Responses of soil inorganic and organic carbon stocks of alpine meadows to the disturbance by plateau pikas


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Abstract
Small burrowing herbivores create extensive disturbances to grassland soil, which may change carbon cycling. We focused on the plateau pika (Ochotona curzoniae) to simultaneously investigate the responses of the soil organic carbon (SOC) and soil inorganic carbon (SIC) stocks of alpine meadows to the disturbance caused by this small burrowing herbivore and its disturbance intensity at the plot scale across five sites on the Qinghai-Tibetan Plateau. The percentage of bare soil area in a disturbed plot was used as a proxy for the disturbance intensity of plateau pikas. Our study found that the disturbance by plateau pikas reduced the SIC stock and increased the SOC stock, whereas it had no effect on the soil total carbon (STC) stock. Our study also found that the SOC and STC stocks were higher at intermediate disturbance intensities of plateau pikas, whereas the SIC stock showed a decreasing trend as the disturbance intensity of plateau pikas increased. Our findings suggest that intermediate disturbance intensities of a small burrowing herbivore (plateau pika) improve soil quality by increasing the SOC stock and benefit soil carbon sequestration by increasing the STC stock.

Highlights
- Explored the SIC and SOC stocks simultaneously in relation to the disturbance by a small burrowing herbivore.
- Soil carbon stocks were evaluated at plot scale across five sites.
- SIC and SOC stocks responded differently to the disturbance by plateau pika and its disturbance intensity.
- The intermediate disturbance intensities were good for the soil quality and soil carbon sequestration.

KEYWORDS
Qinghai-Tibetan Plateau, small burrowing herbivore, soil total carbon, the disturbance intensity

1 | INTRODUCTION

The soil carbon pool is the largest carbon pool in the terrestrial ecosystem, and it stores more than double the quantity of carbon that is held in the atmosphere (Batjes, 1996; Batjes, 2014; Lal, 2004; Shi et al., 2012). As one of the most important vegetation types on the earth (Wang & Fang, 2009), grasslands contain approximately 34% of the global carbon stock in terrestrial ecosystems (White, Murray, Rohweder, Prince, & Thompson, 2000). Soils in grasslands...
have a large potential for storing an appreciable fraction of atmospheric carbon dioxide (CO₂) as relatively stable carbon (Reid et al., 2004). The soil carbon stocks of grasslands have received considerable attention (Chen, Yi, & Qin, 2017; Rui et al., 2011; Yang et al., 2010a; Yurkewycz, Bishop, Crisafiulli, Harrison, & Gill, 2014) because they have important impacts on atmospheric CO₂ concentrations and global climate conditions (McSherry & Ritchie, 2013; Liu et al., 2017a, 2017b). The soil carbon stocks of grasslands are dependent on the balance of carbon input and output, which are controlled by a variety of abiotic and biotic factors, such as precipitation (Yang, Fang, Ma, et al., 2010a), warming (Rui et al., 2011), plant productivity (Steinbeiss et al., 2008), livestock grazing (McSherry & Ritchie, 2013), disturbance by small herbivores (Chen et al., 2017; Sherrod & Seastedt, 2001; Yurkewycz et al., 2014) and land degradation (Liu et al., 2017a).

Small burrowing herbivores are common components of grassland ecosystems (Davidson, Detling, & Brown, 2012; Wilson & Smith, 2015) and they are considered to be important biotic factors affecting soil carbon (Reichman & Seabloom, 2002; Yu et al., 2017b). Previous studies have reported that the disturbance by small burrowing herbivores can increase soil total carbon (STC) (Martínez-Estévez, Balvanera, Pacheco, & Ceballos, 2013; Yurkewycz et al., 2014) and soil organic carbon (SOC) (Yu et al., 2017a), or decrease STC (Sherrod & Seastedt, 2001) and SOC (Sun et al., 2015), demonstrating that there is no consensus concerning the effects of the disturbance by small burrowing herbivores on SOC or STC. In addition to SOC, soil inorganic carbon (SIC) plays an important role in the grassland carbon cycles (Wang et al., 2013; Yang, Fang, Ji, et al., 2010b) and in regional carbon budgets (Liu, Dang, Tian, Wang, & Wu, 2017b), because it is more stable and has a longer turnover time than SOC (Hirmas, Amrhein, & Graham, 2010; Mi et al., 2008). The global SIC stock accounts for approximately 38% of the global STC (Lal, 2004). Soil inorganic carbon mainly accumulates as primary carbonates and secondary carbonates (Batjes, 1996; Batjes, 2014), of which only secondary carbonates have been found to affect SIC (Wu, Guo, Gao, & Peng, 2009). The formation of secondary carbonates in grassland soils increases the sequestration of atmospheric CO₂ through a series of chemical reactions that occur during the carbonate weathering process (Tan et al., 2014). In contrast, acidification and leaching, which enable secondary carbonates to dissolve and decompose to CO₂, may result in SIC release (Lal & Kimble, 2000; Yang et al., 2012). Therefore, it is necessary to simultaneously investigate the changes of the SOC and SIC stocks when examining the effects of disturbance by small burrowing herbivores on soil carbon stocks in grassland ecosystems.

The plateau pika (Ochotona curzoniae) is a common small burrowing herbivore in the Qinghai-Tibetan Plateau (Figure S1) and it often develops alpine meadows into discrete mosaics of vegetated areas and bare soil areas (Figure S2) (Wilson & Smith, 2015), resulting in heterogeneity of soil carbon in the presence of plateau pikas (Yu et al., 2017b). Many studies have compared SOC between vegetated areas and bare soil areas while neglecting to select areas with the absence of plateau pikas as a reference (Yi, Chen, Qin, & Xu, 2016; Yu, Zhang, et al., 2017b). Others have compared SOC between vegetated areas with and without plateau pikas while ignoring the heterogeneity of SOC in the presence of plateau pikas (Sun et al., 2015; Yu, Pang, et al., 2017a). The heterogeneity of SOC in the presence of plateau pikas and difference in the SOC between areas with and without this herbivore should be simultaneously considered when examining SOC in relation to the disturbance by plateau pikas. Furthermore, recent studies have demonstrated that the SOC of alpine meadows is related not only to the disturbance by plateau pikas (Pang & Guo, 2017; Yi et al., 2016; Zhang et al., 2016), but also to the disturbance intensity of plateau pikas (Pang & Guo, 2017; Yu et al., 2017a, 2017b). Thus, more studies are needed to examine the responses of soil carbon stock to the disturbance by the plateau pika and its disturbance intensity.

The plateau pika lives in family groups that often contain approximately two to five adults per family. The population density of plateau pika increases rapidly within a relatively short period of time because plateau pika females can produce three to five litters within a 3-week interval (Fan, Zhou, Wei, Wang, & Jiang, 1999) and young offspring stay with their family group in their first year after birth (Dobson et al., 1998; Qu, Li, Yang, Ji, & Zhang, 2013). This small burrowing herbivore commonly occupies regions that are approximately 3,000 to 5,000 m in elevation and typically burrows a tunnel system with four to six entrances (Wei et al., 2013). The burrowing and burial behaviours of plateau pikas can produce a bare soil patch near each entrance. Thousands of plateau pikas extensively create many bare soil patches, which manifest in alpine meadows as a discrete mosaic of vegetated areas and bare soil areas within a home range (Yu, Zhang, et al., 2017b). The plateau pika occupies approximately 20% of the alpine meadow habitat in the study sites. High plateau pika density is considered to be a contributor, along with overgrazing, to grassland degradation (Smith & Foggin, 1999; Sun et al., 2015). However, recent studies have argued that plateau pikas play important roles in the food webs of alpine meadow ecosystems (Smith & Foggin, 1999) and positively affect soil nutrients (Yu, Zhang, et al., 2017b) and water infiltration (Wilson & Smith, 2015) within their home ranges, which have an average size of 1,262.5 m² (Fan et al., 1999).
Here, we simultaneously investigated the responses of the SIC and SOC stocks of alpine meadows to the disturbance by plateau pikas and to different disturbance intensities across five sites. We hypothesized that: (a) the disturbance by plateau pikas can reduce SIC stock by increasing carbonate leaching losses; (b) the disturbance by plateau pikas can increase the SOC stock by increasing the input of organic matter; and (c) SIC and SOC stocks are related to the disturbance intensity of plateau pikas. The findings of this study can provide insights into how the disturbance by a small burrowing herbivore can influence soil carbon, and the role of plateau pikas in alpine meadow ecosystems of the Qinghai-Tibetan Plateau.

2 | MATERIALS AND METHODS

2.1 | Study sites

Based on site access and the presence of plateau pikas in previous studies (Pang & Guo, 2017; Yu et al., 2017a, 2017b), we selected five sites in the Qinghai-Tibetan Plateau, located in Zhiduo, Gangcha, Luqu, Maqu and Gonghe Counties (Table S1). These sites experience the same cold, humid plateau continental climate and have similar alpine meadows dominated by sedges. A general pattern of how the disturbance by plateau pikas influences the SIC, SOC and STC stocks of alpine meadows can be determined because the five sites range in elevation from 3,000 m to 4,650 m, with average annual precipitation varying from 290 mm to 800 mm. According to the Chinese Soil Classification System (Gong, 2001), the soils of these sites are classified as subalpine meadow soils (similar to Cambisol in the WRB soil classification system) with an approximately 7–11-cm-thick root mat (consisting of compact plant roots) in the topsoil horizon that impedes water infiltration.

2.2 | Survey design

A random stratified and paired design was used to quantify the responses of the SIC, SOC and STC stocks of alpine meadows to the disturbance by plateau pikas and to different disturbance intensities. At each of the five sites, we selected 10 disturbed plots where plateau pikas were present; these disturbed plots were located 3 km to 5 km from each other. Next, we selected a paired, adjacent undisturbed plot for each disturbed plot where plateau pikas were not present; the plots within each disturbed–undisturbed pair were separated by 500 m to 1,000 m. Each paired plot shared the same alpine meadow, which was used as a single management unit, with no obvious differences in vegetation composition or topography. There are two potential reasons why plateau pikas were absent at adjacent sites without any such obvious differences: first, plateau pikas are social mammals that live in family groups, and they are territorial and patchily distributed on alpine meadows; second, the expansion of plateau pikas is a gradual process, and the sites with absence of plateau pikas may be potential invasion zones. The size of each plot was 35 m × 35 m, which is approximately the average area of the plateau pika’s home range (Fan et al., 1999). All plots were fenced to exclude summer grazing by large herbivores. Fences were opened during the winter to allow live-stock grazing, and the grazing intensities between paired disturbed and undisturbed plots were similar.

The area in each disturbed plot was further divided into the vegetated area and the bare soil area (Yu, Zhang, et al., 2017b). The bare soil areas comprised all bare soil patches in the plot and the vegetated area comprised regions covered with vegetation. We estimated the bare soil area in each disturbed plot by measuring each bare soil patch and summing the total area per disturbed plot. The percentage of the bare soil area per disturbed plot was used as a proxy for the disturbance intensity of plateau pikas because the number of bare soil patches is directly related to the population density of plateau pikas (Yu, Zhang, et al., 2017b). In total, we had 10 paired plots at each site and 100 plots across five sites, consisting of 50 disturbed plots and 50 undisturbed plots.

2.3 | Soil sampling and analysis

Field surveys were carried out during early August of 2017; at this time of year, the population density of plateau pikas reaches its yearly maximum (Qu et al., 2013) and the disturbance of alpine meadows by plateau pikas is at its greatest (Yu et al., 2017a, 2017b). In each disturbed plot, five vegetated subplots (1 m × 1 m) were placed in the vegetated area approximately 8 m apart along a W pattern; their positions were adjusted slightly to avoid bare soil areas if needed. In addition, five bare soil patches, serving as bare soil subplots, were determined according to the positions of the vegetated subplots to ensure that the distance between two adjacent vegetated and bare soil subplots was as short as possible; this distance was approximately 1 m. Within each undisturbed plot, five subplots were also placed approximately 8 m apart along a W pattern. We collected soil samples from three land types: undisturbed area without plateau pikas, bare soil area and vegetated area with plateau pikas. In this study, 250 patches in disturbed plots consisting of old and new bare patches were established and these were helpful in identifying a general pattern.

Before collecting the soil samples, plant and litter were cleared from the soil surface. Previous studies found that most burrows produced by plateau pikas generally do not extend below 20 cm (Yu, Zhang, et al., 2017b), although a few burrows can extend to a depth of 60 cm (Fan et al.,
The majority of the plant roots in these alpine meadows are located in the top 10 cm of the soil (Chen et al., 2017). Therefore, we collected soil samples at a depth of 20 cm with a 5-cm-diameter soil corer to measure SOC and STC concentrations. A soil profile with a depth of 20 cm was dug to collect the soil cores for bulk density analysis using a stainless-steel cutting ring (volume, 100 cm³). All soil samples were transported and stored at 4°C prior to analysis. The soil bulk density was calculated by dividing the weight of the dry soil by the volume of the core occupied by the soil. The soils for SOC and STC determinations were air dried and passed through a 2-mm sieve to remove gravel and roots. SOC concentration was measured by the K₂Cr₂O₇-H₂SO₄ oxidation method of Walkey and Black, and STC concentration was analysed by dry combustion (Nelson & Sommers, 1982).

### 2.4 Calculations of soil carbon stocks

To determine the soil carbon stocks for each plot, we averaged the data from the five subplots per plot. We estimated the SIC, SOC and STC stocks at a soil depth of 20 cm as follows:

\[
SIC = STC - SOC
\]

where SIC is the soil inorganic carbon concentration (g kg⁻¹) and STC is the soil total carbon concentration (g kg⁻¹).

\[
SICS_{\text{dist}} = (SIC_{BA} \times BD_{BA} \times T \times (1 - \delta_{BA}) \times 0.01 \times BA) + (SIC_{VA} \times BD_{VA} \times T \times (1 - \delta_{VA}) \times 0.01 \times VA)
\]

where SOC is soil organic carbon (g kg⁻¹); SICS_{\text{dist}} is the soil inorganic carbon stock of disturbed plots (kg m⁻²); SIC_{BA}, BD_{BA} and \(\delta_{BA}\) are soil inorganic carbon concentration (g kg⁻¹), soil bulk density (g cm⁻³) and soil fraction of gravel larger than 2 mm in the bare soil area of disturbed plots, respectively; BA is the percentage of bare soil area in

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**FIGURE 1** Soil bulk density in undisturbed area (undisturbed plot), vegetated area and bare soil area (disturbed plot) \(F = 0.14, p = .869\). We used generalized linear mixed models (GLMMs) with the paired plots nested within site as a random factor to determine the effects of the disturbance by plateau pikas. From top to bottom of the standard boxplot are the maximum, the third quartile, median, first quartile and minimum values. The points outside the standard boxplot are outliers.

**FIGURE 2** Effects of the disturbance by plateau pikas on (a) the soil inorganic carbon (SIC) stock \(F = 134.33, p < .001\), (b) the soil organic carbon (SOC) stock \(F = 14.61, p < .001\) and (c) the soil total carbon (STC) stock \(F = 0.14, p = .713\) across five sites. We used generalized linear mixed models (GLMMs) with the paired plots nested within site as a random factor to determine the effects of the disturbance by plateau pikas.
disturbed plots; \( \text{SIC}_{VA} \), \( \text{BD}_{VA} \) and \( \delta_{VA} \) are soil inorganic carbon concentration (g kg\(^{-1}\)), soil bulk density (g cm\(^{-3}\)) and soil fraction of gravel larger than 2 mm in a vegetated area of a disturbed plot, respectively; and \( VA \) is the percentage of vegetated area in disturbed plots.

\[
\text{SIC}_{\text{undist}} = \text{SIC}_{\text{undist}} \times \text{BD}_{\text{undist}} \times T \times (1 - \delta_{\text{undist}}) \times 0.01 \times 100\% 
\]

where \( \text{SIC}_{\text{undist}} \) is the soil inorganic carbon stock of undisturbed plots (kg m\(^{-2}\)); \( \text{SIC}_{\text{undist}} \), \( \text{BD}_{\text{undist}} \) and \( \delta_{\text{undist}} \) are soil inorganic carbon concentration (g kg\(^{-1}\)), soil bulk density (g cm\(^{-3}\)) and soil fraction of gravel larger than 2 mm in undisturbed plots, respectively; and \( T \) is soil thickness (20 cm). The bare soil area in undisturbed plots without plateau pikas was 0 and the vegetated area was 100% of the total area because we only considered bare soil areas induced by plateau pikas.

### TABLE 1  
Percentage of bare soil area of the total plot area (35 m by 35 m) in the presence of plateau pikas. Significance was evaluated using one-way ANOVA with the Tukey post hoc test. Different letters denote significant differences at \( p < .05 \). Presented are the means ±1 standard deviation for the five sites; each site had 10 replicates (\( n = 50 \)). The bare soil area in Zhiduo was significantly higher than the bare soil areas in the other four sites (\( F = 7.90, p < .001 \))

<table>
<thead>
<tr>
<th>Site</th>
<th>Bare soil area (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Zhiduo</td>
<td>16.41 ± 2.42 a</td>
</tr>
<tr>
<td>Gangcha</td>
<td>8.20 ± 2.85 b</td>
</tr>
<tr>
<td>Luqu</td>
<td>11.41 ± 3.90 b</td>
</tr>
<tr>
<td>Maqu</td>
<td>11.39 ± 5.23 b</td>
</tr>
<tr>
<td>Gonghe</td>
<td>9.78 ± 1.86 b</td>
</tr>
</tbody>
</table>

### 3 | RESULTS

#### 3.1 | Soil bulk density in undisturbed area, vegetated area and bare soil area

There was no significant difference in soil bulk density among undisturbed areas, vegetated areas and bare soil areas, both when analysing the data from the five sites...
FIGURE 4  Soil inorganic carbon (SIC), soil organic carbon (SOC) and soil total carbon (STC) stocks in relation to the bare soil area (%) in the presence of plateau pikas in Zhiduo (A1, A2, A3), Gangcha (B1, B2, B3), Luqu (C1,C2,C3), Maqu (D1, D2, D3) and Gonghe (E1, E2, E3), based on LOESS models.
together and separately for each of five sites (Figure 1; Table S2).

3.2 | Responses of SOC, SIC and STC stocks to the disturbance by plateau pikas

When the data from five sites were analysed together, the disturbance by plateau pikas decreased the SIC stock (F = 134.33, p < .001) (Figure 2a) and increased the SOC stock (F = 14.61, p < .001) (Figure 2b), whereas it had no impact on the STC stock (F = 0.14, p = .713) (Figure 2c).

When the data from each of five sites were analysed separately, responses of SOC and STC stocks to the disturbance by plateau pikas were consistent with the results of the overall scale effect, except for the responses of the STC and SOC stocks in Zhiduo (Table S3). In Zhiduo, the disturbance by plateau pikas reduced the STC and SOC stocks.

3.3 | Responses of SOC, SIC and STC stocks to disturbance intensity of plateau pikas

The disturbance by plateau pikas was associated with bare soil area percentages of 3 to 21% within disturbed plots across the five sites (Table 1). The bare soil area in Zhiduo was significantly higher than the bare soil area at the other four sites (F = 7.90, p < .001). Accounting for an overall scale effect, SIC showed a significant decreasing trend with increasing disturbance intensity, whereas the SOC and STC stocks increased and then decreased as the disturbance intensity of the plateau pikas increased (Figure 3). This study identified general patterns of the responses of the SIC, SOC and STC stocks to the disturbance intensity of plateau pikas across five sites.

Although the responses of the SIC stock to the disturbance intensity of plateau pikas were similar, the responses of the SOC and STC stocks to the disturbance intensity differred among the five sites. The SOC and STC stocks in Gangcha, Luqu, Maqu and Gonghe were in agreement with the general pattern (Figure 4), whereas the SOC and STC stocks in Zhiduo showed decreasing trends with the increase of the disturbance intensity of plateau pikas.

4 | DISCUSSION

Plateau pikas often modify soil biochemical processes by creating discrete and distinctive bare soil patches in alpine meadows (Wilson & Smith, 2015; Chen et al., 2017; Yu et al., 2017, 2017b). Our study examined the effects of the disturbance by plateau pikas on the SOC, SIC and STC stocks at the plot scale, evaluating the differences in soil carbon stocks between plots with and without the presence of plateau pikas.

Our results demonstrate that the disturbance by plateau pikas is associated with lower SIC stock and higher SOC stock, which is consistent with our first and second hypotheses. Generally, SIC is released to the atmosphere as CO2 or redistributed into the deeper soil layers with water infiltration (Yang et al., 2012). We show that there were no differences in soil bulk density among the undisturbed area, vegetated area and bare soil area. The small body weight (approximate 150 g) of plateau pikas is too light to compact the topsoil layer, which is different from large herbivores (Stavi, Ungar, Lavee, & Sarah, 2008). Plateau pikas do not develop foraging tunnels but they do transfer an amount of deeper soil to the soil surface, which may loosen the soils; however, raindrop impacts cause the surface of bare soil to gradually become compact (Guo, Zhou, & Hou, 2012). Despite our inconclusive results based on bulk density, it is reported that the disturbance by plateau pikas increases water infiltration (Wilson & Smith, 2015), which enhances the leaching of carbonates into deep soil (Kindler et al., 2011; Mi et al., 2008), resulting in the reduction of the SIC stock in the topsoil layer. In addition, the soil redistribution induced by plateau pikas increases the exposure of calciferous subsoil material at the surface. In the short term, this may increase the SIC stock in the topsoil, whereas in the long run the SIC stock may decrease gradually, due to carbonate weathering and erosion (Lal & Kimble, 2000; NSSO, 1998).

The larger SOC stocks, observed in association with the disturbance by plateau pikas, can be explained as follows. Firstly, the disturbance by plateau pikas results in increased organic matter input (Liu et al., 2013; Yu, Pang, et al., 2017a; Zhang et al., 2016), due to a high deposition rate of waste from the uneaten food and the clippings of tall plants near the burrow entrance to avoid predator detection (Liu et al., 2009). Secondly, plateau pikas excrete urine and faeces. Thirdly, the burial of litter and waste material protects soil organic matter pools from decomposition, mineralization and removal (Clark, Branch, Hierro, & Villarreal, 2016; Yurkewycz et al., 2014) because the buried soil organic matter is protected from ultraviolet light and cannot be blown away by wind. These findings indicate that the disturbance by plateau pikas benefits the soil quality of alpine meadows by increasing the SOC stock.

However, with respect to the total carbon (STC) stock, its small change due to the disturbance by plateau pikas is a consequence of the balanced increase in SOC stock and the simultaneous decrease in SIC stock. Yet, the SOC accumulation and the SIC depletion caused by the disturbance by plateau pikas are independent. Our results also demonstrate that the effects of the disturbance by plateau pikas on the SOC and STC stocks are site dependent. As far as SOC stock is concerned, the disturbance by plateau pikas increases it in
Gangcha, Luqu, Maqu and Gonghe, while decreasing it in Zhiduo. This is ascribed to the greater area of bare soil at this site. Although the STC stocks exhibited no response to the disturbance by plateau pikas in Gangcha, Luqu, Maqu and Gonghe, a lower STC stock due to disturbance is observed in Zhiduo. The lower STC stock at this site, due to both smaller SIC and SOC stocks, is related to the larger bare soil area, exceeding 13% (Table 1). Our results further clarify that the disturbance intensity of plateau pikas has impacts on SIC and SOC stocks at the plot scale, supporting our third hypothesis that SIC and SOC stocks are closely related to the disturbance intensity by plateau pikas. Generally, the SIC stock is negatively correlated with the disturbance intensity of plateau pikas at the plot scale, which can be attributed to two phenomena. Firstly, water infiltration increases with the increase of disturbance intensity of plateau pikas (Wilson & Smith, 2015), enhancing the leaching of SIC into deep soil. Secondly, as the disturbance intensity increases, more of the calciferous horizon is exposed to the soil surface, which may increase the SIC stock in the topsoil layer temporarily, but the SIC stock eventually decreases, due to erosion and leaching with higher soil temperatures and water infiltration (Tan et al., 2014; Wilson & Smith, 2015; Zhang et al., 2019).

The general pattern of the SOC stock with increasing bare soil area is different from that of the SIC stock: the SOC stock shows a hump-shaped curve with the increase of the bare soil area. This result implies that there is a threshold for the intensity of disturbance by plateau pikas that can maximize the SOC stock. A plateau pika disturbance of a certain intensity can increase the input of organic matter (Liu, Zhang, et al., 2009; Liu, Fan, et al., 2013; Zhang et al., 2016; Yu et al., 2017a) and decrease the decomposition rate of soil organic matter due to burrowing and burial activities (Clark et al., 2016; Yurkewycz et al., 2014). When the disturbance intensity exceeds this threshold, the SOC stock decreases because of the lower input of organic matter resulting from low vegetation biomass (Pang & Guo, 2017; Sun et al., 2015). In addition, at high disturbance intensity plateau pikas may increase the loss of soil organic matter (Chen et al., 2017; Yu et al., 2017a, 2017b) by increasing rates of decomposition, due to increased temperature (Liu et al., 2013), soil aeration and water infiltration (Guo et al., 2012; Wilson & Smith, 2015). Furthermore, the bare soil patches induced by plateau pikas may increase erosion, leading to a loss of soil organic matter.

With the increase of the disturbance intensity, the response of the STC stock approaches that of the SOC stock, but not the SIC stock; this finding can be attributed to the proportions of the SIC and SOC to STC stocks. On average, the SOC stock accounts for 74% (55%–87%) of the STC stock; therefore, the STC in the topsoil in this study is mainly composed of SOC. However, the responses of the SOC and STC stocks to the disturbance intensity differs among the five sites. In Gancha, Luqu, Maqu and Gonghe, the responses of the SOC and STC stocks to the disturbance intensity are consistent with the general pattern. However, in Zhiduo, the SOC and STC stocks decrease with the increase of the disturbance intensity. The SOC and STC stocks peak at bare soil area percentages of 9–11% in Gancha, Luqu, Maqu and Gonghe, suggesting that the SOC and STC stocks may decrease when the percentage of bare soil area exceeds 9–11%. In Zhiduo, the percentage of bare soil area is greater than 13%, much higher than the threshold of the bare soil area in the other four sites (9–11%). This observation, in turn, supports the results from the other four sites, validating the general patterns of the effect of the disturbance intensity of plateau pikas on the SOC and STC stocks. Our findings show that an intermediate disturbance intensity of plateau pikas is beneficial to alpine meadows by improving soil quality and increasing carbon sequestration, whereas higher disturbance intensities are detrimental to alpine meadows because the larger bare soil area reduces the soil carbon stock.

5 | CONCLUSIONS

Our study focuses on plateau pikas to simultaneously investigate the responses of the SIC and SOC stocks to the disturbance and disturbance intensity by this small burrowing herbivore. Our results show that the disturbance by plateau pikas is associated with higher SOC stock and lower SIC stock, but does not influence the STC stock. The SIC stock is negatively correlated with the disturbance intensity of plateau pikas, whereas the SOC and STC stocks peak at intermediate disturbance intensities. Our findings suggest that the intermediate disturbance intensities of a small burrowing herbivore can improve soil quality with higher SOC stock and enhance carbon sequestration with higher STC stock.

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CONFLICTS OF INTEREST

No conflict of interest exits in the submission of this manuscript. All authors approved the manuscript for publication.
REFERENCES


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