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Analysis

Wind tunnel simulation and evaluation of soil conservation function of alpine grassland in Qinghai–Tibet Plateau

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ABSTRACT

Aiming at studying soil conservation function of alpine grassland in the Qinghai–Tibet Plateau, this paper simulated soil erosion changes under different degrees of human disturbance in a wind tunnel laboratory. Three types of grasslands were selected, which include alpine meadow (QH-1), alpine steppe meadow (QH-2) and alpine steppe (QH-3), and the soil erosion rate was taken as the index to measure soil conservation function. The experimental results show that the soil erosion rates of three grassland samples increase with wind velocity under different treatments but the increment of erosion rate varied greatly. Under original status, soil erosion rates are in turn QH-1<QH-2<QH-3, which indicates that the soil conservation services are QH-1>QH-2>QH-3. When the aboveground vegetation was cut, the soil erosion rate change of QH-1 is the same as that of QH-3 and compared with the original status both of them changed a little. And when the root system was destroyed the erosion rates range in turn as QH-1<QH-2<QH-3. So the data suggest that soil conservation service for the three types of grasslands should be QH-1>QH-2>QH-3. The economic values of soil conservation were estimated, which include the values of organic carbon fixation, nutrient retention and reducing soil disuse.

1. Introduction

The ecosystem services in grasslands have aroused great interest in people as grassland ecosystem degradation becomes more and more serious, and have been evaluated qualitatively and quantitatively by researchers in the recent years. Sala and Paruelo (1997) studied the ecosystem services of grasslands, such as maintaining atmosphere components, serving as gene bank, improving microclimate and conserving soil, and they also evaluated the economic values of some services. Costanza et al. (1997) calculated the mean annual value per unit area for each type of grassland ecosystem service, including air regulation, water regulation, erosion control, sediment reduction, soil formation, and so on, at a global scale. For evaluating the ecosystem services of grasslands, Xie et al. (2001), using biomass index, corrected the mean values of grassland ecosystem services provided by Costanza et al. Based on the correction and grassland ecosystem classification, it was calculated that the annual value of ecosystem services in natural grasslands of China was U\$1491.9 $\times 10^9$. Using the same method, Xie et al. (2003) proposed that the annual value of ecosystem services in the natural grassland of the Qinghai–Tibet Plateau was 257.178 $\times 10^9$ yuan (RMB), of which alpine meadow contributed 65.52%. Zhao et al. (2004) also evaluated six ecosystem services in grasslands of China, including erosion control, precipitation interception, carbon fixation, waste decomposition, nutrient cycle, and habitat.

Soil conservation is one of the important ecosystem services in grasslands. Pimentel et al. began to study the soil conservation function of ecosystem early in 1995 (Pimentel et al., 1995). Xiao et al. (2003) estimated the potential and actual soil erosion quantities in the Qinghai–Tibet Plateau by GIS and Universal Soil Loss Equation (USLE), and they regarded the difference between the two quantities as the soil conservation quantity of the ecosystem in the plateau.

The accuracy of the evaluation results, mentioned above, based on either models or the Costanza method was lower due to great differences in ecosystem structure and functions of grasslands. At present, there are fewer studies on the ecosystem service of soil conservation in grasslands and their evaluation, especially on their experimental research.

The Qinghai–Tibetan Plateau (QTP), which extends over 2.5 million km^2, is the youngest and highest plateau in the world. The plateau ecosystem is very fragile and sensitive to global climate changes (Cao et al., 2004). The soil development history is quite young and formed a thin and skeletal soil layer because of the gravel parent materials of the glacofluvial deposit, eluvium and fluvial sediment and slow soil formation under cold climate. And thus the alpine grassland is an area that is extremely prone to desertification. In fact, parts of the QTP experiences increasingly severe land desertification resulting from a warm, dry climate and adverse human activities in this area (Dong et

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al., 1993; Li, 1988). Soil erosion by wind is the first and most important cause of sandy desertification (Dong et al., 1987).

Alpine grassland, with an area of 112.8×10^9 ha, is the largest distribution zone of natural alpine grassland in China. On one hand, the alpine grassland ecosystem is an important base for agricultural and livestock production. On the other hand, it is an ecological barrier that protects water sources and conserves soil because many big rivers, such as the Huanghe (Yellow) River, the Changjiang (Yangtze) River and the Lancang River originate from the plateau. Unfortunately, long-term overgrazing has resulted in considerable deterioration and soil erosion, land desertification and pest damage which become more serious day by day in the grasslands. Once the grassland soil was destroyed the grasslands could not only lose their productivity but also release soil carbon. Apparently, the soil conservation function of the alpine grassland is of great importance for protecting eco-environment in the QTP.

Aimed at studying the soil conservation function of different grassland types and their economic valuation, this research conducted a wind tunnel simulation experiment to (1) quantitatively evaluate the soil conservation service; (2) stimulate and analyze the effect of disturbance degree on soil conservation service through different treatments; (3) and evaluate the economic values of soil conservation. The soil erosion rate is an indicator measure of the function of soil conservation. In general the higher the soil erosion rate, the lower is the soil conservation function.

2. Experiment and Calculation Methods

2.1. Sampling

Experimental samples were collected from alpine meadow, alpine steppe meadow and alpine steppe in the Qinghai–Tibet Plateau. The natural conditions of the sampling sites are listed in Table 1. Both the alpine meadow soil and the alpine steppe meadow soil belong to the alpine meadow soil distributed in the regions with cold and moist climate. The castanozems developed under the warm and arid climate.

In order to preserve original vegetation status and soil structure, we firstly dug out soil and plants around the sampling point, then collected samples using a soil sample box. Three samples were collected in each sampling site, and the sample size was 45 cm×25 cm×11 cm.

2.2. Experiment

Soil erosion rates and organic matter contents were observed under different wind velocities and different disturbance degrees in a wind tunnel laboratory. Three replications were designed for each treatment.

Generally, sand-moving wind velocity is 5 m/s. However in the sampling sites, soil erosion quantity was little when wind velocity is 5 m/s due to high vegetation coverage. So we selected 8 m/s as the sand-moving wind velocity. And according to the meteorological records in the sampling sites, the maximum wind velocity was about 23 m/s. Therefore, the experimental wind velocities were 8, 10, 15, 20, and 23 m/s respectively.

Four treatments were designed for samples in the experiment as follows:

(1) Under different wind velocities, keeping the original status (OS) of grass vegetation;
(2) Under different wind velocities, cutting all ground vegetation (CGV);
(3) Under different wind velocities, breaking down all root systems (BRS);
(4) Under the same wind velocity, with different disturbance degrees (slight disturbance, medium disturbance, severe disturbance and complete destruction) for the three sites.

The disturbance treatment means cutting the ground vegetation as well as breaking down the root system. A sample was divided into similar grids. The disturbance degrees were determined by the proportion of disturbed treatment area to the total area of sampled grassland block: slight disturbance≤25%, medium disturbance 50%, severe disturbance 75% and complete destruction 100%.

The experiment was made in the wind tunnel laboratory of Lanzhou Cold and Arid Regions Environment and Engineering Institute, Chinese Academy of Sciences. The experimental section of the wind tunnel is 16.23 m long, with a cross-section of 0.6 m×1.0 m and a wind velocity of 0.5–40 m/s.

The soil sample was put in the leeward 12.6 m to the entrance of the wind tunnel. The surface of the sample was always level with the bottom of the wind tunnel. A pitometer was erected on the entrance of the wind tunnel to monitor wind velocity. After wind blowing, the moved soil was weighed with scales. In addition, the nutrient and organic matter contents of the surface soil before and after wind blowing were measured by a conventional method.

2.3. Calculation of Soil Conservation Quantity

For grassland ecosystem, the soil conservation rate is the difference of soil erosion rates between the ecosystem without grassland and the original grassland ecosystem, it can be expressed as:

$$S_C = S_r - S_g \tag{1}$$

where S_C is the soil conservation quantity per unit area (kg/(ha·min)); S_r is the soil erosion rate per unit area of disturbed grassland

Table 1
Natural conditions of the sampling sites.

Site	Location	Altitude (m)	Mean annual temperature (°C)	Mean annual precipitation (mm)	Vegetation types	Soil
QH-1 (Haibei)	37° 37′ N 101° 19′ E	3230	−1.7	580	Perennial *Kobresia humilis*-dominated meadow with a coverage of 75%–90%	Alpine meadow soil, soil layer 50–60 cm, 0–10 cm with dense root system, soil order and texture: topsoil, middle loam; subsoil, middle loam; sandy middle loam; bottom soil: heavy sandy middle loam.
QH-2 (Riyue Mountain)	36° 40′ N 100° 53′ E	3400	−1.5	500	*Kobresia bellardii*-dominated steppe meadow with a coverage 60%–70%	Alpine meadow soil, 0–10 cm with dense root system. Soil order and texture: topsoil, middle loam; subsoil, sandy middle loam,; bottom soil: heavy sandy middle loam.
GH-3 (Qinghai Lake)	36° 33′ N 100° 23′ E	3215	−1.0	450	*Achnatherum splendens*-dominated steppe with a coverage of 40%–60%	Castanozems, sandy loam, 0–10 cm with dense root system. Soil order and texture: topsoil, middle loam; subsoil, light sandy middle loam; bottom soil: middle sandy middle loam.