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Spatial distribution of the herbaceous layer and its relationship to soil physical–chemical properties in the southern margin of the Gurbantonggut Desert, northwestern China

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ABSTRACT

Herbaceous plants, particularly ephemerals, exhibit higher variability than any other plants in desert ecosystems. The spatial distribution of herbaceous plants is restricted by environmental factors and presents obvious regularity. To elucidate the restriction and distribution regularity of herbaceous plants, we investigated the characteristics of the herbaceous layer and the soil physical–chemical properties at the bottom, middle, and top of sand dunes in the southern margin of the Gurbantonggut Desert, northwestern China. Redundancy analysis (RDA) was performed to analyze the relationship between herbaceous layer characteristics and soil physical–chemical properties. Results showed that: (1) the distribution of the herbaceous layer at different positions on the sand dunes exhibited clear selectivity. Soil in the middle and lower parts of the sand dunes demonstrated higher water, organic carbon (SOC), total nitrogen (TN), and total phosphorus (TP) contents, as well as higher electrical conductivity (EC), than that at the top of the sand dunes. Accordingly, the herbaceous layer in the middle and lower parts of the sand dunes presented higher density, coverage, and above-ground biomass and contained fewer species than that at the top of the sand dunes. (2) RDA showed that TN and TP were the two key factors that significantly influenced herbaceous layer characteristics ($p < 0.01$) and explained 10.1% and 41.9% of the variance, respectively. SOC and EC also significantly influenced herbaceous layer characteristics ($p < 0.05$) but only explained 4.2% and 3.5% of the variance, respectively. Soil water (SW) and pH did not significant influence herbaceous layer characteristics ($p > 0.05$). Moreover, herbaceous layer coverage and above-ground biomass showed positive correlations with TP and TN, whereas species number was negatively correlated with soil physical–chemical properties. Our results suggested that the spatial distribution of the herbaceous layer was sensitive to changes in soil physical–chemical properties. In particular, TN and TP significantly influenced the coverage, species diversity, and above-ground biomass of the herbaceous layer.

1. Introduction

Spatial distribution of plants and its relationship to environmental factors is one of the main topics in ecological studies [1,2]. The herbaceous layer is an important component of the plant community, considering its role in net primary productivity, carbon dynamics, energy flow, and nutrient cycling in desert ecosystems [3,4]. Compared with other life forms, the occurrence of herbaceous plants (especially ephemerals) exhibit relatively higher variability in desert regions. Nonetheless, the spatial distribution of herbaceous plants remains restricted by environmental factors and demonstrates apparent regularity [5].

As hydrothermal conditions are vital for plant germination, growth, reproduction, life span, and distribution patterns in the desert region, most studies have focused on exploring the influence of hydrothermal conditions on desert vegetation. For instance, in the Gurbantonggut Desert, seed germination and seedling growth of ephemeral plants are strongly dependent on temperature and water conditions during spring [6]; moreover, early spring snowmelt water is the primary water source for seedling establishment of the ephemeral layer, whereas rainfall after the seedling stage often plays a vital role in primary productivity or growth [7]. Spatial distribution of plants is related to soil properties [8]. However, few studies have investigated the distribution characteristics of the herbaceous layer, the soil physical–chemical properties at the longitudinal dune scale and their relationships.

Herbaceous plants at the bottom of sand dunes exhibit higher coverage, density, and productivity than those at the top of sand dune [9,10].

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Accordingly, soil at the lower part of sand dune presents higher water content, salinity, organic matter, nitrogen, and phosphorus than that at the top of the sand dune [11,12]. Furthermore, whether or not a correlation exists between herbaceous layer distribution characteristics and soil physical–chemical properties at the longitudinal dune remains to be elucidated. As such, we investigated herbaceous layer characteristics and soil physical–chemical properties at the bottom, middle, and top of the sand dune in the southern margin of the Gurbantonggut Desert, northwestern China. The relationship between herbaceous layer characteristics and soil physical–chemical properties was also discussed using redundancy analysis (RDA).

2. Materials and methods

2.1. Study site

The study site is situated in the southern margin of the Gurbantonggut Desert, north-western China (44°12′–44°21′N, 87°50′–87°54′E), which is the second largest desert in China. Typically, this region has a continental arid temperate climate, with a dry, hot summer and a cold winter. The annual mean precipitation is between 70 and 150 mm, whereas the annual mean evaporation rate exceeds 2000 mm. Snow usually covers the land to a depth of 20 cm for about 3 to 5 months and melts quickly during late March [13]. The landform morphology has apparent differentiation from east to west and north to south. Most of the longitudinal dunes extend from north to south, with lengths of several to several dozen kilometers, and the landform morphology exhibits no apparent changes. By contrast, the landform morphology of the desert from east to west shows great variability and most of the sand dunes exhibit disordered patterns [8]. The stable and semi-stable sand dunes dominate the southern margin of the Gurbantonggut Desert. Stable aeolian sandy soil is distributed in the interdune lands and in the middle/lower slopes of the dunes. Semi-stable aeolian soil is found on the middle and upper/middle slope, where the sand dune surface is unstable, with flowing zones of 10 to 40 m [14]. The study site has abundant psammophyte and drought-tolerant plants, among which *Haloxylon ammodendron* and *H. persicum* are the dominant shrub species in the local plant community. *H. ammodendron* occupies interdunes and the flat slopes of the dunes, whereas *H. persicum* mainly occupies on the top of the dunes [15]. Annual and perennial herbaceous plants and sub-shrubs occupy the bottom layer of the local plant community.

2.2. Field methods

In early April 2014, three typical sand dunes with an approximately north to south direction were selected as study areas. Both sides of the sand dunes are asymmetrical, and the west slope is less steep than the east slope. Base on the landform and the plant distribution characteristics on the sand dunes, we arranged the sampling location at the bottom (A), middle (B), and top (C) of the east slope (Fig. 1). Each sampling location had forty-five 1 × 1 m quadrats for herbaceous layer investigation

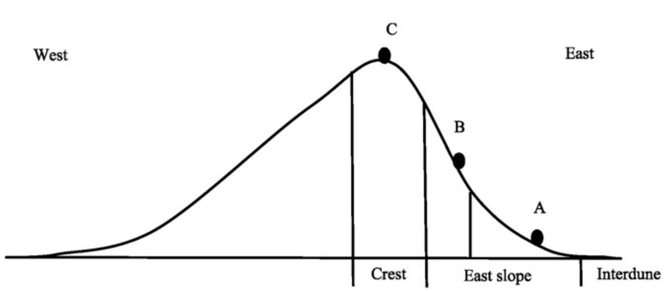

Fig. 1. Location of sampling points on the sand dunes in the Gurbantonggut Desert. A: bottom, B: middle, C: top of the sand dune.

and soil sampling during the periods of seedling (April 14), flowering (May 4), and fruiting (June 4). Species composition, richness and plant density, coverage, height, and above-ground biomass were investigated with 15 replicates at each site. Four cores (diameter = 5 cm) from 0 to 10 cm were collected within each 1 m × 1 m quadrat and were thoroughly mixed to form one composite sample to determine soil physical–chemical properties. Soil samples were transported to the laboratory on ice and then stored in aluminum boxes. The samples were oven dried at 105 °C for >12 h and used to calculate soil water content. In each quadrat, 15 to 30 individuals of each species were randomly selected for measuring height. The height of the herbaceous layer was calculated by averaging the height of each species. We also estimated herbaceous layer coverage by visual observation and used harvest method to measure above-ground biomass.

2.3. Soil chemical analysis

Soil samples were air-dried in a ventilated room and hand-sieved through a 2 mm mesh to remove roots and other debris before analysis. pH and electrical conductivity (EC) were measured using a potentiometer and the conductivity method, respectively (at a soil to water ratio of 1:5). Soil organic carbon (SOC) was measured using the $K_2Cr_2O_7$ method (Walkley–Black), and total nitrogen (TN) was determined using the Kjeldahl procedure with a UDK140 automatic steam distilling unit (Automatic Titroline 96, Schott, Germany). Total phosphorus (TP) was measured using the HCl–HF fusion-Mo Te Sc colorimetry method [16].

2.4. Data analysis

Differences in the herbaceous layer characteristics and soil physical–chemical properties were assessed among the three different sampling locations and across the three different growth periods by using one-way ANOVA. Significant differences in herbaceous layer characteristics and soil physical–chemical properties were tested using least-significant difference after verifying homoscedasticity (Levene test, $p < 0.05$) assumptions, or Tamhane's T2 when the variance was not homoscedasticity [17]. All statistical analyses were conducted in SPSS ver. 18 (SPSS, Chicago, IL).

RDA was performed using CANOCO software (version 4.5, Microcomputer Power, Inc., Ithaca, NY) to assess the effect of soil physical–chemical properties on herbaceous layer characteristics. Prior to the RDA analysis, a detrended correspondence analysis of herbaceous layer characteristics was performed to confirm that the linear ordination method was appropriate for analysis (gradient lengths <3). The forward-selection procedure was implemented in RDA to determine significance of environmental variables (soil physical–chemical properties) ($p < 0.05$) by using a Monte Carlo test with 999 permutations.

3. Results and analysis

3.1. Species composition and distribution of herbaceous layer

In the study area, 34 species of herbaceous plants, which belong to 13 families, were identified and counted (Table 1). These plants consisted of 24 species of ephemerals, 5 species of ephemeroids, and 5 species of annual herbaceous plants and accounted for 70.6%, 14.7%, and 14.7% of the total species, respectively. A total of 22, 17, and 19 species of herbaceous plants were recorded at the bottom, middle, and top of the sand dune, respectively. Six species (i.e., *Lactuca undulate*, *Koelpinia linearis*, *Hyalea pulchella*, *Erodium oxyrrhynchum*, *Nepeta micrantha*, and *Euphorbia turczaninowii*) were found in all sampling locations. Five species (i.e., *Alyssum minus*, *Isatis violascens*, *Salsola nitraria*, *Gagea nigra*, and *Silene nana*) occurred only at the bottom of the sand dune, and ten species (i.e., *Erysimum cheiranthoides*, *Echinops gmelinii*, *Epilasia acrolasia*, *Scorzonera pusilla*, *Corispermum lehmannianum*,