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Field measurement of infiltration rate using an oscillating nozzle rainfall simulator in the cold, semiarid grassland of Mongolia

H. Kato [a,*], Y. Onda [a,1], Y. Tanaka [b], M. Asano [a]

[a] Graduate School of Life and Environmental Sciences, University of Tsukuba, 1-1-1 Tennodai, Tsukuba, Ibaraki 305-8572, Japan
[b] Department of Geography, Kyung Hee University, Seoul 130-701, Republic of Korea

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ABSTRACT

Recent intensive grazing in Mongolia may be significantly reducing the infiltration rate of rangeland. This study measured infiltration rates using simulated rainfall with high raindrop impact for small plots established on steppe grassland, desert grassland, and shrubland sites in Mongolia. The response of the infiltration rate to short-term livestock removal was also investigated. On the steppe grassland, a high infiltration rate was measured on an ungrazed plot with relatively dense vegetation cover; a statistically significant correlation was found between the total surface cover and final infiltration rate, indicating that surface cover by rock fragments also increased the infiltration rate to some extent. For desert grassland and shrubland, however, the surface cover condition was not a major factor controlling the final infiltration rate. After 4 years of livestock removal, the surface vegetation cover of the ungrazed plot was greater than that of the grazed plot, but no appreciable change occurred in soil penetration resistance. These results suggest that the high infiltration rate on the ungrazed plot was maintained mainly by the recovery of surface vegetation cover after the short-term livestock removal; this may indicate a potential mechanism of recovery from desertification processes for Mongolian rangeland.

1. Introduction

Mongolia is located in northeastern Asia, and approximately 75% of its total land area consists of cold, semiarid grassland that is subjected to grazing throughout the year (Begzsuren et al., 2004). Grazing, the cold climate, and the short growing period have led to sparse plant cover in the grasslands of Mongolia (Munkhtsetseg et al., 2007). Currently, Mongolian grasslands, particularly the desert grasslands of southern Mongolia (Bayasgolan and Dagvadorj, 2005), are considered to be in the process of desertification caused by overgrazing (Chuluun and Ojima, 2001). The rise in livestock numbers since Mongolia's development of a market-oriented economy may affect the growth, density, and distribution of grassland plants (Chen et al., 2006), which may in turn lead to a drastic increase in soil erosion (Onda et al., 2007). However, the process of desertification due to overgrazing in this region is not yet fully understood.

In arid and semiarid rangelands, the process of desertification due to overgrazing has been described in terms of changes in surface vegetation and reduction in the infiltration rate (Rietkerk et al., 2000). In general, the soil in a semiarid area has a low organic content and large percentage of silt portions, which results in high soil susceptibility to surface sealing and crusting (Abu-Awwad and Shatanawi, 1997; Mills and Fey, 2004). Thus, the loss of surface vegetation cover decreases the infiltration rate significantly because the direct kinetic energy impact of raindrops on a bare surface promotes the development of surface sealing and crusting (Evans, 1980). Thus, the recent overgrazing in Mongolia may be reducing the infiltration rate of the grassland.

On semiarid grasslands, the relationship between the surface vegetation cover and infiltration rate has been examined by means of field rainfall simulation experiments on the prairies of North America (Blackburn, 1975; Dadkhah and Gifford, 1980; Thurow et al., 1986; Gutierrez and Hernandez, 1996), Mediterranean ecosystems (Cerdà et al., 1998; Seeger, 2007), and rehabilitated grassy hillslopes in Australia (Loch, 2000a). The results of these rainfall simulation experiments have demonstrated positive relationships between surface vegetation cover and infiltration rate. However, on the grassland of Mongolia, although some runoff data were collected on a hillslope plot (Onda et al., 2007), very few data on the infiltration rate are currently available. Therefore, the role of surface vegetation cover in the infiltration rate in this region is not yet sufficiently understood.

Reduction of the infiltration rate increases overland flow generation and surface erosion, which results in the increase of sediment and nutrient loss (Schlesinger et al., 1999; Brazier et al., 2007) and a

* Corresponding author. Tel./fax: +81 29 853 7189.
E-mail addresses: hiroakis980@ybb.ne.jp (H. Kato), onda@geoenv.tsukuba.ac.jp (Y. Onda), ytanaka@khu.ac.kr (Y. Tanaka), asano@a5.keio.jp (M. Asano).
[1] Tel./fax: +81 29 853 7189.

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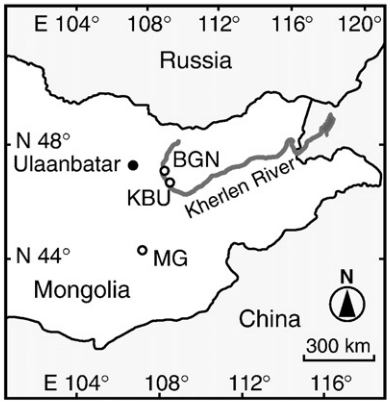

Fig. 1. Map of the study area.

decrease in plant available soil water (Rietkerk et al., 2000). Such changes have been considered primary causes of the change in dominant vegetation type from grassland to shrubland (Wainwright et al., 2000; Ritchie et al., 2003) as part of the so-called desertification process. On the semiarid grassland of the Jornada Long Term Experimental Range (LTER), southern New Mexico, where such a transition of surface vegetation has occurred over the last hundred years, the process is considered to be largely irreversible (Hennessy et al., 1983; Gibbens et al., 1992). It has been thought that the infiltration rate does not recover unless surface vegetation cover recovers; however, in San Simon Valley in southern Arizona, the infiltration rate of degraded grassland increased, primarily due to recovery from livestock-induced soil compaction after long-term livestock removal (Castellano and Valone, 2007). However, in this case, the infiltration rate was measured using a double-ring infiltrometer, which does not simulate the raindrop impacts of rainfall; thus the infiltration rate may not have sufficiently recovered because the surface vegetation cover had not recovered at that site. Investigating the response of the infiltration rate to livestock removal is essential to understanding potential mechanisms of recovery from desertification on degraded rangelands; however, such investigation has been hampered by the lack of infiltration-rate field data.

To address this problem, we carried out a series of field infiltration tests for various surface cover conditions using a modified rainfall simulator and small plots (1 m^2). In addition, we conducted a comparative analysis of infiltration rates between a site with short-term livestock exclusion and a site with year-round open range grazing. The objectives of this study were to elucidate the fundamental relationships between surface vegetation cover and infiltration rate on steppe, desert grassland, and shrubland and to determine the effect of short-term livestock exclusion on the recovery of the infiltration rate for steppe grassland.

2. Study sites

The sites selected for this study were located in steppe and desert steppe regions of Mongolia (Fig. 1). One study area was in Khentii Province, 100 km east of Ulaanbaatar, and featured steppe grassland with tall-grass prairie. The other was in Mandalgobi in Dundgobi Province, 250 km south of Ulaanbaatar, and was covered by desert grassland with short grasses and shrubs. Both study areas have been subjected to grazing by domestic livestock under nomadic and seminomadic patterns of land use. Sheep, goats, cattle, and horses are typical livestock in these areas.

In Khentii Province, the experimental sites were selected in two regions having different grazing conditions (according to data provided by the Statistical Office of Mongolia): Kherlen-bayan Ulaan (KBU; 47°13′N, 108°44′E) and Baganuur (BGN; 47°40′N, 108°29′E). These areas have a cold, semiarid climate with an annual mean temperature of 2 °C (data provided by the Institute of Meteorology and Hydrology, Ministry of Nature and Environment, Mongolia). Average annual precipitation over the 11 years from 1993 to 2003 was 181 mm for the KBU region and 213 mm for the BGN region (Sugita et al., 2007). Most (>80%) of the annual precipitation occurs during the warm rainy season between June and September, and the hilly land is used for pastures. Sandstone and granite underlie the KBU and BGN sites,

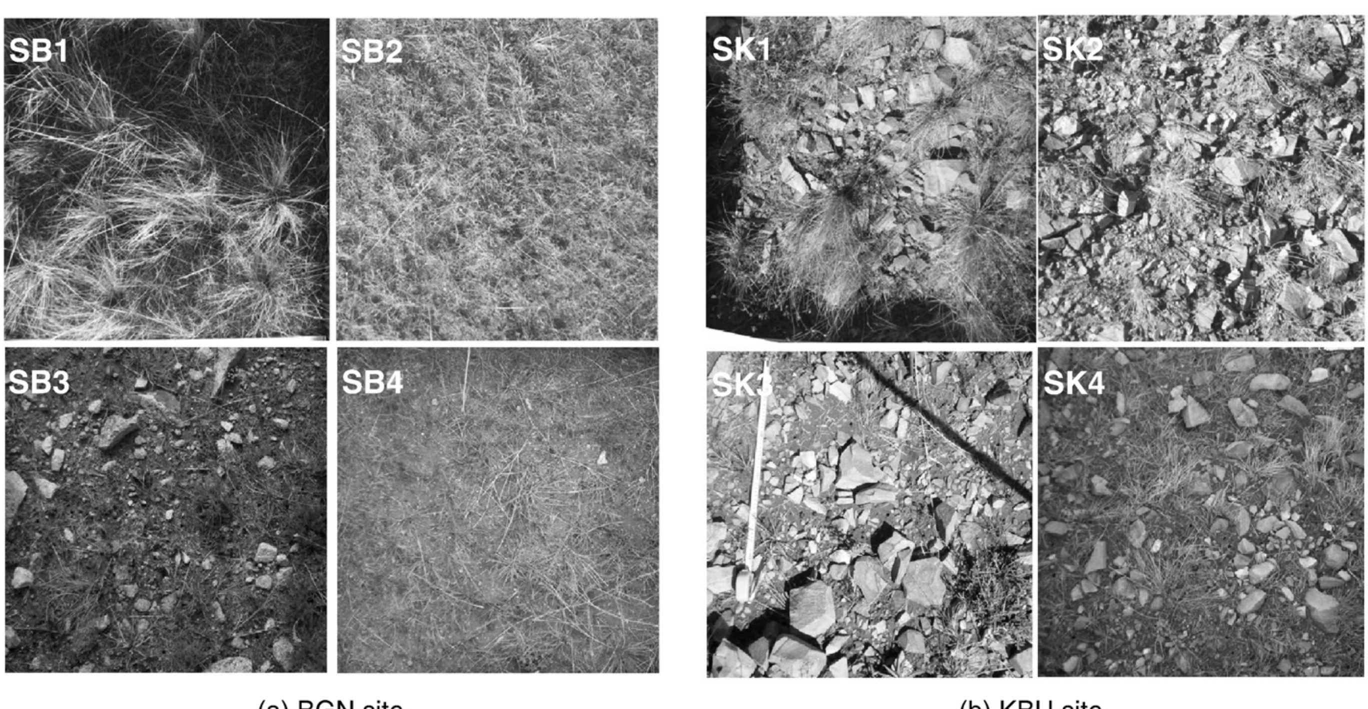

Fig. 2. Surface conditions of the experimental plots in the steppe grassland.