

1 **Effect of plateau pikas disturbance and patchiness on ecosystem carbon emission of**
2 **alpine meadow on the northeastern part of Qinghai-Tibetan Plateau**

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20 **Abstract**

21 Plateau pikas (*Ochotona curzoniae*) disturbance and patchiness intensify the spatial
22 heterogeneous distribution of vegetation productivity and soil physicochemical properties,
23 which may alter ecosystem carbon emission process. Nevertheless, previous researches have
24 mostly focused on the homogeneous vegetation patches rather than heterogeneous land
25 surface. Thus, this study aims to improve our understanding of the difference in ecosystem
26 respiration (Re) over heterogeneous land surface in an alpine meadow grassland. Six different
27 land surface: large bald patch, medium bald patch, small bald patch, intact grassland, above
28 pika tunnel and pika pile were selected to analyze the response of Re to pikas disturbance and
29 patchiness, and the key controlling factors. The results showed that (1) Re under intact
30 grassland were 0.22-1.07 times higher than pika pile and bald patches; (2) soil moisture (SM)
31 of intact grassland was 2-11% higher than those of pika pile and bald patches despite pikas
32 disturbance increased water infiltration rate, while soil temperature (ST) under intact
33 grassland was 1-3°C less than pika pile and bald patches; (3) Soil organic carbon (SOC) and
34 total nitrogen (TN) under intact grassland were approximate 50 % and 60 % less than above
35 pika tunnel, whereas 10-30 % and 22-110 % higher than pika pile and bald patches; and (4)
36 Re was significantly correlated with SM, TN and vegetation biomass ($P < 0.05$). Our results
37 suggested that pikas disturbance and patchiness altered ecosystem carbon emission pattern,
38 which was mainly attributed to the reduction of soil water and supply of substrates. Given that
39 the wide distribution of pikas and large area of bald patches, the varied Re under
40 heterogeneous land surfaces should not be neglected for estimation of ecosystem carbon
41 emission at plot or region scale.

42 **Keywords:** pikas disturbance; patchiness; ecosystem respiration; alpine meadow; the
43 Qinghai-Tibetan Plateau

44 **Introduction**

45 Ecosystem respiration (Re) is the key process to determine the carbon budget in the terrestrial
46 ecosystem. Thus, even a small imbalances between CO₂ uptake via photosynthesis and CO₂
47 release by ecosystem respiration can lead to significant interannual variation in atmospheric
48 CO₂ (Schimel et al., 2001; Cox et al., 2000; Grogan and Jonasson, 2005; Oberbauer et al.,
49 2007; Warren and Taranto, 2011). Dependent on autotrophic (plant) and heterotrophic
50 (microbe) activity, ecosystem respiration is mainly controlled by abiotic factors (primarily
51 temperature and water availability) (Chimner and Welker, 2005; Flanagan and Johnson, 2005;
52 Nakano et al., 2008; Buttlar et al., 2018), and supply of carbohydrate fixed by leaves,
53 vegetation litter and soil organic matter (Janssens et al., 2001; Reichstein et al., 2002).
54 Therefore, any external disturbance altering environmental conditions and affecting
55 vegetation growth would exert profound influence on ecosystem carbon emission.

56 One of the basic function of terrestrial ecosystem is to regulate carbon balance between
57 the atmosphere and ecosystem (Canadell et al., 2007; Le Quéré et al., 2014; Ahlström et al.,
58 2015). However, this balance would be broken by widespread land degradation (Post and
59 Kwon, 2000; Dregne, 2002), which accompanied with the reduction of photosynthetic fixed
60 carbon dioxide from atmosphere and carbon sequestration by soils (Defries et al., 1999;
61 Upadhyay et al., 2005). It was estimated that land degradation had resulted in 19-29 Pg C loss
62 worldwide (Lal, 2001). Over the past decades, grasslands have experienced patchiness
63 throughout the world and this process is still ongoing (Baldi et al., 2006; Wang et al., 2009;
64 Roch and Jaeger, 2014). Patchiness generally refers to a landscape that consists of remnant
65 areas of native vegetation surrounded by a more heterogeneous and patchy situation (Kouki
66 and Löfman, 1998). Other than climate change (Yi et al., 2014), vegetation self-organization
67 (Rietkerk et al., 2004; Venegas et al., 2005; McKey et al., 2010) or anthropogenic
68 disturbances (Kouki and Löfman, 1998; Yi et al., 2016), rodents burrowing activities were
69 also considered as the origin of the patchiness (Wei et al., 2006; Davidson and Lightfoot,
70 2008). This patchiness intensified spatial heterogeneity of land surface and led to the
71 changing of the structure and function of the original ecosystem (Herkert et al., 2003;
72 Bestelmeyer et al., 2006; Lindenmayer and Fischer, 2013). For instance, there is abundant
73 evidence that patchiness not only intensified the spatial heterogeneous distribution of

74 ecosystem organic carbon (C) and vegetation productivity (Yan et al., 2016; Qin et al., 2018)
75 but also altered the pattern of coupled water and heat cycling between the land surface and the
76 atmosphere (Saunders et al., 1991; You et al., 2017; Ma et al., 2018). Consequently, this may
77 alter ecosystem carbon emission process (Juszczak et al., 2013).

78 Plateau pikas (*Ochotona curzoniae*, hereafter pikas) are small mammals endemic to the
79 alpine grasslands on the Qinghai-Tibetan Plateau (QTP) (Smith and Foggin, 1999; Lai and
80 Smith, 2003). Living in underground, they excavated deep layer soil to surface through
81 foraging and digging activities (Lai and Smith, 2003) and led to substantial bald piles on the
82 ground. The bald pile was considered to gradually become bald patches under soil erosion,
83 gravity, freeze-thaw and other factors (Chen et al., 2017; Ma et al., 2018). As a consequence,
84 natural vegetation patches and adjacent bald patches with different sizes, and pikas piles
85 represent the most common landscape pattern in the alpine meadow grassland on the QTP.
86 Previous studies have demonstrated that pikas disturbance and patchiness weaken the function
87 of alpine meadow as a carbon sink (Liu et al., 13; Peng et al., 2015; Qin et al., 2018) and
88 accelerated ecosystem carbon emission rate (Qin et al., 2015a). Nevertheless, most of these
89 studies have mainly focused on ecosystem carbon emission rate under the homogeneous land
90 surface rather than heterogeneous land surfaces. Thus, the specific aims of this study were to
91 (1) investigate the spatial heterogeneity of Re among different surface types (plateau pika pile,
92 above pika tunnel, different sizes of bald patches and vegetation) of alpine grassland; (2)
93 illuminate the potential regulating mechanism of pikas disturbance and patchiness to
94 ecosystem respiration (Re) in an alpine meadow grassland in the northeastern part of
95 Qinghai-Tibetan Plateau (QTP).

96 **Materials and methods**

97 **Site description**

98 This study was conducted at the permanent plots at Suli Alpine Meadow Ecosystem
99 Observation and Experiment Station (98°18'33.2", 38°25'13.5", 3887 m a.s.l.), Northwest
100 Institute of Eco-Environment and Resources, Chinese Academy of Science. The study area is
101 characterized by a continental arid desert climate, with low mean annual air temperature, little
102 rainfall, and high evaporation (Wu et al., 2015). The mean annual air temperature was
103 approximately -4°C and the annual precipitation ranged from 200 to 400mm, respectively

104 (Chang et al., 2016). The permafrost type at our site is transition and the active layer depth is
105 2.78 ± 1.03 m (Chen et al., 2012). The dominant plant species in the study area were *Kobresia*
106 *capillifolia*, *Carex moorcroftii* (Qin et al., 2014). Soils was classified as “felty” with a pH of
107 8.56, 30.96 % silt and fine, 57.52 % fine sand and 10.68 % coarse sand, and soil bulk density
108 is 1.41 g cm^{-3} within a 0-40 cm depth of the soil layer (Qin et al., 2015b). The grassland in
109 this area suffered from degradation due to permafrost degradation and external disturbance
110 from grazing livestock and small mammals, i.e. plateau pikas (Yi et al., 2011, Qin et al.,
111 2015a). As a result, a mosaic pattern of vegetation patches, bald patches with different sizes
112 and pika piles was common.

113 **Field observation**

114 At early June 2016, three $100 \text{ m} \times 100 \text{ m}$ plots were established as replicates. Each 100×100
115 m plot was in a distance of less than 50 m, which has the similar plant and terrain. In each
116 plot, six representative land surfaces were selected: (1) large bald patch with size larger than
117 9.0 m^2 (LP), (2) medium bald patch with size of $1.0\text{-}9.0 \text{ m}^2$ (MP), (3) small bald patch with
118 size of less than 1.0 m^2 (SP), (4) intact grassland patch (IG), (5) above pika tunnel (PT), (6)
119 old pika pile (PP) (Figure 1) (Yi et al., 2016; Qin et al., 2018). There were no other mammals,
120 e.g. marmot and zokor in our study plots. All of the piles in each plot were created by plateau
121 pikas. They were distinguished easily in aerial photographs. Large bald patches had less
122 vegetation cover and the smallest side was larger than 3 m. Medium patches also covered by
123 less vegetation cover and the largest side was in a range of 1 to 3 m and small bald patches
124 were characterized by less vegetation cover and the largest side was less than 1 m. Intact
125 grassland was characterized by high vegetation cover and no large and medium bare land was
126 found. Pika tunnel and pika pile usually co-existed. Pika tunnel is approximately 6 cm in
127 diameter and pika pile is in the front of pika tunnel, 60 cm in diameter and less vegetation
128 cover. We calculated the threshold area of large, medium and small patches by aerial
129 photograph. Each aerial photograph has 12 million pixels. At a height of 20 m, the resolution
130 of each pixel is $\sim 1 \text{ cm}$ and each photograph covers $\sim 26 \text{ m} \times 35 \text{ m}$ of ground. Pixels in each
131 aerial image were first classified into two groups, i.e. vegetated or bare patches (Yi, 2017).
132 Then patches with different sizes were created using OpenCv Library. And finally, fractions
133 of vegetation and bare patches (large, medium and small patches) were calculated. For each

134 surface type in each plot, six 1 m × 1 m quadrats were set up, of which three was used for soil
135 saturated hydraulic conductivity measurement and three for soil compactness measurement,
136 soil and vegetation sampling. We also set up another three 1 m × 1 m quadrats and three 2 m
137 × 2 m quadrats in each surface type in a 100 m × 100 m plot for measuring soil temperature,
138 soil moisture and ecosystem respiration.

139 (Insert Figure 1 here)

140 A meteorological tower was established in our observation station since 2008. Air
141 temperature (°C) at 2.0m was measured by HMP45C (Vaisala, Helsinki, Finland), and
142 precipitation was measured using an all-weather precipitation gauge (Geonor T-200B,
143 Norway) (Wu et al., 2015). Soil temperature and moisture at 10 cm were measured by using
144 an auto-measurement system (Decagon Inc., USA) from early June to the late August. The
145 system consisted of an EM50 logger and five 5TM sensors. The data were logged
146 automatically every 30 minutes. Soil saturated hydraulic conductivity and compactness were
147 measured one time in each month from June to August. Soil saturated hydraulic conductivity
148 was measured by Dual Head infiltrometer (Decagon Inc., USA). The measurement process
149 included soak time 15 minutes, hold time 20 minutes at low pressure head (5 cm) and high
150 pressure head (15 cm) with 2 cycles. Each measurement takes 95 minutes altogether. Soil
151 compactness was measured with TJSD-750 (Hangzhou Top Instrument co., LTD, Hangzhou,
152 China) from the soil surface to 10 cm depth. Ecosystem respiration rates were measured using
153 the LICOR-8150 Automated Soil CO₂ Flux System, which was an accessory for the
154 LI-8100A could connect 16 individual chambers at one time and were sampled and controlled
155 by the LI-8100A Analyzer Control Unit. The air temperature inside of the chamber was
156 measured using the internal thermistor of the chamber. The ecosystem CO₂ fluxes were
157 calculated by the equation as follow.

$$158 \quad F_c = \frac{10VP_0 \left(1 - \frac{W_0}{1000}\right)}{RS(T_0 + 273.15)} \frac{\partial C'}{\partial t}$$

159 where F_c is the soil CO₂ efflux rate (μmol m⁻² s⁻¹), V is volume (cm³), P_0 is the initial pressure
160 (kPa), W_0 is the initial water vapor mole fraction (mmol mol⁻¹), R is the ideal gas constant (J
161 K⁻¹mol⁻¹), S is soil surface area (cm²), T_0 is initial air temperature (°C), and $\partial C'/\partial t$ is the initial

162 rate of change in water-corrected CO₂ mole fraction ($\mu\text{mol}^{-1} \text{s}^{-1}$).

163 Six LICOR-8100-104 long-term opaque chambers (20cm in diameter LICOR, Inc.,
164 Lincoln, NE, USA) were used to measure alternately between three replicates for six land
165 surface types. Therefore, 3 days at least were required to complete one rotation measurements
166 of ecosystem respiration. To measure ecosystem respiration, eighteen polyvinyl chloride
167 collars with a 20 cm inner diameter and a 12 cm height were inserted into the soil with 3-4 cm
168 exposed to the air (Qin et al., 2013). All of the collars were installed at least 24 h before the
169 first measurement to reduce disturbance-induced ecosystem CO₂ effluxes. Ecosystem
170 respiration rates were measured every 7-10 days from June 16 to August 20 in 2016
171 depending on weather conditions. A round-the-clock measurement protocol was carried out
172 and ecosystem respiration rates were measured every 30 minutes. Each measurement takes 1
173 minute and 45 seconds, including pre-purge 10 seconds, dead band 15 seconds, observation
174 length 1 minute and post-purge 20 seconds.

175 **Soil and vegetation sampling**

176 Soil samples were collected during the periods of late July to early August 2016. In each
177 surface type of each plot, five soil cores were collected using a stainless-steel auger (5 cm in
178 diameter) at depths of 0-10, 10-20, 20-30 and 30-40 cm, and bulked as one composite sample
179 for each depth in each quadrat. Another five soil cores were sampled by cylindrical cutting
180 ring (7 cm in diameter and 5.2 cm in depth) to determine soil bulk density from each land
181 surface type. Pika tunnel was approximate 6 cm in diameter and 40 cm in depth. Therefore,
182 soil samples were available to collect at depth of 40cm. Totally, 512 soil samples were
183 collected. Soil samples were firstly air-dried, then removed gravel and stone with manual
184 sieving and finally weighed. The remaining soil samples with diameter less than 2 mm were
185 ground to pass through a 0.25 mm sieve for analysis of soil organic carbon (SOC) and soil
186 total nitrogen (TN) concentration. SOC was measured by dichromate oxidation using
187 Walkley-Black acid digestion (Nelson and Sommers, 1982). TN was determined by digestion
188 and then tested using a flow injection analysis system (FIAstar 5000, Foss Inc., Sweden).
189 Aboveground and belowground biomasses were determined within a 1 m × 1 m quadrat on 4
190 August 2016 during peak biomass and species diversity. There were a total of 108
191 aboveground and belowground vegetation samples (3 plots × 6 land surface types × 3

192 replicates) from the study area. Aboveground biomass was determined by clipping all
193 above-ground living plants at ground level, drying (oven-dried at 65°C for 48 h) and weighing.
194 Belowground biomass was sampled by collecting five soil columns, and each soil column was
195 5 cm in diameter and 40 cm in depth. Soil cores were washed with a gentle spray of water
196 over a fine mesh screen until soil separated from the roots, and then drying (oven-dried at
197 65°C for 48 h) and weighing.

198 **Statistical analysis**

199 The soil organic C and total N densities in different land surface were calculated using the
200 equation (2) and (3):

$$201 \quad \text{SOC} = \sum_{i=1}^n \rho * (1 - \sigma_{\text{gravel}}) * C_{\text{SOC}} * D_i \quad (2)$$

$$202 \quad \text{TN} = \sum_{i=1}^n \rho * (1 - \sigma_{\text{gravel}}) * C_{\text{TN}} * D_i \quad (3)$$

203 where SOC is soil organic C density (kg m⁻²), TN is soil total N density (kg m⁻²), ρ is the soil
204 bulk density (g cm⁻³), σ_{gravel} is the relative volume of gravel (% w/w), C_{SOC} is soil organic C
205 content (g kg⁻¹), C_{TN} is soil total N content (g kg⁻¹) and D_i is soil thickness (cm) at layer i ,
206 respectively; $i=1, 2, 3$ and 4 .

207 The data were presented as mean \pm standard deviation. Statistical analyses were performed
208 using the SPSS 17.0 statistical software package (SPSS Inc., Chicago, IL, USA). One-way
209 analysis of variance (ANOVA) and a multi-comparison of a least significant difference (LSD)
210 test were used to determine differences at the $p=0.05$ level. The relationships of ecosystem
211 respiration with biotic and abiotic factors were analyzed by Pearson correlation analysis using
212 R.

213 **Results**

214 **Ecosystem respiration**

215 Ecosystem respiration showed significant difference among varied land surface types during
216 the growing season (Table 1, $P<0.001$). Except for the pika pile, ecosystem respiration
217 maximized in August and minimized in June (Figure 2). In June, ecosystem respiration under
218 intact grassland, above pika tunnel, small patch and pika pile had no significant difference and
219 the lowest ecosystem respiration was found under large and medium patches (Figure 2).

220 Average ecosystem respiration under intact grassland was $4.01 \mu\text{mol m}^{-2} \text{s}^{-1}$ in July, which
221 was 24.35 % to 137.39 % higher than other surface types (Figure 2). In August, average
222 ecosystem respiration were $4.07 \mu\text{mol m}^{-2} \text{s}^{-1}$ and $4.85 \mu\text{mol m}^{-2} \text{s}^{-1}$ for intact grassland and
223 above pika tunnel, $2.59\text{-}3.81 \mu\text{mol m}^{-2} \text{s}^{-1}$ for bald patches and $1.18 \mu\text{mol m}^{-2} \text{s}^{-1}$ for pika pile
224 (Figure 2).

225 (Insert Table 1, Figure 2 here)

226 **Microclimate and soil hydrothermal characteristics**

227 Mean temperature and total rainfall during the growing seasons from 1 May to 30 September
228 in 2016 were $6.18 \text{ }^{\circ}\text{C}$ and 343.4 mm , respectively (Figure 3). Soil temperature and moisture
229 were significantly different among various land surface types (Table 1, $P < 0.05$). The monthly
230 average soil temperature was in a range of $8.20\text{-}13.72 \text{ }^{\circ}\text{C}$ during June to August, which was
231 approximate $1\text{-}3 \text{ }^{\circ}\text{C}$ higher under pika pile and bald patches than the intact grassland (Figure
232 4a, $P < 0.05$). The monthly mean soil moisture from June to August was approximate 30 % for
233 intact grassland and above pika tunnel, 25 % for small patch and pika pile, and 20 % for
234 larger and medium patch (Figure 4b). Soil saturated hydraulic conductivity also showed
235 significant variation under different land surface types ($P = 0.027$, Table 2). For example, soil
236 saturated hydraulic conductivity under large bald patch, medium bald patch, small bald patch,
237 intact grassland patch, above pika tunnel and old pika pile were 1.54, 1.53, 2.14, 2.13, 2.12
238 and 2.58 cm h^{-1} , respectively (Figure 5). Soil saturated hydraulic conductivity under intact
239 grassland patch was approximate 40 % higher than medium and large patches and 17 % lower
240 than pika pile, while it was no significant difference among intact grassland patch, small patch
241 and above pika tunnel ($P > 0.05$).

242 (Insert Table 2, Figure 3 to 5 here)

243 **Soil and vegetation properties**

244 Soil and vegetation properties showed significant variation under different land surface types
245 (Table 2) ($P < 0.001$). Soil compactness was over 0.30 Pa in intact grassland and above pika
246 tunnel, approximate 0.20 Pa for bald patches and less than 0.10 Pa for pika pile (Figure 6),
247 respectively. Mean SOC and TN density under intact grassland were 52.45 % and 59.14 %
248 less than above pika tunnel, whereas they were 9.69-30.12 % and 22.47-109.62 % higher than
249 pika pile and bald patches (Figure 7). Aboveground and belowground biomass under intact

250 grassland were approximate 30 % higher than above pika tunnel, 90 % higher than pika pile,
251 123-252 % and 134-289 % higher than bald patches (Figure 8a, b).

252 (Insert Figure 6 to 8 here)

253 **Factors regulate ecosystem respiration**

254 We analyzed the relationships of ecosystem respiration with biotic and abiotic factors for six
255 land surface types (Figure 9). Correlation analysis showed that ecosystem respiration had no
256 significant correlation with soil temperature ($P>0.05$, Figure 9). However, ecosystem
257 respiration was significantly and positively related to soil moisture ($P<0.01$), soil total
258 nitrogen ($P<0.05$), aboveground ($P<0.05$) and belowground biomass ($P<0.05$) (Figure 9).

259 (Insert Figure 9 here)

260 **Discussion**

261 **Effect of pikas disturbance on ecosystem respiration**

262 Pikas burrowing activities increased oxygen content in deep soil, which contributed to the
263 decomposition of soil organic matter (Martin, 2003). The deposition of urine and feces by
264 small herbivorous mammals could also promote ecosystem nutrition circulation (Clark et al.,
265 2005). It was suggested that excreta deposited by pikas and frequently haunted in or near their
266 burrows supplied organic C available to microbial decomposition with an increase in
267 ecosystem CO₂ emission (Cao et al., 2004). Indeed, SOC and TN densities reached up to
268 14.54 and 0.98 kg m⁻² in above pika tunnel, which was 2.45 and 2.10 times higher than that of
269 intact grassland (Figure 7), respectively. The consistent results reported that the contents of
270 available soil nutrients around the pikas burrow were higher than those in control sites on an
271 alpine meadow (Zhang et al., 2016). We also found that SOC and TN densities under pika pile
272 decreased 13.35 % and 42.93 % than intact grassland. This was because pika burrowing
273 activity transferred of deeper, nutrient-poor soil to the soil surface, improved soil aeration
274 increased rate of organic carbon mineralization and soil erosion took away soil nutrition (Wei
275 et al., 2006; Qin et al., 2015a; Chen et al., 2017). However, except July, no significant
276 difference of Re was found between intact grassland and above pika tunnel, while Re under
277 pika pile was 42.08 % less than intact grassland (Figure 2). The similar result was also found
278 in an alpine meadow on the QTP (Peng et al., 2015), which indicated that ecosystem
279 respiration decreased with increasing of pika holes because of grassland biomass regulated

280 soil C and N with increasing number of pika holes. These results confirmed that pikas
281 disturbance did not increase ecosystem carbon emission directly, but facilitated CO₂ emission
282 into the atmosphere through pika holes (Qin et al., 2015a). The difference of ecosystem
283 respiration between intact grassland and pika piles was mainly related to changes in
284 vegetation biomass and soil moisture. For example, both aboveground and belowground
285 biomass decreased 244.62 % and 279.89 % under pika piles compared with the intact
286 grassland (Figure 8). The reduction of vegetation biomass production decreased aboveground
287 plant respiration and root respiration by decreasing carbon allocation (e.g., root exudates and
288 litter, and available SOC) (Raich and Potter, 1995; Högberg et al., 2002; Yang et al., 2018).
289 Consistent with previous studies which demonstrated that pikas burrowing activity increased
290 water infiltration rate (Hogan, 2010; Wilson and Smith, 2015), our results also showed that
291 soil saturated hydraulic conductivity in pika pile was significantly higher than bald and
292 vegetation patches (Figure 5). Nevertheless, the increased water infiltration was unable to
293 increase soil moisture under pika piles. For example, soil moisture under pika piles was
294 approximate 5 % lower than intact grassland (Figure 4). Our result was discrepant with
295 previous studies which reported old pika mound had the highest soil moisture during the
296 summer (Ma et al., 2018) and moderate pika burrowing activities increased surface soil
297 moisture (Li and Zhang, 2006). This difference may be contributed to the high pika density in
298 alpine meadow (Guo et al, 2017). Moreover, pika piles were loose (Figure 6) with less
299 vegetation cover (Figure 8), which was not beneficial for soil moisture storage.

300 **Effect of patchiness on ecosystem respiration**

301 Our results clearly showed that patchiness resulted in significant reduction of ecosystem
302 carbon emission. Compared with the intact grassland, ecosystem respiration decreased
303 approximate 17-48 % for bald patches (Figure 2). Two possible mechanisms could account
304 for the effects of patchiness on ecosystem respiration. On one hand, the reduction of SOC and
305 TN decreased microbial respiration by decreasing substrate supply to microbes in the
306 rhizosphere (Nobili et al., 2001; Scott-Denton et al., 2010). Our results indicated that
307 patchiness caused evident loss of SOC and TN (Figure 7) due to reduction in C input from
308 vegetation and increasing in C output from soil erosion (Qin et al., 2018). Previous study have
309 shown that the spatial heterogeneity of soil respiration was attributed to uneven soil organic

310 carbon and total nitrogen content (Xu and Qi, 2010). Soil organic carbon was considered as
311 the basic substrate of CO₂ emission by microbial decomposition (Sikora and McCoy, 1990)
312 and soil total N enhanced ecosystem CO₂ emission by providing a source of protein for
313 microbial growth (Tewary et al., 1982). On the other hand, low moisture availability would
314 limit microbial respiration by restricting access to C substrates, reducing the diffusion of C
315 substrates and extracellular enzymes, and limiting microbial mobility (Yuste et al., 2003;
316 Wang et al., 2014). Our results showed that soil moisture under large and medium patches
317 decreased 10 % than intact grassland (Figure 4). Previous studies had reported that the soil
318 compaction of bald patches decreased the rate of water infiltration (Wuest et al., 2006; Wilson
319 and Smith, 2015), which was similar with our results showed that bald patches had less
320 saturated soil hydraulic conductivity (Figure 5). Low vegetation cover under bald patches was
321 not beneficial for water retention and utilization, where most of soil water was mainly lost as
322 a way of evaporation (Yi et al., 2014). We have measured evaporation of the intact grassland,
323 isolate grassland, large patches, medium patches and small patches since the early June 2016.
324 Three years results indicated that evaporation under bald patches were higher than the intact
325 grassland (data were not shown here).

326 **Factors affected ecosystem respiration**

327 Most previous studies showed that soil temperature explained most of the temporal variation
328 of ecosystem respiration on the alpine grassland on the QTP (Lin et al, 2011; Qin et al., 2015c;
329 Zhang et al., 2017). Our results indicated that soil temperature under pika piles and bald
330 patches was approximate 1 to 3 °C higher than intact grassland (Figure 4), which mainly
331 resulted from the heterogeneity of surface albedo, surface soil water retention, heat
332 conduction properties and radiation (Beringer et al., 2005; Pielke, 2005; Yi et al., 2013; You et
333 al., 2017). It was suggested that pikas disturbance create a better soil temperature buffer for
334 them to avoid the extreme cold in winter (Ma et al., 2018), whereas high soil temperature
335 under bald patch was a disadvantage for the recovery of vegetation because patch surface had
336 the smallest soil moisture content (Figure 4) and the largest daily range of soil temperature
337 (Ma et al., 2018). It was well known that rising of soil temperature under natural condition
338 enhanced ecosystem respiration by stimulating decomposition of soil organic matter (Conant
339 et al., 2008), increasing plant biomass (Yi et al., 2014) and activity of microbial enzymes

340 (Bond-Lamberty and Thomson, 2010). However, obvious relationship between Re and soil
341 temperature was not found in the present study (Figure 9), which suggested that other factors
342 involved in controlling Re induced by pikas disturbance and patchiness. Our results showed
343 that Re were positively correlated with soil moisture, soil total nitrogen, aboveground and
344 belowground biomass (Figure 9). Pikas disturbance and patchiness led to the drying and
345 loosening of soil (Figure 4 and 6). It was considered that loose, dry surface sediments and
346 strong winds were the primary factors responsible for soil erosion (Dong et al., 2010b) and
347 wind erosion was especially common in arid and semi-arid regions (Zhang and Dong, 2014).
348 This resulted in the reduction of soil organic carbon, total nitrogen and vegetation biomass
349 (Figure 7 and 8). The alteration of these biotic and abiotic factors induced by pikas
350 disturbance and patchiness led to the decline of ecosystem respiration. Nevertheless, the
351 decline of ecosystem respiration did not completely offset the sequestration of C fixed by
352 photosynthesis because of the lower vegetation cover under bald patches and pika piles.
353 Given the large area covered by bald patches in alpine grasslands, patchiness was more
354 susceptible to erosion and exert greater influence on ecosystem respiration than pikas
355 disturbance. Recent study has also reported that bald patches of various sizes on the
356 grasslands played a much more important role than pikas direct disturbance in reducing
357 vegetation cover, aboveground biomass, soil carbon and nitrogen (Yi et al., 2016).

358 **Effect of pikas disturbance on patchiness**

359 Natural vegetation patches, bald patches with different sizes and pikas piles coexisted on the
360 alpine meadow (Figure 1), which supported that alpine grassland had also experienced
361 fragmentation (Qin et al., 2018). Several proposed mechanisms may be accounted for the
362 formation and development of patchiness in alpine grassland. As one of dominant form of
363 land utilization, alpine grasslands are widely used for grazing. Previous studies suggested that
364 overgrazing destroyed the original vegetation and led to decrease in the coverage and
365 looseness of soil (Dong et al., 2013), which was prone to form bald patch due to soil erosion
366 (Fécan et al., 1998; Zhang and Dong, 2014). Other than livestock, alpine grassland is also
367 habitats for many small mammals such as plateau pika, zokor (*Eospalax fontanierii*), marmot
368 (*Marmota himalayana*) and fox (*Vulpes ferrilata*). Pikas were considered to create a patchy
369 matrix by changing soil properties (Chen et al., 2017), digging tunnels and burying activities

370 (Dong et al., 2013). On one hand, pikas bury vegetation by fresh excavated soil, then small
371 bare soil patches are formed and further large soil patches are then formed by linking small
372 bare soil patches by wind and/or water (Wei et al., 2007; Ma et al., 2018). On the other hand,
373 pikas dig tunnel underground. Although pikas make burrows are the primary homes to a wide
374 variety of small birds and lizards (Smith and Foggin, 1999), the collapse of pika tunnels
375 results in the emergence of bald soil patches (Zhou et al., 2003; Cao et al., 2010). Moreover,
376 alpine grassland is underlain by extensive permafrost (Chen and Wu, 2007). The repeated
377 freeze and thaw cause the crack of the sod around the barren area (Yang et al. 2003) and
378 create precondition for forming bald patch. However, to date, there are no direct evidences to
379 demonstrate the potential mechanism for forming and developing of patchiness for alpine
380 grassland on the QTP. It is, therefore, critical to perform long-term repeated monitoring
381 studies to determine whether bald patches are developed from pika piles or burrow tunnels
382 and what the major factors affecting bald patch expansion are (Yi et al., 2016).

383 **Conclusions**

384 In this study, we investigated soil physicochemical properties, vegetation biomass and
385 ecosystem respiration (Re) under six land surfaces originating from pikas disturbance and
386 patchiness. We also analyzed the dominant factors regulated the Re. Our results showed that
387 pikas disturbance and patchiness decreased soil moisture but increased soil temperature,
388 which may be conducive to pikas survive in cold season but disadvantage for vegetation
389 growth. Patchiness caused evident decreasing in SOC and TN density, while both SOC and
390 TN density showed different response under pika piles and burrows. Both pikas disturbance
391 and patchiness decreased ecosystem carbon emission, and ecosystem respiration sharply
392 correlated with soil moisture, TN and vegetation biomass. Our results indicated that pikas
393 disturbance and patchiness led to the changing of ecosystem respiration process owing to the
394 drying of soil and the reduction of substrate supply. However, the decline of ecosystem
395 respiration may not able to offset the sequestration of C fixed by photosynthesis.

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669 **Table 1.** ANOVA results of soil temperature, soil moisture and ecosystem respiration under
 670 different land surface types.

	Soil temperature			Soil moisture			Ecosystem respiration		
	June	July	August	June	July	August	June	July	August
<i>F</i>	8.614	10.955	1.806	387.472	210.878	97.060	5.270	10.447	8.855
<i>P</i>	<0.001	<0.001	0.106	<0.001	<0.001	<0.001	0.001	<0.001	<0.001

671 **Table 2.** ANOVA results of soil compactness, aboveground biomass, belowground biomass,
 672 soil hydraulic conductivity, SOC and TN density under different land surface types.

	Soil compactness	Aboveground biomass	Belowground biomass	Saturated hydraulic conductivity	SOC density	TN density
<i>F</i>	81.506	6.193	12.925	2.752	145.942	50.567
<i>P</i>	<0.001	0.002	<0.001	0.027	<0.001	<0.001

673

674 **Figure legends**

675 **Figure 1.** An aerial photo of field observation of ecosystem respiration at six surface types: (1)
676 Large bald patch (LP), (2) Medium bald patch (MP), (3) Small bald patch (SP), (4) Intact
677 grassland patch (IG), (5) above pika tunnel (PT) and (6) old Pika pile (PP).

678 **Figure 2.** Ecosystem respiration of different surface types: (1) large bald patch (LP), (2)
679 medium bald patch (MP), (3) small bald patch (SP), (4) intact grassland patch (IG), (5) above
680 pika tunnel (PT) and (6) old pika pile (PP). The upper solid lines, the bottom solid lines, the
681 bold solid horizontal line and the empty dot mean the maximum value, minimum value,
682 median and abnormal value. Letters on the error bars indicate significant differences among
683 different surface types at $P < 0.05$.

684 **Figure 3.** Daily average air temperature and precipitation of the study site in 2016.

685 **Figure 4.** Monthly average soil temperature and soil moisture at 10 cm depth under different
686 surface types: (1) large bald patch (LP), (2) medium bald patch (MP), (3) small bald patch
687 (SP), (4) intact grassland patch (IG), (5) above pika tunnel (PT) and (6) old pika pile (PP).

688 **Figure 5.** Soil saturated hydraulic conductivity (SHC) under different surface types: (1) large
689 bald patch (LP), (2) medium bald patch (MP), (3) small bald patch (SP), (4) intact grassland
690 patch (IG), (5) above pika tunnel (PT) and (6) old pika pile (PP).

691 **Figure 6.** Soil compactness under different surface types: (1) large bald patch (LP), (2)
692 medium bald patch (MP), (3) small bald patch (SP), (4) intact grassland patch (IG), (5) above
693 pika tunnel (PT) and (6) old pika pile (PP).

694 **Figure 7.** Soil organic carbon (SOC) (a) and total nitrogen (TN) (b) density of different
695 surface types: (1) large bald patch (LP), (2) medium bald patch (MP), (3) small bald patch
696 (SP), (4) intact grassland patch (IG), (5) above pika tunnel (PT) and (6) old pika pile (PP).

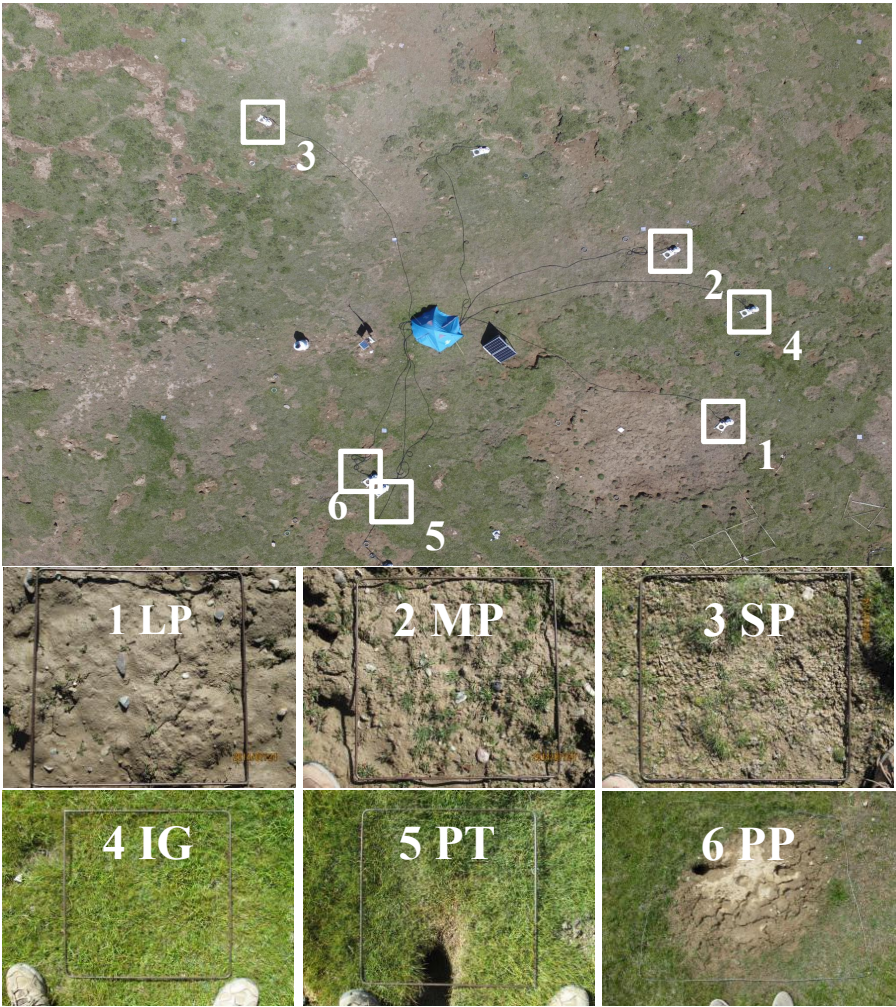
697 **Figure 8.** Aboveground biomass (AGB) (a) and belowground biomass (BGB) (b) under
698 different surface types: (1) large bald patch (LP), (2) medium bald patch (MP), (3) small bald
699 patch (SP), (4) intact grassland patch (IG), (5) above pika tunnel (PT) and (6) old pika pile
700 (PP).

701 **Figure 9.** The correlation coefficient charts between ecosystem respiration (R_e) and biotic
702 and abiotic factors for all six land surfaces. The diagonal line in the figure shows the
703 distributions of the variables themselves. The red line means the frequency distribution of

704 variables. The lower triangle (the left bottom of the diagonal) in the figure shows scatter plots
705 of the two properties. The upper triangle (the upper right of the diagonal) in the figure
706 indicates the correlation values of the two parameters; the asterisk indicates the degree of
707 significance (***) indicates significant differences at $P < 0.001$, ** indicates significant
708 differences at $P < 0.01$, * indicates significant differences at $P < 0.05$). The bold bigger
709 numbers mean the higher correlation.

710 **Figure 1.**

711



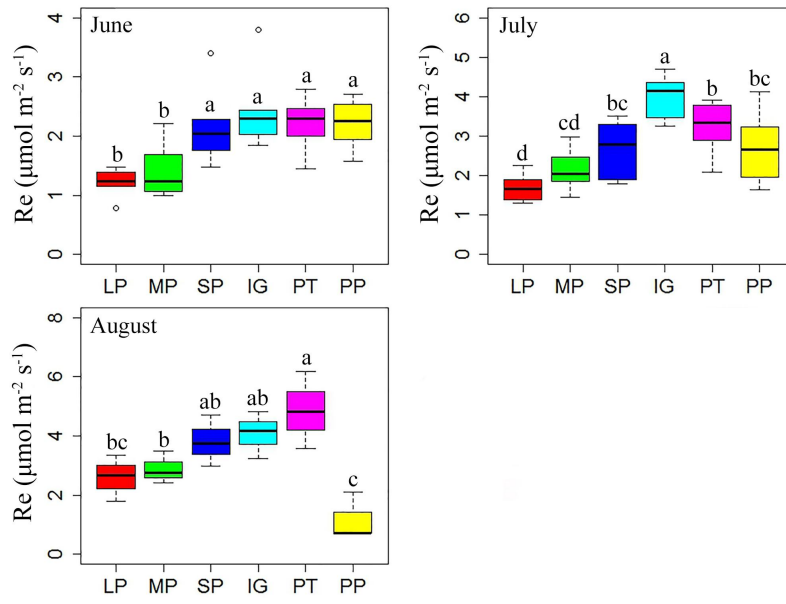


Figure 3.

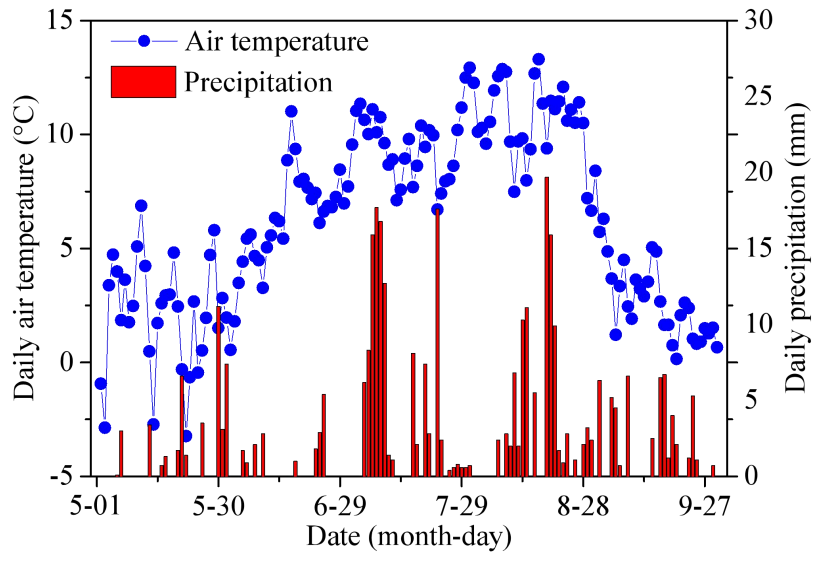


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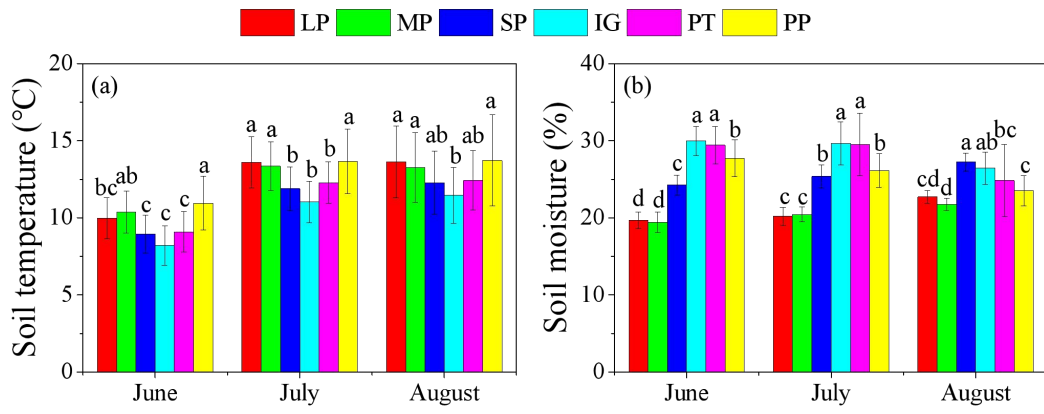
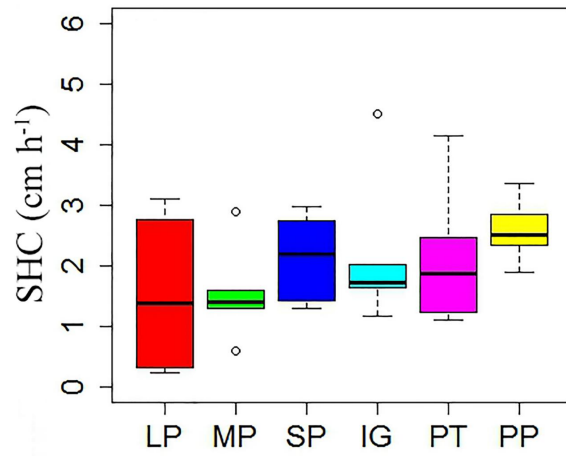
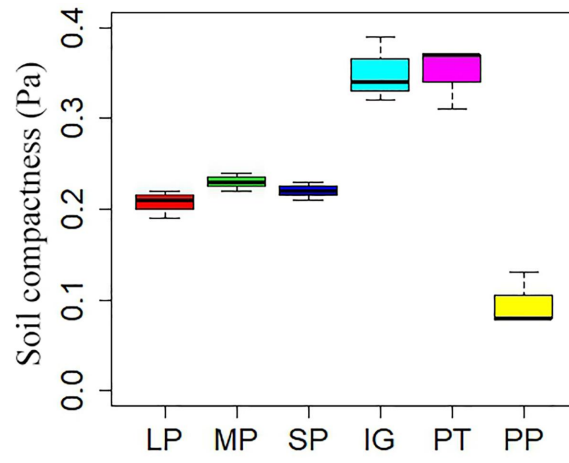


Figure 5.

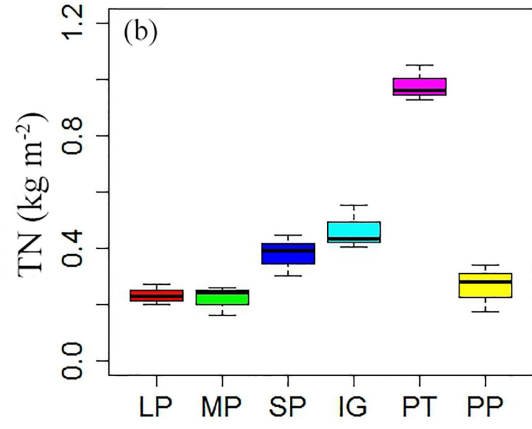
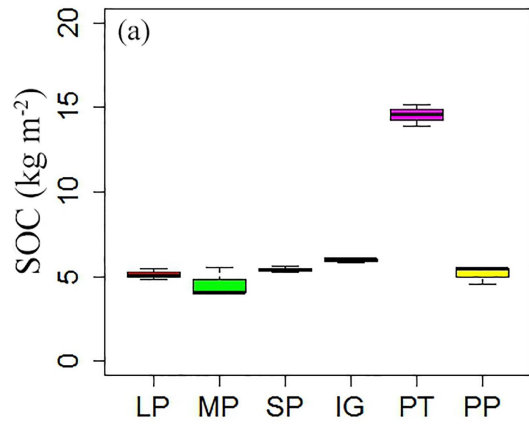


720 **Figure 6.**



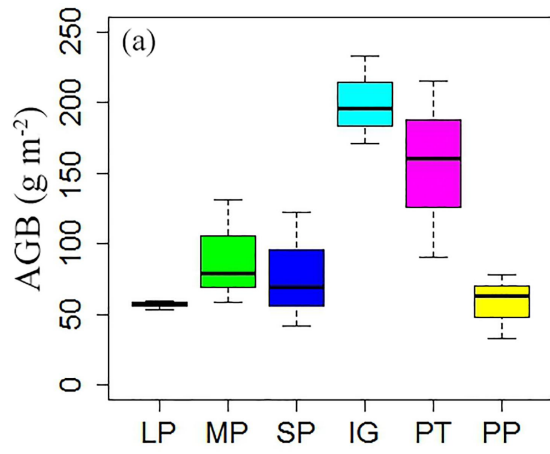
721

722 **Figure 7.**

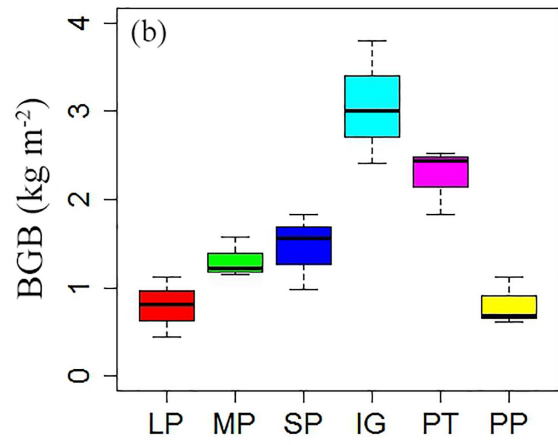


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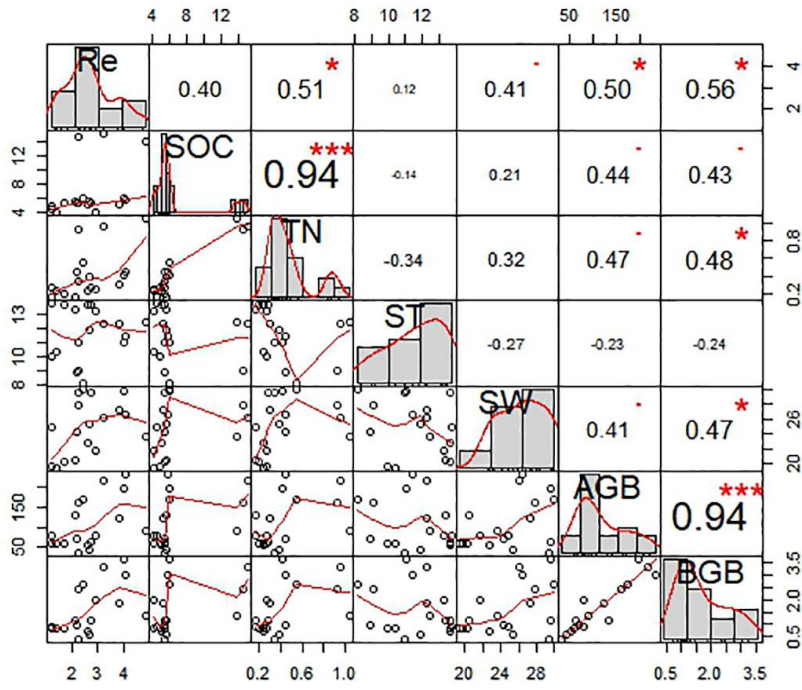
724 **Figure 8.**



725



726 **Figure 9.**



727