Aeolian Research 30 (2018) 48–53

Contents lists available at ScienceDirect

Aeolian Research

journal homepage: www.elsevier.com/locate/aeolia

Heterogeneity and loss of soil nutrient elements under aeolian processes in the Otindag Desert, China

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A R T I C L E I N F O

Keywords:
Aeolian processes
Nutrient element
Desertification
Otindag Desert

A B S T R A C T

The heterogeneity of the composition of surface soils that are affected by aeolian processes plays important roles in ecological evolution and the occurrence of aeolian desertification in fragile ecological zones, but the associated mechanisms are poorly understood. Using field investigation, wind tunnel experiments, and particle size and element analyses, we discuss the variation in the nutrient elements of surface soils that forms in the presence of aeolian processes of four vegetation species (*Caragana microphylla* Lam*, Artemisia frigida* Willd. Sp. Pl., *Leymus chinensis* (Trin.) Tzvel. and *Stipa grandis* P. Smirn) growing in the Otindag Desert, China. These four vegetation communities correspond to increasing degrees of degradation. A total of 40 macro elements, trace elements, and oxides were measured in the surface soil and in wind-transported samples. The results showed that under the different degradation stages, the compositions and concentrations of nutrients in surface soils differed for the four vegetation species. Aeolian processes may cause higher heterogeneity and higher loss of soil nutrient elements for the communities of *Artemisia frigida* Willd. Sp. Pl*., Leymus chinensis* (Trin.) Tzvel, and *Stipa grandis* P. Smirn than for the *Caragana microphylla* Lam community. There was remarkable variation in the loss of nutrients under different aeolian transportation processes. Over the past several decades, the highest loss of soil elements occurred in the 1970s, whereas the loss from 2011 to the present was generally 4.0% of that in the 1970s. These results indicate that the evident decrease in nutrient loss has played an important role in the rehabilitation that has occurred in the region recently.

1. Introduction

Aeolian processes are one of the key controls on erosion, transportation, and deposition of surface soils in arid and semiarid regions (Breshears et al., 2003; Wang et al., 2008, 2012; Field et al., 2009; Bui et al., 2015) and are the fundamental drivers of the redistribution of soil and vegetation resources (Schlesinger et al., 1990, 1996; Puigdefabregas, 2005; Sankey et al., 2012; Wang et al., 2017a,b,c). At present, approximately 900–300 MT of surface soils have been eroded, transported, and re-deposited on the global scale (Shao et al., 2011). As these materials are redistributed, the resulting heterogeneity and loss of soil nutrient elements have potential impacts on both the physical and chemical properties of soils (Lyles and Tatako, 1986; Field et al., 2010; Swet and Katra, 2016; Stiles et al., 2017) and the variation in the productivity of the regional ecosystem (Swap et al., 1992; Chadwick et al., 1999; Matson et al., 1999; Galloway et al., 2004), which may affect the regional and global ecology. For instance, at large scales high concentrations of molybdenum (Mo) and phosphorus (P) play important roles on nitrogen (N) fixation (Silvester, 1989), and the variation in the concentrations of potassium (K) and magnesium (Mg) affects the community structure of the ecosystems (Woodward et al., 1984; Boy and Wilcke, 2008).

In arid and semiarid regions of China, aeolian processes result in not only the loss of the carbon (C) and N in the surface soils, but also the variation in the balance of other nutrient elements. The variations in the components and concentrations of soil nutrient elements may contribute to and accelerate the succession and degradation of vegetation in such regions. For instance, in some regions of semiarid China, P, sulfur (S), barium (Be), aluminum (Al), molybdenum (Mo), lead (Pb), cadmium (Cd), and nickel (Ni) may have great impacts on the

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https://doi.org/10.1016/j.aeolia.2017.12.004
Received 28 September 2017; Received in revised form 19 December 2017; Accepted 20 December 2017
Available online 29 December 2017
1875-9637/

communities of *gramineae*, *cyperaceae* and *leguminosae* (Chen and Wang, 2000). Variation in sodium (Na) concentration may affect the development of dominant species (Liu, 2004). Phosphorus is one of the key factors controlling the development of meadow steppe environment (Zhang et al., 2013) and low concentrations of selenium (Se), copper (Cu), iron (Fe), manganese (Mn), and cobalt (Co) may have large negative effects on the growth of vegetation (Li et al., 1988; Fu et al., 1994, 2000).

There were variations in the response of different vegetation communities to the heterogeneity of soil nutrient elements. However, under aeolian processes the heterogeneities in both the transport and loss of the nutrient elements are still poorly understood, which limit the recognition of the effects of aeolian processes on the succession and degradation of vegetation. Therefore, by field investigation, wind tunnel experiments and statistical analyses, we evaluated the variation patterns of the nutrient elements under aeolian processes for the communities of *Caragana microphylla* Lam, *Artemisia frigida* Willd. Sp. Pl., *Leymus chinensis* (Trin.) Tzvel. and *Stipa grandis* P. Smirn in the Otindag Desert, China. The objectives of this study were: 1) to evaluate the difference in element contents of surface soils among different communities, and 2) to quantify the effects of aeolian processes on the element loss from soils of different vegetation communities.

2. Materials and methods

2.1. The study area and field sampling

The field investigation was conducted throughout the Otindag Desert (42.2–43.7°N, 112.7–116.6°E). Considering the large areas of the desert and the degraded stages of the vegetation, a total of 20 surface soil samples (five sampling sites for each community) from different vegetation communities and in different degraded stages (Table 1) were collected from the communities of *Caragana microphylla* Lam, *Artemisia frigida* Willd. Sp. Pl., *Leymus chinensis* (Trin.) Tzvel. and *Stipa grandis* P. Smirn (Fig. 1). Because soil disturbance by human activity such as reclamation, only extends to a depth of about 30 cm in the Otindag Desert, so we sampled soils within this uppermost layer. These samples were well preserved and transported to the laboratory for wind tunnel experiments and further analyses. More details of the regional environment, sampling, wind tunnel experiments, and the procedures for the particle size analysis are documented in Wang et al. (2017c).

2.2. The measurement of soil nutrient elements in laboratory

After the wind tunnel experiments and particle size analyses were finished, approximately 0.05 g soil from each sample was dissolved in an ultrapure solution composed of 3 ml HNO_3, 3 ml HF, and 1 ml $HClO_4$. The solution was heated in Teflon crucibles at 120 °C for 30–45 min and then at 180 °C for approximately 6 h. After the solution had dried up, another solution containing 1 ml HF, 1 ml HNO_3, and 0.1 ml $HClO_4$ was added, and the heating continued for 7–10 h. These procedures were repeated until no solid particles remained in the solution. After the solution cooled, 3 ml aliquots of the solution were extracted with a plate and then heated until the solution reached the boiling point. After the samples cooled again, the solution was diluted with ultrapure water to a 25 ml solution, and the concentrations of macro, trace, and rare earth elements in the samples were then determined using an ICP–MS (Elan DRC-e, PE, USA) and an ICP–OES (Optima 5300DV, PE, USA). The concentrations of 40 elements / oxides were measured including cobalt (Co), thallium (Tl), caesium (Cs), indium (In), rubidium^{87} (Rb^{87}), uranium (U), bismuth (Bi), molybdenum (Mo), beryllium (Be), yttrium (Y), lanthanum (La), cerium (Ce), praseodymium (Pr), neodymium (Nd), samarium (Sm), europium (Eu), terbium (Tb), dysprosium (Dy), holmium (Ho), erbium (Er), thulium (Tm), ytterbium (Yb), lutetium (Lu), rubidium^{85} (Rb^{85}), barium (Ba), chromium (Cr), lithium (Li), manganese (Mn), nickel (Ni), phosphorus

Table 1
Brief descriptions of the vegetation communities sampled in this study. Grade A to E show the degrees of degradation from slight to severe, sequentially.

Community/degraded stage	*Stipa grandis.*	*Artemisia frigida* Willd.	*Leymus chinensis*	*Caragana microphylla* Lam.
Grade A	No mobile sand appears on the surfaces, and vegetation cover > 80%	No mobile sand appears on the surfaces, and vegetation cover > 80%	No mobile sand appears on the surfaces, and vegetation cover > 80%	No mobile sand accumulates under shrubs
Grade B	No mobile sand appears on the surfaces, and vegetation cover varies between 80% and 60%	No mobile sand appears on the surfaces, and vegetation cover varies between 80% and 60%	No mobile sand appears on the surfaces, and vegetation cover varies between 80% and 40%	Little mobile sands accumulate under shrubs
Grade C	No mobile sand appears on the surfaces, and vegetation cover varies between 60% and 40%	Few patches of mobile sands appear, and vegetation cover varies between 60% and 40%	Few mobile sands appear on the surfaces, and vegetation cover varies between 40% and 20%	Some sands appear on inter-mounds
Grade D	Some mobile sands appear on the surfaces, and vegetation cover varies between 40% and 20%	Some mobile sands appear on the surfaces, and vegetation cover varies between 40% and 20%	Some mobile sands appear on the surfaces, and vegetation cover varies between 20% and 10%	Vegetation cover < 30% while area of mobile sands < 50%
Grade E	Large quantity of mobile sands appear on the surfaces, and vegetation cover < 20%	Large quantity of mobile sands appear on the surfaces, and vegetation cover < 20%	Large quantity of mobile sands appear on the surfaces, and vegetation cover < 10%	Mobile dunes or sand sheets appear with vegetation cover < 5%