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Effects of crop abandonment and grazing exclusion on available soil water and other soil properties in a semi-arid Mongolian grassland

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ABSTRACT

Improper cropping and overgrazing have led to land degradation in semi-arid regions, resulting in desertification. During desertification, vegetation changes have been widely observed, and are likely controlled to some extent by soil water. The purpose of this study was to investigate changes in soil physical properties, organic C, and vegetation induced by land-use changes, with special reference to the dynamics of available soil water. We selected four study sites in a typical Mongolian steppe grassland: grassland protected from grazing, grazed grassland, abandoned cropland, and cultivated cropland. Grazing exclusion increased the cover of perennial grass, with little increase in the root weight. Since there was no difference in available water between the grasslands with and without grazing, there appears to be no serious soil compaction due to overgrazing. On the other hand, vegetation cover and the number of species were poor in both abandoned cropland and cultivated cropland. However, the root weight was greater in abandoned cropland. Although the abandonment of cultivation appeared to increase organic C, available water did not differ significantly in comparison with cultivated cropland. The silt contents were significantly lower in abandoned and cultivated cropland than in both grasslands, suggesting the effects of wind erosion. In addition, the silt contents were positively correlated with the volume fraction of storage pores for available water. Therefore, the lower silt contents may constrain the volume of available water in abandoned cropland. Moreover, the unsaturated hydraulic conductivity results indicated that the diameters of storage pores for available water at the present study sites were smaller than those suggested by previous studies. Although the differences in vegetation cover by different land-use types were observed at every site, differences in the volume of available water were observed at between abandoned cropland and cultivated cropland. The reason why the no differences in available water between grazed grassland and grasslands protected from grazing may be short time of grazing exclusion for 2 years for evaluating the effects of exclusion on soil properties.

1. Introduction

Improper cropping and overgrazing are the main factors responsible for soil degradation in semi-arid regions. Overgrazing alters the floristic composition from perennial grasses to annual forbs and from species that are palatable to livestock to non-palatable species (McIntyre and Lavorel, 2001; Pakeman, 2004; Diaz et al., 2007). These changes have also been reported in Mongolia (Fernandez-Gimenez and Allen-Diaz, 1999, 2001; Sasaki et al., 2005, 2007). In addition, improper cropping and subsequent abandonment can decrease the species richness and the cover of perennial grasses (Zhao et al., 2005). Subsequently, it takes a long time to restore the vegetation in abandoned cropland (Dean and Milton, 1995; Cody, 2000; Kosmas et al., 2000; Zhao et al., 2005).

In semi-arid regions, maintaining a high vegetation cover is essential for soil conservation, and vegetation cover is strongly controlled by the soil water regime in semi-arid regions such as Mongolia (Miyazaki et al., 2001). Therefore, the unsaturated hydraulic properties of soils may play important roles in semi-arid regions. Nevertheless, there have been insufficient investigations of the effect of land-use types on unsaturated hydraulic properties, including the effects of grazing exclusion versus overgrazing (Proffitt et al., 1995; Greenwood et al., 1998; Zhao et al., 2007) and

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continuing cultivation versus the abandonment of cultivation (Ahuja et al., 1998; Or et al., 2000; Schwartz et al., 2003). These studies cited above mainly focused on the range of near-saturated hydraulic conductivity, which depends on the sizes and volume fractions of macropores, and have not sufficiently considered the availability of water for plants. In general, plant-available water is held in pores ranging from 0.2 to 30 μm (Kay and VandenBygaart, 2002), 0.5 to 50 μm (Greenland, 1977), or 0.2 to 60 μm (Hermawan and Cameron, 1993). Only a few studies have examined the relationship between the soil pores that hold available water and land-use changes (Greenland, 1977; Hermawan and Cameron, 1993; Pagliai et al., 1995, 2004; VandenBygaart et al., 1999; Kay and VandenBygaart, 2002). However, it is not yet fully understood which pore size classes are most responsible for the availability of water to plants after grazing exclusion and the abandonment of cultivation in semi-arid grasslands.

A positive correlation between soil organic C and available water has been well documented (Hudson, 1994; Emerson, 1995), as has the negative correlation between bulk density and available water in compacted soils (Archer and Smith, 1972; Zhao et al., 2007). These relationships also exist for croplands under continuous tillage (Bowman et al., 1990; Zhao et al., 2005) and for some continuously grazed grasslands (Zhao et al., 2007) in semi-arid regions. For example, declines in organic C and available water are associated with increasing bulk density. Although the effects of land-use changes, such as grazing exclusion and the abandonment of cultivation, on soil organic C and physical properties are significant during the early stages of the change (Zhao et al., 2005), limited quantitative research has been carried out (Martinez-Fernandez et al., 1995; Greenwood et al., 1998; Li and Shao, 2006), and the results of these studies are not always consistent. The purpose of the present study was to investigate the differences in soil physical properties, organic C, and vegetation that result from land-use changes, with special reference to the dynamics of available soil water. Understanding these aspects is important to identify the factors that control the recovery process of vegetation in overgrazed grasslands and abandoned croplands.

2. Materials and methods

2.1. Site description

To investigate the effects of changes in land use from grazing to grazing exclusion and from cultivation to the abandonment of cultivation, we selected a typical area in which all four land uses were occurred. The study sites were located in the Kherlen Bayan-Ulaan (KBU) of Mongolia, where the meteorological and topographical conditions and the parent materials of the soils were similar among sites.

KBU (47°12′50.3″N, 108°44′14.4″E) is located in the middle reaches of the Kherlen River and has a steppe climate. Based on meteorological data provided by Mongolia's Institute of Meteorology and Hydrology, Ministry of Nature and Environment, mean annual precipitation is about 180 mm (the average from 1993 to 2003), and most of the annual precipitation falls in summer, from May to July. The summer rain is critical for the growth of grasses. Annual potential evaporation is 508 mm (Asano et al., 2007), therefore, KBU is classified as a semi-arid region (index is 0.35). The mean annual temperature is 2.5 °C (the average from 1993 to 2003), with a maximum temperature of about 30 °C in July and a minimum of about −30 °C in January. The dominant grass species are *Stipa krylovii*, *Carex duriuscula*, and *Cleistogenes squarrosa*. The dominant soils are Haplic Kastanozems (FAO/ISRIC/ISSS, 1998) based on the soil profile and the physical and chemical properties of the soils. The soil parent materials are loess deposits. In KBU, the number of grazing livestock (sheep, goat, cattle and house) decrease to a minimum of about 25,500 during the spring, summer and autumn, and increases to a peak of about 115,700 in winter. Since the KBU grassland is used as an overwintering place for local herders, it is under the overgrazing condition in winter time (Onda et al., 2007).

We selected four study sites: Grassland that had been protected from grazing (grazing exclusion, EG) since July 2002 as part of the Rangelands Atmosphere-Hydrosphere-Biosphere Interaction Study Experiment in Northeastern Asia (RAISE). The size of the protected area was 170 m × 200 m. The EG study site was situated within this exclosure, but more than 10 m from the fence used to exclude livestock. Grazed grasslands (GG) had been actively grazed for at least a few hundreds years. The GG study site was located more than 10 m from the fence used to protect the EG sites from grazing. The abandoned cropland (AC) had been cultivated from 1962 until 1991. Wheat and maize had been cultivated using synthetic fertilizer and irrigation from 1972 to 1991. The dominant plant species after 10 years of lying fallow (see Section 2.3 for details) differed from those in the surrounding grasslands. This site was located 50 m from the final site type, the cultivated cropland (CC). The CC site has been managed by Buyant Bulag Co., Ltd. since 1992. Before 1992, the land use was similar to that at the AC site. Since 1992, wheat was sown once per year in the summer, without irrigation or fertilizer. The CC site was 50 m from the AC site. The CC sites was protected from grazing, and the AC site was not.

2.2. Soil and vegetation surveys

The soil and vegetation surveys were carried out in 2004 at each study site. Soil sampling was performed using 20 m × 20 m quadrats at each site. The quadrat was established at each site after using a soil auger to confirm that the soil profile was typical of the study area. Within each quadrat, we obtained 16 bulk soil samples (each 200 cm^3) at 4-m intervals to a depth of 5 cm for chemical analysis and to estimate the total root weight. We also collected 16 core samples (each 100 cm^3) to a depth of 5 cm to assess the soil physical properties adjacent to the locations of the bulk soil samples. Our previous research (data not shown) indicated that the majority (>44%) of the organic C was found with in this layer. Vegetation was sampled in five quadrats (each 1 m × 1 m), which was separated by a minimum distance of 8 m, at each site. In each quadrat, we recorded the cover (%) using the method of Penfound and Howard (1940) and the height (cm) of all plant species.

2.3. Vegetation data analysis

Species richness was determined using the numbers of plant species found in the five quadrats at each site. All plant species were classified by growth form and life history (perennial grass, perennial forbs, annual forbs and shrubs) and their palatability to livestock. These classifications were based on Jigjidsuren and Johnson (2003), Grubov (2001), and information provided by Mongolian botanists. We then calculated the extended summed dominance ratio (E-SDR$_2$; Yamamoto et al., 1995) as follows to permit a quantitative comparison of the study sites.

$$E\text{-SDR}_2 = \frac{100}{2}\left(\frac{\sum_{i=1}^{n} C_i}{\sum_{i=1}^{n} C_i^d} + \frac{\sum_{i=1}^{n} H_i}{\sum_{i=1}^{n} H_i^d}\right) \quad (1)$$

where C_i is coverage level for the plant, and H_i is the height of one for the plant in ith quadrat, n is the number of quadrat (in this study, 5), and superscript d indicates the values of the dominant species. Plant roots were collected by hand from the soil samples used for the soil chemical analysis. These roots were washed with water and oven-dried at 60 °C for 48 h then weighed.