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The contribution of plateau pika disturbance and erosion on patchy alpine grassland soil on the Qinghai-Tibetan Plateau: Implications for grassland restoration

Jianjun Chen [a,b], Shuhua Yi [a,c,*], Yu Qin [a]

[a] State Key Laboratory of Cryospheric Sciences, Northwest Institute of Eco-Environment and Resources, Chinese Academy of Sciences, 320 Donggang West Road, Lanzhou 730000, China
[b] University of Chinese Academy of Sciences, No. 19 A Yuquan Road, Beijing 100049, China
[c] School of Geographic Sciences, Nantong University, 999 Tongjing Road, Nantong 226007, China

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ABSTRACT

Patchy alpine grassland with soil excavated by plateau pika (*Ochotona curzoniae*) and with bald patches is common on the Qinghai-Tibetan Plateau (QTP) where desertification has developed rapidly over the last few decades. This may have significant effects on alpine grassland restoration, by changing soil properties. In this study, the contribution of plateau pika disturbance and erosion on patchy alpine grassland soil were examined by classifying the surface of the patchy grassland into 4 types—vegetation patch, new pika pile, old pika pile and bald patch—and comparing the gravel content of the top layer of soil, soil moisture, soil hardness, soil organic carbon (SOC), and soil total nitrogen (TN) among them in the four study areas with different climatic conditions, altitudes, and grassland types on the QTP. We also analyzed the relationship between the amount of soil surface gravel and the Green Fractional Vegetation Cover (GFVC) using aerial photos. The results showed that (1) gravel content was significantly greater in bald patches and pika piles than in vegetation patches ($p < 0.05$); (2) soil moisture, hardness, SOC and TN were the highest in vegetation patches, and significantly lower in pika piles than in vegetation patches ($p < 0.05$); (3) GFVC was negatively and linearly correlated with the amount of soil surface gravel, with the amount of soil surface gravel in non-vegetation patches significantly greater than in vegetation patches ($p < 0.001$). Our results suggested that pika burrowing activity may increase the gravel content of the top layer of soil and decrease soil moisture, hardness, SOC and TN, which can increase soil erosion and hinder vegetation restoration.

1. Introduction

Grassland is a major part of the global terrestrial ecosystem that accounts for nearly 40% of the earth's terrestrial area (excluding areas of permanent ice cover) and plays a key role in regulating climate change by balancing greenhouse gases (Scurlock and Hall, 1998; Loveland et al., 2000; Wang and Fang, 2009). Grassland also makes a significant contribution to food security by providing the feed requirements of ruminants used for meat and milk production (O'Mara, 2012; Gang et al., 2014). Therefore, the healthy development of grassland is of great significance to both food security and climate change.

Alpine grassland is one of the most important grassland types, and >48% of alpine grassland is distributed on the Qinghai-Tibetan Plateau (QTP) (Lin et al., 2015). Over the past few decades, alpine grasslands have been extensively degraded, leading to a decline in water retention capability, biodiversity, carbon sequestration, grassland production, soil nutrients, and opportunities for recreation (Dong et al., 2010a; Harris, 2010; Li et al., 2013a; Parras-Alcántara et al., 2015; Lü et al., 2016; Zhang et al., 2016). Along with other factors (permafrost degradation, rodent damage, grassland fire, etc.), climate change and overgrazing are believed to be the major causes of this degradation (Cheng and Wu, 2007; Wang et al., 2007; Zhang et al., 2014; Pereira et al., 2016). Although significant efforts have been made to restore alpine grassland in Qinghai Province of China by fencing and reseeding (Dong et al., 2010a; Dong et al., 2014), only a few studies have reported positive effects from restoration (e.g. Wu et al., 2010a, 2010b; Feng et al., 2010). For example, some artificial grasslands once again began to deteriorate after 7–8 years of restoration (Shang et al., 2008; Dong et al., 2014), and fencing only had a significant effect on the non-degraded and moderately degraded grassland (Li et al., 2013b). The reason for the poor recovery of alpine grassland may be attributed to different underlying soil textures of the QTP: the alpine grassland soil is very thin and contains substantial gravel in most areas. Further, few studies have only focused on these characteristics, leading to an insufficient understanding of alpine grassland degradation. It is, therefore, critical to determine the reason

* Corresponding author at: State Key Laboratory of Cryospheric Sciences, Northwest Institute of Eco-Environment and Resources, Chinese Academy of Sciences, 320 Donggang West Road, Lanzhou 730000, China.
E-mail address: yis@lzb.ac.cn (S. Yi).

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for the failure of restoration attempts before taking further restoration measures.

Gravel, defined by the Food and Agriculture Organization of the U.N. (FAO) as particles with diameter between 2 and 76 mm (Miller and Guthrie, 1984), is common in soil profiles of alpine grassland on the QTP. Qin et al. (2015a) found that in a semi-arid basin on the northeast part of the QTP, alpine grassland soil with higher gravel content usually contains less soil water, organic carbon, and nitrogen, making it harder for vegetation to recover. However, gravel distributed under the soil layer is prevented from coming to the ground surface of the QTP by alpine meadows, which are rarely eroded by natural forces due to resistant hard sod, unless they suffer physical destruction by rodents and erosions (Li et al., 2013a). A recent study hypothesized that the alpine grassland root layer is hard, plateau pika piles are loose, dry, and susceptible to wind and water erosion, and bald patches (with little vegetation) contain large amounts of gravel (Dong et al., 2010b). To our knowledge, there is no direct field data to test the hypothesis to date.

Plateau pika (*Ochotona curzoniae*), a small lagomorph, is widely distributed in alpine grassland of the QTP. Burrowing activity of a plateau pika usually creates a patchy alpine matrix. On the QTP, alpine grassland contains various sizes and types of patches, such as spoil mounds displaced by burrowing of plateau pika, bald patches, and vegetation patches (Qin et al., 2015b; Wei et al., 2007). In fact, the patches are found in many ecosystems and are usually controlled by erosion processes and plant growth (Cerdà, 1997; Bochet, 2015; Certini et al., 2015). Yet, few studies have investigated the effects of plateau pika disturbance on gravel and the distribution of alpine grassland patches on the QTP. Therefore, we hypothesize that changes in soil properties following disturbances (caused by plateau pika) play an important role in gravel and patchy distribution and further influence vegetation growth.

Since no long-term observation of changes in soil properties is available, to test our hypothesis, we classified patchy alpine grassland into four types: vegetation patches (VP, undisturbed vegetated areas), new pika piles (NP, areas of newly excavated soil on a pika pile), old pika piles (OP, no new excavated soil on the pika pile), and bald patches (BP, areas with little vegetation). Each type represents the different stages of ecological succession under the burrowing activity of plateau pika and erosion. In this work, we aimed to: 1) investigate whether soil properties and gravel content of soil were affected by plateau pika disturbance; and 2) explore the potential impact of changes in soil properties on soil erosion and vegetation growth.

2. Materials and methods

2.1. Study area and fieldwork

In this study, ecological sampling was conducted in the central and northeastern parts of the QTP (Fig. 1). In order to study the universality and spatial difference of the effects of plateau pika and erosion on soil properties, four study areas with different climatic conditions, altitudes, and grassland types were chosen: Upstream of the Yellow River Source (UYS), Downstream of the Yellow River Source (DYS), Source Region of the Shule River (SSL) and the Qinghai-Tibet Line (QTL) (Table 1).

In the summer of 2014, we selected 37 alpine grassland sites in the study area (Fig. 1 and Table 1) that are mostly relatively flat grassland (slopes of <4°). The site selection was based on the following three aspects: 1) the discrete degree of the selected sites was proportional to the basin area and inversely proportional to the underlying surface heterogeneity; 2) the selected sites covered all grassland types as much as possible; and 3) the selected sites could be reached by vehicles.

On each site, we classified the grassland surface into 4 types (Figs. 2 and 3): vegetation patch, new pika pile, old pika pile, and bald patch. We judged new and old pika piles based on three aspects: 1) whether spoil mound has new excavated soil; 2) whether spoil mound is higher than the surrounding ground; and 3) whether spoil mound has vegetation. If a spoil mound is higher than the surrounding ground, has new excavated soil but no vegetation, then we classify it as a new pika pile, otherwise old pika pile. We then established 12 sampling quadrats (0.5 m by 0.5 m) with 3 replicates for each grassland surface type. Due to a thicker soil layer, better hydrothermal conditions, and lower altitude (these factors were conducive to vegetation restoration) at DYS compared to the other regions, there were no bald patches for most areas of the DYS, but the new and old pika piles were widespread. Therefore, there were only 9 quadrats for each site at DYS. In terms of setting the sampling quadrats, we first determined the type of each patch and then randomly selected three patches for each patch type. The quadrats were mainly used to confine the range of sampling, especially the vegetation patches and bald patches where the quadrat environment was similar to the surrounding environment. In the vegetation and bald patches, the sampling locations were randomly distributed over the whole quadrat. In the new and old pika piles, the sampling locations were randomly distributed on the new and old piles.

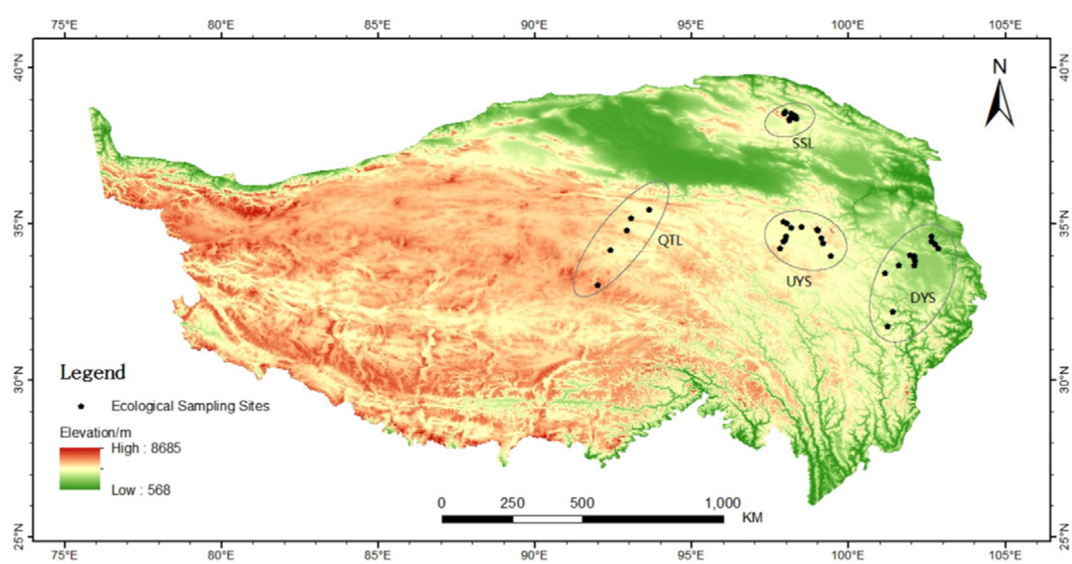

Fig. 1. Spatial distribution of ecological sampling sites on the Qinghai-Tibetan Plateau (UYS: Upstream of the Yellow River Source; DYS: Downstream of the Yellow River Source; SSL: Source Region of the Shule River; QTL: the Qinghai-Tibet Line).