

Changes in Soil Properties along Grazing Gradients in the Mountain and Forest Steppe, Steppe and Desert Steppe Zones of Mongolia

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ABSTRACT

Recent debates about the condition of Mongolia's rangelands and possible causes of rangeland change highlight the need for greater understanding of changes in grassland soil fertility and physical characteristics associated with grazing. As part of a large observational study of grazing effects on different Mongolian ecological zones and soil types (ecological sites), we studied soil characteristics along grazing gradients from winter shelters in the mountain and forest steppe, steppe and desert steppe ecozones of Mongolia. Our objective was to determine how grazing affects soil properties in winter pastures in different ecological zones and ecological sites within zones, based on grazing gradients. Our findings did not support our hypothesis that livestock grazing along a grazing gradient from winter shelters would lead to increased concentrations of nutrients (C, NO₃⁻, P, K and humus) near the shelters. Instead, where soil chemical properties differed with distance, they were lowest close to winter shelters and higher with increasing distance. As hypothesized, we observed greater bulk densities nearer to winter shelters than farther away. Our hypothesis that grazing effects on soil properties would vary among ecological sites also was not supported. Further experimental and observational studies are needed to understand grazing effects on soil properties at different spatial scales and to examine feedbacks between livestock-induced changes in plant communities and soil quality.

Keywords: Mongolia, soil, nutrients, rangelands, degradation

INTRODUCTION

Mongolian rangelands cover over 75% of the country's territory, are an important part of Mongolia's ecology, culture and economy (Fernandez-Gimenez and Allen-Diaz, 1999; Gunin et al., 1999; Hilbig, 1995), and among the most intact temperate grasslands

globally (Khishigbayar et al., 2015). Recent debates about the condition of Mongolia's rangelands and possible causes of rangeland change (Addison et al., 2012) highlight the need for greater understanding of changes in grassland soil fertility and physical characteristics associated with grazing. Milton et al., (1994) and Whisenant (1999) defined degradation as a continuum of conditions from reversible to irreversible changes in both biotic and abiotic indicators. Irreversible degradation in rangelands is associated with soil loss or changes in soil nutrients (Whisenant, 1999). Given mounting concern about the condition of Mongolian rangelands (Lui et al. 2013; Hilker et al., 2014), and the potential importance of soil quality as a criterion for determining the health of rangelands (NRC, 1994), it is important to understand the effects of livestock grazing on major soil chemical and physical attributes of Mongolian rangelands.

Large mammal grazers can affect soil characteristics directly and indirectly through interactions of trampling, herbivory and excretion in Mongolian rangelands (Augustine and Frank, 2001). Several past studies in Mongolia, Inner Mongolia and the Tibetan Plateau have investigated the effects of livestock grazing on soil physical and chemical properties using space-for-treatment designs based on grazing gradients (Fernandez-Gimenez and Allen-Diaz, 2001; Stumpp et al., 2005), inside and outside of grazing exclosure comparisons (Hirobe et al. 2013), experimental manipulation of grazing intensity (Deng et al., 2014; Xu et al., 2014; Lui et al., 2014; Sun et al., 2014), or experimental removal of grazing to observe whether soil properties respond to grazing removal (Pei et al., 2007; Steffens et al., 2008; Sarula et al., 2014). Results of past observational and experimental studies led to different conclusions about the effects of livestock grazing on soil chemical and physical properties. Two observational studies in Mongolian rangelands along grazing gradients from water points found that carbon (C), nitrogen (N), and phosphorous (P) increased with greater relative grazing pressure and livestock densities near water points and decreased with increasing distance from water (Fernandez-Gimenez and Allen-Diaz, 2001; Stumpp et al., 2005). In contrast, exclosure and experimental studies of the effects of grazing on soils found declines in soil organic matter (SOM), soil organic C, and total soil N with increasing grazing intensity, with the highest levels of SOM, C, N, mineralization and nitrification in ungrazed exclosures (Pei et al., 2007; Steffens et al., 2008; Deng et al., 2014; Sarula et al., 2014; Xu et al., 2014; Wang and Batkhishig, 2014; Lui et al., 2014; Sun et al., 2014; and Hirobe et al. 2013).

As part of a large observational study of grazing effects on different Mongolian ecological zones and soil types (ecological sites), we studied soil characteristics along grazing gradients from winter shelters in the mountain and forest steppe, steppe and desert steppe ecozones of Mongolia. Our objective was to determine how grazing affects soil properties in winter pastures in different ecological zones and ecological sites within zones, based on grazing gradients.

Based on findings from previous observational studies we, hypothesized that soil total C, soil nitrate (NO₃-), SOM (humus), and P and potassium (K) would be higher in heavily grazed sites due to nutrient redistribution through livestock trampling, herbivory and excretion (Fernandez-Gimenez and Allen-Diaz, 1999; Augustine and Frank, 2001; Stumpp et al., 2005). We hypothesized that soil bulk density would be highest close to winter camps due to higher livestock densities and trampling (Avaadorj and Baasandorj, 2006), and that bulk density would decline with distance from the camp. Finally, we expected that the relationship between grazing intensity and soil properties would vary on ecological sites (different soil types) within a given ecological zone.

STUDY SITE

We sampled soils in three mountain and forest steppe *soums* (Bayangol and Saikhan *soums* in Selenge *Aimag*; Erdenetsogt *soum* in Bayankhongor *Aimag*), four steppe *soums* (Bayan, Bayantsagaan, Erdenesant, and Undurshireet *soums* in Tuv *Aimag*), and four desert steppe *soums* (Bayantsagaan, Bayangobi, Bayan Undur and Jinst *soums* in Bayankhongor *Aimag*).

STUDY METHODS

In each study area, we sampled soils in winter pasture areas along grazing gradients with plots located at 100m, 500m and 1000m from winter camps in each zone. We sampled 13 gradients (39 plots) in the mountain and forest steppe, 18 gradients (54 plots) in the steppe, and 17 gradients (51 plots) in the desert steppe. Soils were collected from 0-20 cm in depth from one point at the center of each plot. A soil pit was dug and full soil description was made at this point, with one soil sample collected for laboratory analysis from each pit.

Laboratory analyses of soil chemical and physical characteristics was carried out at the Soil Ecological Laboratory of the Geo-ecology Institute of the Mongolian Academy of Sciences, Ulaanbaatar according to the Mongolian Standard Soil Testing Procedures. Soil pH was determined using Thermo Orion 370 pH meter (Thermo Fisher Scientific Inc., 2008). Soil organic matter and total carbon were determined using Tyurin's method (Bel'chicova, 1965). Soil nitrate amount was determined using the Kjeldahl method (Bremner and Mulvaney, 1982). Mobile P and K were determined using Machigin's method (Machigin, 1952; Kheifet, 1965). Soil bulk density was determined by weight and volumetric analyses (Baatar et al., 1994).

Data were inspected for normality and tested for homogeneity of variances using Mauchly's test of sphericity. Initially we used multivariate analyses with distance and ecological sites as fixed factors and looked at their interaction terms to test our 3-rd hypothesis. Interaction terms were not significant in all three ecological zones, therefore we combined data over all ecological sites within each ecozone and examined the distance effect for each variable. We used ANOVA to assess changes in soil characteristics with distance from winter camp in each ecological zone. Humus, C, NO_3^- , P, K, bulk density (BD), and pH were dependent variables, distance (3 different distances from winter camp: 100m, 500m, 1000m) was considered a fixed factor, winter camp was considered a random factor, and we used a type III model. We used Bonferroni's multiple-comparison correction to determine which pairs of distances differed. Statistical tests were performed using SPSS statistics 22 (IBM Corp, 2013) and were considered significant at $p < 0.05$.

RESULTS

In the mountain and forest steppe, humus, C, and NO_3^- were all significantly less at 100m than at the 500m and 1000m distances (Figure 1a and 1b). There was no significant difference between 500m and 1000m distances. P and K had similar patterns but were not significant except K at 100m was significantly less than 1000m. Bulk density was highest at the 100m distance and was significantly greater than BD at 500m and 1000m distances (Figure 1a). Soil pH did not differ significantly over the gradient (Figure 1b).

In the steppe zone, humus, C, and P were all significantly less at 100m than at the 500m and 1000m distances (Figure 2a) but there was no significant difference between 500m and 1000m. NO_3^- was significantly different from each other at all distances: lowest closer to the winter camps. K had similar pattern but 100m and 500m both were significantly lower than 1000m (Figure 2b). BD (500m and 1000m was not significant) and pH both significantly decreased with increasing distance from the winter shelters (Figure 2a and 2b). The same pattern was observed in the desert steppe, where humus and total C both increased significantly with each distance from the winter shelter (Figure 3).

DISCUSSION

Our findings did not support our hypothesis that livestock grazing along a grazing gradient from winter shelters would lead to increased concentrations of nutrients (C, NO₃, P, K and humus) near the shelters. Instead, where soil chemical properties differed with distance, they were lowest close to winter shelters and higher with increasing distance. As hypothesized, we observed greater bulk densities nearer to winter shelters than farther away. Our hypothesis that the relationship between grazing effect and soil properties would vary on ecological sites (different soil types) within a given ecological zone was not supported.

Our results contrast with past observational studies of soils along grazing gradients in Mongolia, but align with experimental and enclosure studies that show declining soil quality with increasing grazing intensity. Further experimental and observational studies are needed to determine the effects of grazing on soil characteristics at different spatial scales, and to identify meaningful and efficient indicators of rangeland change and degradation based on soil characteristics. In particular, feedbacks between soils quality changes and changes in vegetation must be further explored in order to understand how grazing- and trampling-induced changes in plant community composition may influence soil quality, and how livestock-induced changes in soil physical and chemical properties influence plant communities.

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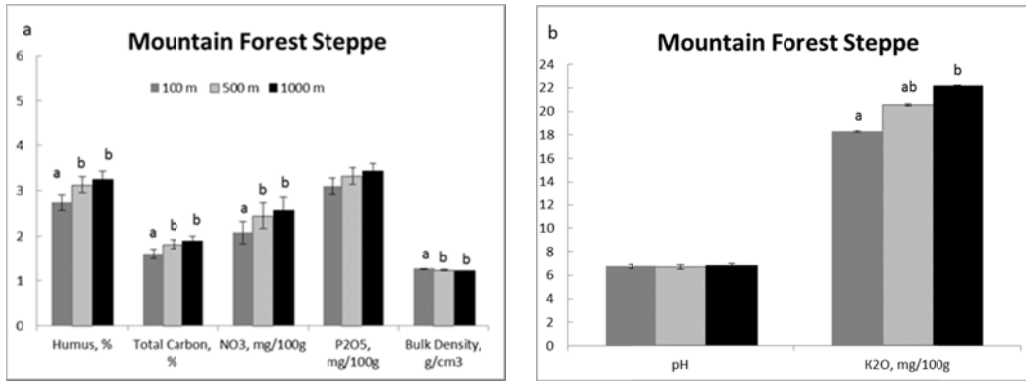


Figure 1. Mountain Forest Steppe soil characteristics: a) humus, C, NO₃⁻, P, BD and b) pH and K.

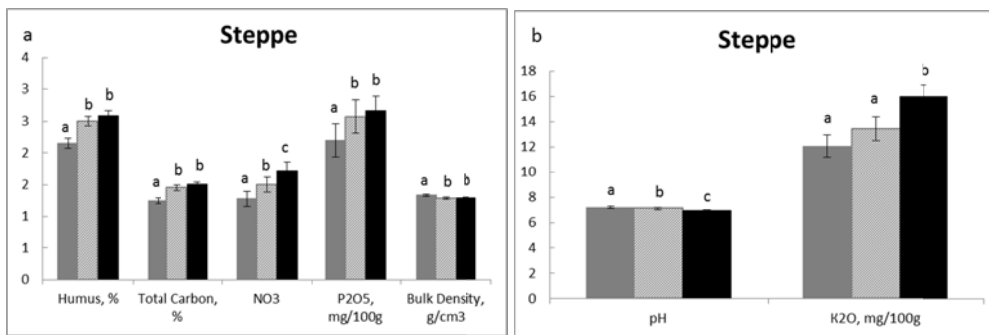


Figure 2. Steppe soil characteristics: a) humus, C, NO₃⁻, P, BD and b) pH and K.

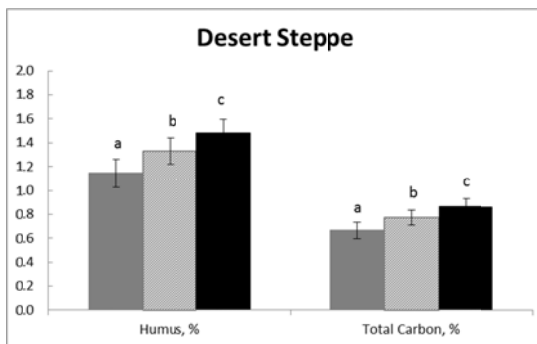


Figure 3. Desert Steppe soil characteristics: humus and total carbon.