of cyanobacteria crust. Previous study have d found a

63 well relationship between biocrust and vegetation coverage, i.e. the occurrence frequency of

64 cyanobacteria crust also increased with reducing vegetation coverage owing to overgrazing, .(Li et

65 al., 2015). Moreover, and the biocrust types vary with the succession stage of alpine meadows (Li

66 et al., 2016b). For instance, as the degree of degradation increases, the moss-dominated crust is

67 transformed into cyanobacteria-dominated crust, followed by lichen-dominated crust from

68 *Graminoid*-dominated vegetation degradation to *Kobresia humilis* meadow (light degradation) and

69 then to *K. pygmaea* meadow (moderate degradation) (Li et al., 2016). Thus, we suggest that the

70 impact of biocrust on hydrologic processes in alpine meadows may differ from that in arid areas,

71 and vice versa.

72 To date, although numerous studies have pointed out that biocrust has substantial effects on

73 soil water retention and soil moisture infiltration processes by altering soil microenvironments, such

74 as soil roughness, soil porosity, and aggregation, no consensus has been reached. For instance, some

75 studies have found that biocrust could increase soil water infiltration and reduce runoff by increasing

76 soil porosity and aggregate stability compared with bare soil in cool desert ecosystems (Kidron and

77 Benenson, 2014; Wei et al., 2015). In contrast, other studies ~~found~~reported that soil water infiltration

78 was significantly reduced in crusted areas compared with non-crusted areas in arid ecosystems (Li

79 et al., 2010; Xiao and Hu, 2017). These discrepancies highlight the necessity to further explore the

80 effects of biocrust on hydrological processes, such as exploring the specific hydrological processes

81 by conducting soil infiltration experiments and soil water retention curve measurements.

82 Furthermore, most previous studies were mainly conducted in arid and semi-arid ecosystems, and

83 very few studies have focused on the effects of biocrust on the soil's hydrological processes in alpine

84 ecosystems. Therefore, it is crucial to assess the role of biocrust in soil water retention and

85 infiltration in alpine meadows.

86 To address these knowledge gaps. In this study, normal *Kobresia* meadow and biocrust

87 meadow in QTP were selected. ~~b~~Both soil and hydrological features were measured, with the aim

88 of exploring the role of biocrust in hydrological processes in alpine ecosystems. Specifically, the

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89 objectives of this study were to explore the effect of biocrust on soil-hydrological features in alpine

90 ecosystems, to reveal how biocrust affects soil water retention by altering soil and vegetation

91 properties. Our results, and could provide insights into the management of biocrust in alpine

92 meadows.

93 **2 Materials and methods**

94 **2.1 Site description**

95 The field test sites were located in the northeastern Qinghai-Tibet Plateau ($101^{o} 19^{\prime}$ E, $37^{o} 37^{\prime}$

96 N), in Qinghai Province, China (Fig.1a). The area has a continental plateau climate with a mean air

97 temperature of -1.7°C and a mean annual precipitation of approximately 562 mm (Dai et al., 2020).

98 It should be noted that approximately 80% of the precipitation occurs during the growing season

99 (between May and September), and the other 20% occurs during the non-growing season. The main

100 vegetation type in this region is the *Kobresia* meadow, which is dominated by *Kobresia humilis*

101 (Fig.1b). The soil type in the study area is silt loam according to the in the USDA soil taxonomy

102 system of classification (Cusack and others 2018), with a soil thickness of approximately 60–80 cm.

103 The pH and EC is 7.5 m s m^{-1} and 6.7 in the study area, respectively. (Li et al., 2016).

104 **2.2 Experimental design and soil sampling**

105 In August 2020, we choose two study sites on the northeastern Qinghai-Tibet Plateau to avoid

106 pseudoreplication, and two types of soil surfaces were selected in each study site, i.e. normal

107 *Kobresia* meadow (NM, Fig. 1b) and biocrust meadow (BM, Fig. 1c). To reduce the differences

108 caused by spatial heterogeneity, the BM was selected adjacent to the NM. The vegetation cover in

109 BMs is usually less than 20% with a thick turf but no litter layer in topsoil, and the BM type is

110 dominated by cyanobacteria crust (ca. 80%) (Li et al., 2016). In contrast, NM has a dense vegetation

111 cover and is mainly dominated by *Kobresia pygmaea*, with average plant heights of 1–3 cm.

112 Furthermore, a clear typical turf horizon and litter layer was observed within the topsoil in NM, that

113 is, the Afe horizon. BM had a higher root biomass than that of NM, owing to its thick turf (Table 1).

114 We obtained the disturbed soil samples (i.e. non-ring knife soil sample) in NM and BM. ~~and~~

115 ~~f~~Four quadrats (1 × 1 m) were randomly selected for soil sampling with a depth of 10 cm in each

116 treatment using an earth boring auger, and then brought back to the laboratory to measure and

117 analyze soil organic matter (SOM), soil microbial biomass carbon (MBC), microbial biomass

118 nitrogen (MBN), total carbon (TC), total nitrogen (TN), and ~~soil particle size distribution~~soil texture

119 (PSD). Undisturbed cylindrical ring samples (i.e. ring knife soil sample) were also obtained in each

120 treatment to determine the soil bulk density (BD), soil porosity, and soil hydraulic properties (i.e.,

121 soil water retention and soil water supply capacity). The soil infiltration rates were measured using

122 a double-ring infiltrometer for each treatment.

123 **2.3 Laboratory measurements and analyses**

124 First, the disturbed soil samples were sieved through 0.25 mm and 2-mm soil sieves to remove

125 debris and roots for the analysis of soil properties.~~;~~ SOM was measured based on the Walkley &

126 Black procedure (Nelson and Sommers, 1982), MBC and MBN were measured by the chloroform

127 fumigation-direct extraction method (Vance et al., 1987), and TC and TN were measured using an

128 element analyzer (Elementar Vario EL III, Hanau, Germany). PSD was determined using a

129 Mastersizer 2000 (Malvern Instruments, UK). BD was measured as the ratio of the oven-dry soil

130 mass to the core volume (100 cm^3). The soil total porosity, soil capillary porosity, and soil non-

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

132
$$\mathrm{TP} = (1 - \frac{BD}{d_s}) \times 100\%$$
$$(1) \,,$$

$$CP = CWC \times BD \qquad (2),$$

$$NCP = TP - CP \qquad (3),$$

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

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

$$h = A\theta^{-B},$$

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

2.4 Statistical analysis

In this study, to compare the differences between BM and NM on soil water retention and soil properties, we conducted one-way analysis of variance (ANOVA) statistical tests to determine differences in plant and soil properties for the same soil layers between the BM and NM, and a least-significant-difference test ($P<0.05$) was conducted when significant differences were detected by ANOVA. To explore the relationship between soil properties and ~~soil~~ soil water retention, and quantitative evaluation of the effects of soil properties on soil-soil water retention, Pearson's correlation and variance partition in the analysis were used by R software version 3.4.3 (R

155 Development Core Team, 2006) with the "hier.part" and "corrplot" packages. Furthermore,

156 structural equation modeling was used to examine the soil properties' direct and indirect effects on

157 soil water retention.

158

159 **3 Results**

160 **3.1 ~~Soil texture~~~~Soil particle size distribution~~Soil texture among two surface soil types**

161   Silt content dominated the ~~soil particle size distribution~~soil texture in the 0–40 cm soil layer

162 across the two surface soil types (mean 61.69%), followed by sand (mean 30.13%), and clay (mean

163 8.18%) (Fig. 2). Specifically, the 0–10 cm ~~soil layer's~~ clay content in BM was 9% higher than that

164 in NM, whereas the 10–40 cm ~~soil layer's~~ clay content in BM was 16% lower than that in NM,

165 especially for the 10–20 cm soil layer ($P<0.001$). In contrast, the 0–40 cm ~~soil layer's~~ silt content

166 in BM was higher than that in NM, especially for the 20–30 cm soil layer ($P<0.05$). However, no

167 clear pattern was observed for the sand content between BM and NM. Overall, ~~in the~~ 0-40 cm ~~soil~~

168 ~~layer,~~ clay content (8.62%) in NM was 11% higher than that in BM (7.69%), whereas in the 0-40

169 cm ~~soil layer,~~ silt content (61.24%) in NM was nearly equal to that in BM (62.13%).

170 **3.2 Soil physicochemical properties among two surface soil types**

171   There were no significant differences for 0–40 cm BD, 0–40 cm TP, 0–40 cm CP and 0–40 cm

172 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

173 CP in NM were 7% and 5% higher than that of BM. No clear pattern was observed for NCP in NM

174 and BM (Fig.3). Furthermore, the 0–20 cm TN and SOM in NM were much higher than those in

175 BM and reached a significant level at 0–10 cm ($P<0.05$), whereas the 30–40 cm TN and SOM in

176 NM were lower than those in BM (Fig.3). Similarly, the 0–10 cm ~~soil layer's~~ TC and C: N ratio in

177 NM were significantly higher than those in BM, whereas the 30–40 cm ~~soil layer's~~ TC and C: N

178 ratio in NM were lower than those in BM (Fig.3). Additionally, the 0–40 cm ~~soil layer's~~ MBC and

179 MBN in NM were higher than those in BM and reached a significant level at 0–10 cm ($P<0.05$)

180 (Fig. 4).

3.3 Soil hydrological processes among two surface soil types

182   The soil hydrological processes varied between crust BM and NM (Fig.5 and Table 1). Given

183 that parameter A fitted by the Gardner model represents the soil water retention (a higher A value

184 indicates higher soil water retention), the soil water content was reduced with decreasing matric

185 potential and reduced sharply at high matric potential, but remained stable at low matric potential

186 (Fig. 5~~),)~~. ~~the~~ The 0–30 cm layer's soil water content and soil water retention in NM were higher

187 than those in BM, whereas the 30–40 cm layer's soil water content and soil water retention in NM

188 were lower than those in BM (Table 1 and Fig. 6b). Similarly, the 0–10 and 20–30 cm ~~layers'~~ soil

189 water supply capacity (i.e., A*B fitted by the Gardner model) in NM was higher than that in BM,

190 while the 10–20 and 30–40 cm ~~layers'~~ soil water supply capacity in NM was lower than that in BM

191 (Fig. 6a). Furthermore, the surface infiltration rate in the BM was significantly lower than that in

192 the NM (Table 1).

3.4 Dominated factors affecting soil-soil water retention

194   Pearson correlation analysis showed that soil water retention was significantly negatively

195 related to BD, but significantly positively related to TP, CP, and SOM (Fig.7a), whereas ~~soil particle~~

196 ~~size distribution~~soil texture exerted weak soil water retention (Fig.7a). Furthermore, the variance

197 partition showed that SOM explained the greatest variability in soil-soil water retention (24.40%),

198 followed by CP (21.24%), BD (18.22), and TP (18.22%) (Fig. 8b), and structural equation modeling

199 showed that the effect of SOM on soil water retention was achieved by altering CP and BD (Fig. 8).

200 **4 Discussion**

201 **4.1 Effect of biocrust on soil properties**

202   The effects of biocrust on soil properties have been widely explored in previous studies (Guo

203 et al., 2008; Liu et al., 2019). Compared with non-biocrust and most studies conducted in arid

204 regions, ~~have found that~~ the presence of biocrust could improve soil aggregation and stability (Wu

205 et al., 2020), increase soil fertility (Zhou et al., 2020)~~,~~ and reduce soil erosion (Chamizo et al., 2017).

206 In this study, however, we found that the presence of cyanobacteria crust could improve topsoil

207 texture compared with normal meadow, but not that of deep soil. The 0–10 cm ~~soil layer's~~ clay

208 content in cyanobacteria crust meadow was higher than that for normal meadow, whereas the 10–

209 40 cm ~~soil layer's~~ clay content in cyanobacteria crust meadow was lower than that for normal

210 meadow, which is in line with previous studies conducted in arid and semi-arid regions (Liu et al.,

211 2016; Wu et al., 2020). The higher clay content in cyanobacteria crust meadow was attributed to the

212 exudation and cohesiveness of the biocrust, which promoted clay and silt formation and reduced

213 sand content (Wang et al., 2021). Furthermore, we found that the 0–20 cm ~~soil layer's~~ soil bulk

214 density in normal meadow was lower than that in cyanobacteria crust meadow, thereby leading to

215 higher soil porosity and total capillary porosity in normal meadow. Such higher soil capillary

216 porosity in normal meadow was attributed to its higher soil organic matter content, which was also

217 confirmed by the significant positive relationship between soil organic matter and soil capillary

218 porosity (Fig. 7). Because Iit has been well documented that a higher soil organic matter could

219 improve soil aggregation and stability and subsequently increase soil capillary porosity (Cui et al.,

220 2021).

221   Moreover, ~~more~~ most previous ~~found~~ indicated that the presence of cyanobacteria crust can

222   also improve soil nutrient conditions in the process of mobile sand fixation (Belnap et al., 2004;

223   Guo et al., 2008; Li et al., 2005a). However, we found that the presence of cyanobacteria crust

224   reduces the 0–10 cm ~~layer's~~ soil total carbon, total nitrogen, and C: N ratio compared with normal

225   meadow, which is in contrast to most previous studies conducted in arid and semi-arid regions

226   (Chamizo et al., 2012b; Zhao et al., 2010). A ~~probable~~ possible reason for these differences may

227   ascribe to the environmental differences. It is well documented~~documeted~~ that the formation of

228   biocrust is a changing process from simple to complex in its morphology, the early cyanobacteria

229   crust was formed only under favorable hydrothermal conditions such as temperature, soil water,

230   solar radiation, and nutrient content (Belnap et al., 2004; Li et al., 2005b). For instance, biocrust is

231   metabolically active when the external environment is wet, and its metabolically active environment

232   is sensitive to temperature (Belnap et al., 2004; Li et al., 2005b), otherwise the biocrust may choose

233   to enter the dormant stage when the external environment is under unfavorable conditions. Therefore,

234   compared to the higher soil temperatures in arid and semi-arid lands, the biocrust in alpine

235   ecosystems may be in a dormant stage owing to its lower temperature and less available nutrients.

236   Moreover, the biocrust in our study was mostly dominated by cyanobacteria crust, which was

237   vulnerable to external disturbances such as grazing activity~~.; thus~~Thus, the biocrust may choose

238   dormancy when it is subjected to grazing pressure, ~~which~~ this evidence was also confirmed by the

239   significantly lower microbial soil carbon and microbial soil nitrogen content in cyanobacteria crust

240   meadow compared with normal meadow (Fig. 4).

241   **4.2 Effect of biocrust on soil hydrology and their underlying mechanisms**

242   We found that soil water infiltration was greatly reduced in cyanobacteria crust meadow

243   compared with that in normal meadow, which was consistent with the results of a previous study

244   conducted in alpine meadows (Li et al., 2016b). However, it is in contrast to other studies conducted

245   in cool desert ecosystems where biocrust increased soil water infiltration and reduced runoff by

246   increasing soil porosity and aggregate stability compared with physical crusts and non-crusted bare

247   soils (Kidron and Benenson, 2014; Wei et al., 2015). These discrepancies were associated with soil

248   texture and biocrust developmental stage. In general, soil water infiltration in coarse-textured soils

249   is higher than that in fine-textured soils owing to its large pores compared with the narrow pores in

250   fine-textured soils, which reduces the movement of water into the soil (Belnap, 2006). However, we

251   found that the establishment of cyanobacteria crust increased clay content and subsequently reduced

252   soil macropores, which hindered soil water infiltration. Therefore, we conclude that the soil in the

253   cyanobacteria crust meadow may be more vulnerable to runoff generation and consequent soil

254   erosion, owing to its lower soil water infiltration and soil water retention capacity. On the other hand,

255   biocrust can reduce available pore spaces for water to infiltrate by clogging the soil surface

256   conductive pores owing to its higher water absorption and swelling of biocrust (Fischer et al., 2010),

257   and consequently reduce soil infiltration. In addition, soil water infiltration was also affected~~altered~~

258   by the developmental stage of the biocrust in homogeneous soil. A previous study ~~indicated~~ found

259   that soil hydraulic parameters differed significantly between cyanobacterial biocrust and moss

260   biocrust (Wang et al., 2017). For instance, Chamizo et al. (2012a) reported that the incipient-

261   cyanobacterial crust had a lower soil infiltration rate than that of the cyanobacterial crust, whereas

262   the dark-colored mosses' crust had higher surface soil infiltration capacity by increasing

263   macroporosity and unsaturated hydraulic conductivity in the grasslands ~~dominated by A. splendens~~

264   (Jiang et al., 2018). In our study, the biocrust was dominated by incipient-cyanobacterial crust,

265   which had low biological activity and low porosity owing to the predominance of vesicle pores,

266   thereby leading to a lower soil infiltration rate.

267   Furthermore, the soil water retention and soil water supply capacity varied significantly

268   between the biocrust and normal meadows. We found that in the 0–10 cm soil water retention and

269   soil water supply capacity in normal meadow were higher than that in cyanobacteria crust meadow,

270   which was not in line with previous studies conducting in drylands in which biocrusts enhanced

271   surface soil water retention capacity and water availability (Sun et al., 2022). We speculate that the

272   lower soil water retention in the cyanobacteria crust meadow was related to its lower soil organic

273   matter; this evidence was also confirmed the lower microbial biomass carbon (Fig. 4a). Furthermore,

274   the structural equation model indicated that the effect of soil organic matter on water retention was

275   mainly achieved by altering soil bulk density and soil porosity (Fig. 8) because higher soil organic

276   matter could reduce soil bulk density and thereby increase soil porosity (Liu et al., 2019), leading

277   to higher soil water retention. This result was also confirmed by the significant positive relationship

278   between soil organic matter and soil water retention (Fig. 7). Considering soil organic matter was

279   derived from vegetation litter and root biomass, whereas the vegetation litter in cyanobacteria crust

280   meadow was lower than that in normal meadow owing to its lower aboveground biomass and

281   vegetation coverage, ultimately resulting in lower soil organic matter in cyanobacteria crust meadow.

282 **4.3 Implications for the effect role of biocrust in alpine meadows**

283   Grassland ecosystems cover more than 60% of the QTP and provide important ecosystem

284   services, such as biodiversity conservation, carbon storage, and water conservation (Dong et al.

285   2020). However, in recent decades, grasslands in the QTP have suffered from serious degradation

286   due to increasing human activity (Cao et al. 2019). Biocrust is an important surface feature of the

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287 degraded alpine meadows. It is acknowledged that biocrust has a positive effect on soil nutrient and

288 soil water content retention in arid regions. In contrast, we found that the presence of cyanobacteria

289 crust decreased soil water retention and soil infiltration rate, which did not improve water

290 conservation in alpine meadows. Therefore, the soil in the cyanobacteria crustbiocrust region may

291 be more vulnerable to runoff generation and consequent soil erosion. Moreover, soil nutrients, such

292 as SOM, TC, and TN, were reduced significantly in the cyanobacteria crust meadow, suggesting

293 that the growth of vegetation in the cyanobacteria crust meadow may be limited by soil nutrients.

294 Considering the negative effects of biocrust on alpine meadows, some steps should be taken to

295 reduce the formation of cyanobacteria crustbiocrust in degraded alpine meadows, such as reducing

296 grazing intensity and . Nevertheless, our study results were only obtained onlyby conducting ed in

297 site scale, which may not sufficiently to extrapolate the whole QTP owing to its high spatial

298 heterogeneity. Thus, a

299 it is necessary larger scale or more study sites is necessary to have a generalizability conclusion

300 regarding the effects of biocrust on hydrological processes in alpine meadow of QTP owing to

301 itsconsidering the high spatial heterogeneity in QTP. –

302 **5 Conclusions**

303 Soil hydrological processes were significantly affected by the establishment of cyanobacteria

304 crustbiocrust, and we found that the cyanobacteria crustbiocrust could reduce topsoil water and

305 infiltrate topsoil, which suggested that the establishment of cyanobacteria crustbiocrust did may not

306 favor soil hydrological processes in alpine meadows. Furthermore, the presence of cyanobacteria

307 crustbiocrust increased topsoil clay content, while the 0–30 cm layer's soil capillary porosity in NM

308 was higher than that in BM, indicating that the presence of cyanobacteria crustbiocrust reduced soil

porosity and thereby reduced topsoil water infiltration. This suggested that the discrepancies in soil water retention and topsoil infiltration were close to physicochemical properties, and that SOM plays a role in soil water retention by affecting CP and BD. Our study ~~are~~may helpful ~~provides insight into the role of~~ for making reasonable management policies to maintaining the sustainability of meadow ecosystems in the long run, especially under intensity~~es dramatic~~ human activity and climate change in QTP.~~climate changes during the anthropocenebiocrust in soil hydrological processes in alpine ecosystems.~~

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Author contribution

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

Declaration of competing interest

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

Data availability statement

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

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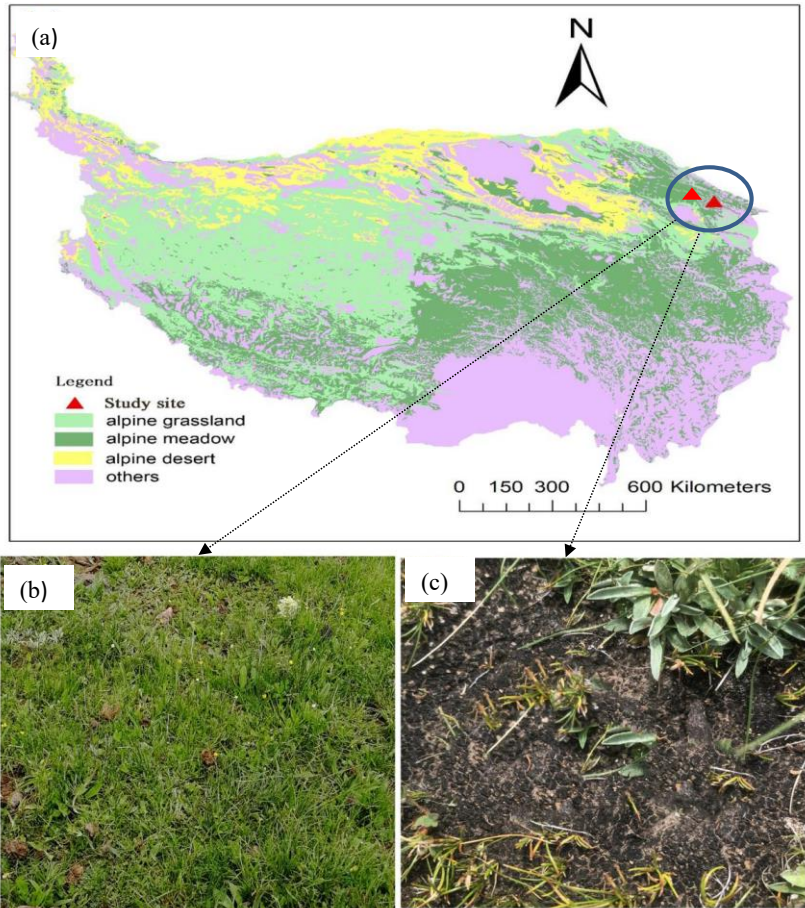
Fig.1 The study site (a) and two type meadows in this study: normal *Kobresia* meadow (b) and

biocrust meadow (c)

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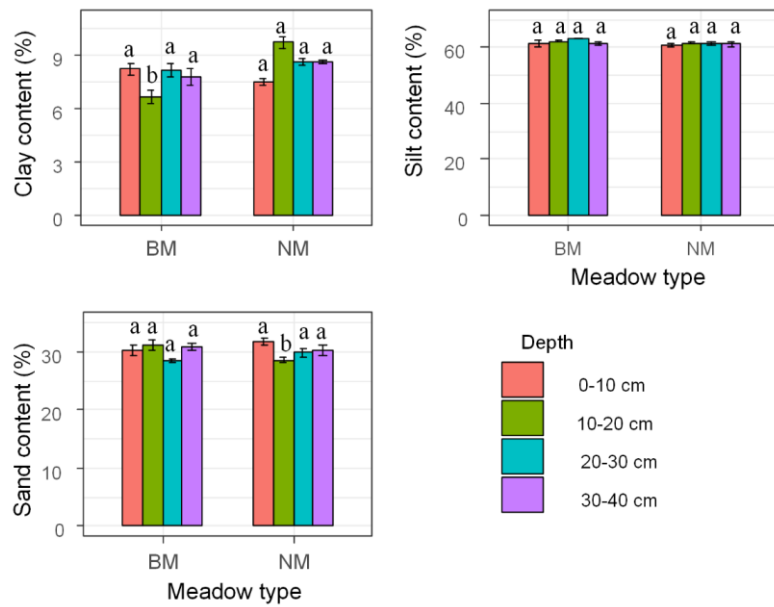
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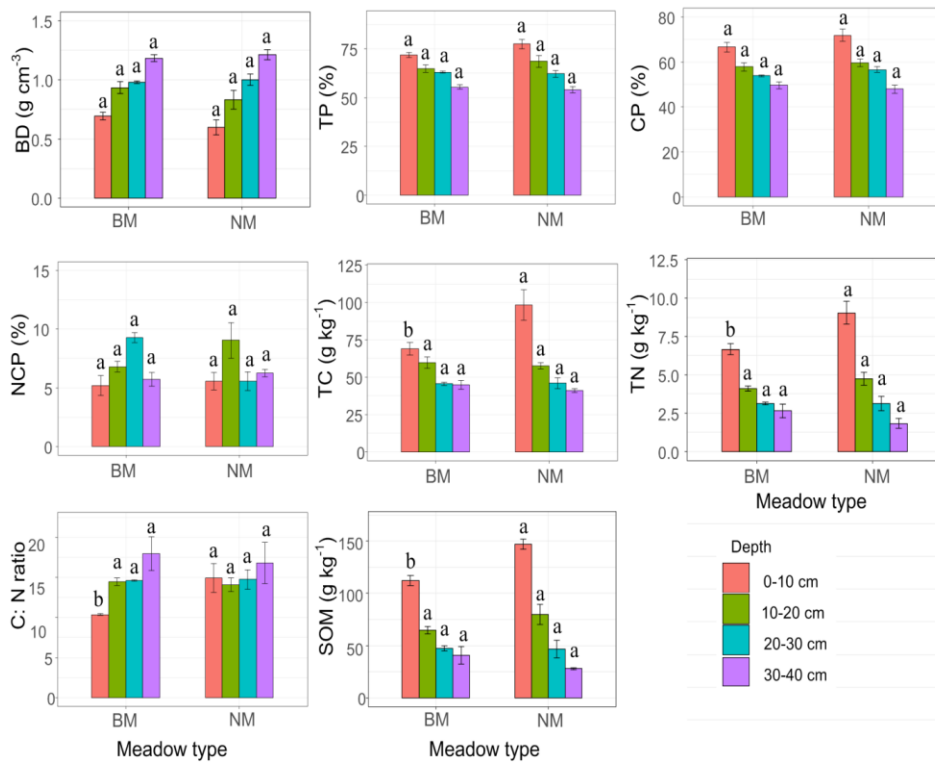
453   Fig.2 Soil texture<s>Soil particle size distribution</s><s>Soil texture</s> among two surface soil types. Note: NM,

454   normal *Kobresia* meadow; BM, biocrusts meadow, the different letters mean significant differences

455   (P<0.05) between normal *Kobresia* meadow and crust meadow at the same soil layer.

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

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

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

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

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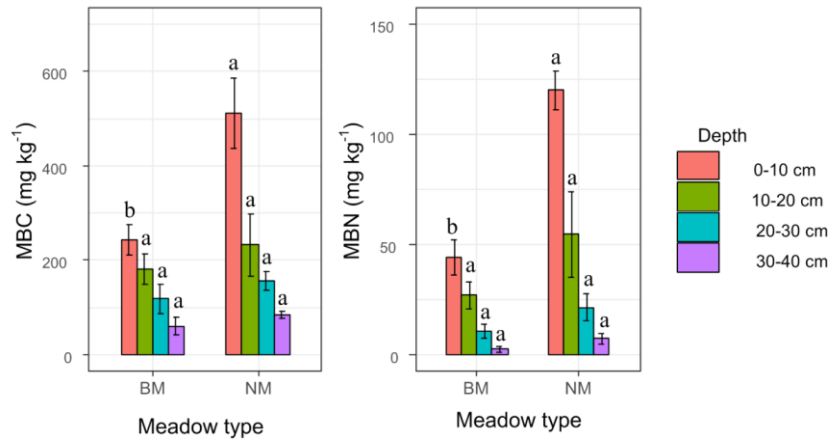
464 Fig. 4 Soil microbial biomass carbon (MBC) and microbial biomass nitrogen (MBN) among two

465 surface soil types, the different letters mean significant differences (*P*<0.05) between normal

466 *Kobresia* meadow and crust meadow at the same soil layer

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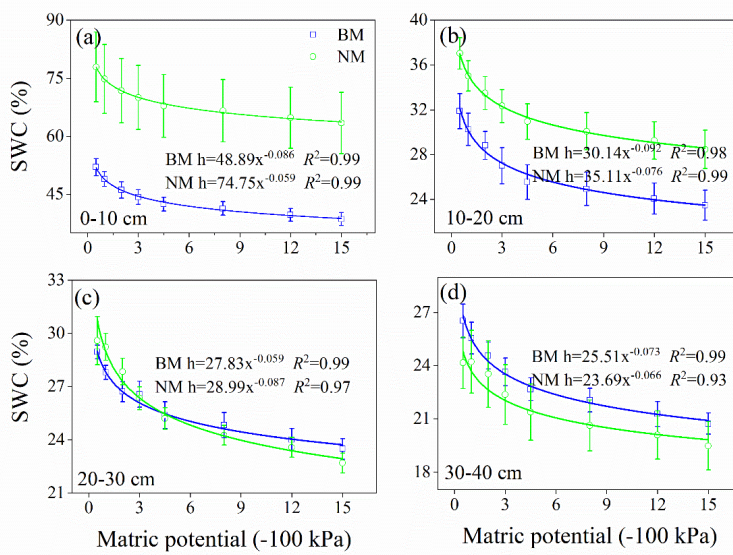
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469 Fig.5 Soil water retention curve of different soil layer (a: 0-10 cm, b: 10-20 cm, c: 20-30 cm, d: 30-

470 40 cm) among two surface soil types between soil water content (SWC) and matric potential. Note:

471 NM, normal Kobresia meadow; BM, biocrusts meadow, the soil water retention curve was fitted by

472   Gardner model (i.e. h = Aθ⁻ᴮ), A and B are the fitting parameters; a higher value of A indicated a

473   higher soil water-holding capacity.

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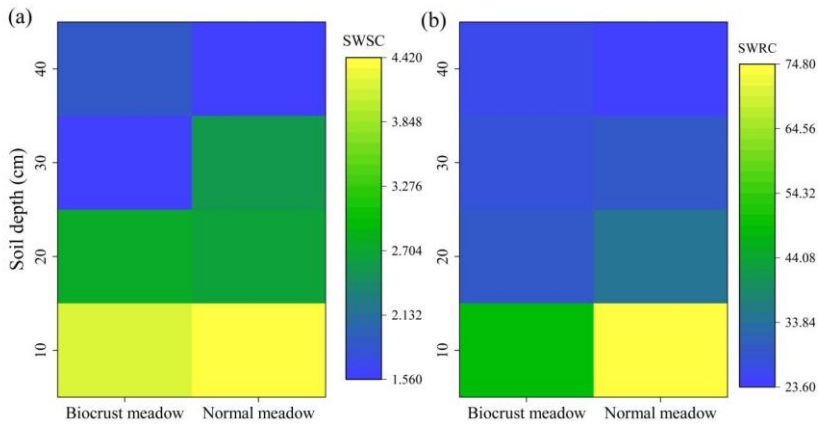
475

476   Fig.6 Soil water supply capacity (SWSC) (a) and soil water retention capacity (SWRC) (b)of

477   different soil layer among two surface soil types, the SWSC was represent the A*B from Gardner

478   model, the SWRC represent the A from Gardner model, a higher value of A*B and A indicated a

479   higher soil water supply capacity and soil water retention capacity, respectively.

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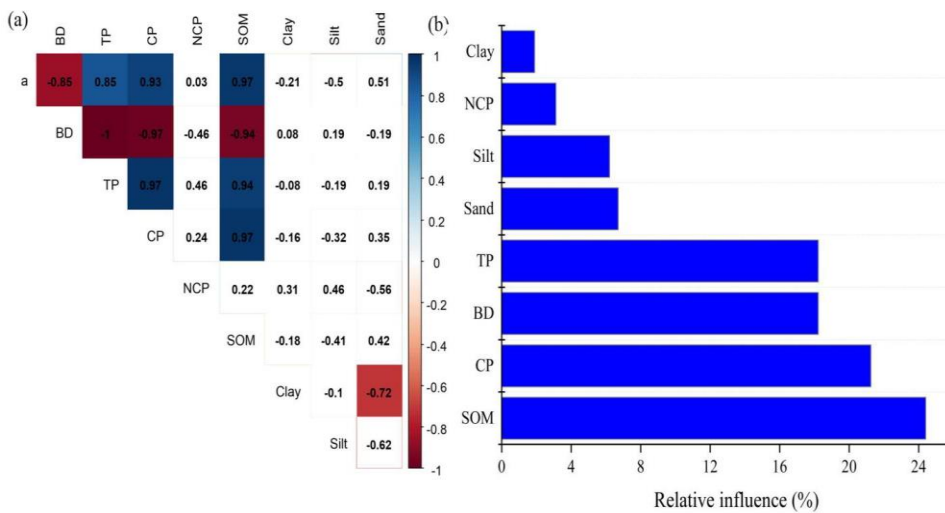
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482   Fig. 7 Pearson correlation between soil water retention and soil properties (a) among two surface

483 soil types, and the relative influence of soil properties on soil water retention (b). Note: the "*",

484 "**"and "***" indicated significant at 0.05, 0.01 and 0.001 level, respectively. Note: a: the

485 parameter fitted by Gardner model, BD: soil bulk density, TP: soil total porosity, CP: capillary

486 porosity, NCP: non-capillary porosity, SOM: soil organic matter.

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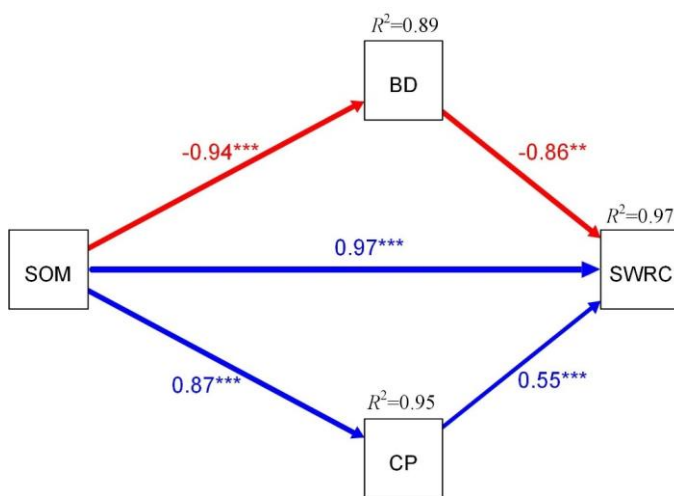
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490 Fig. 8 Structural equation modeling of the direct and indirect effects of soil properties on soil water

491 retention capacity (SWRC) among two surface soil types. Standardized path coefficients, adjacent

492 to arrows, are analogous to partial correlation coefficients, and indicative of the effect size of the

493 relationship. Continuous blue and red lines represent positive and negative correlations, respectively.

494 Model fit: Fisher.C=5.48, df=2, P-value=0.065.

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503   Table 1 The soil saturated hydraulic conductivity, soil water content and root dentisy across two
504   type meadow
505

	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

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