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Effect of vegetation coverage on aeolian dust accumulation in a semiarid steppe of northern China

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ABSTRACT

Wind erosion and sand storms are common phenomena in semiarid steppes of northern China and could have important impact on soil nutrient balances. Vegetation coverage is one of the key factors influencing wind erosion and aeolian dust accumulation. We conducted a field experiment to investigate the effects of vegetation coverage on airborne dust accumulation and evaluated effects of dust input on the contribution of nutrients to vegetation-mulched fields. Five vegetation coverage treatments (15%, 35%, 55%, 75% and 95%) were constructed, with 0% coverage as a control. Vegetation coverage significantly affected dust accumulation in degenerated semiarid grasslands. The amounts of dust trapped by the increasing coverages were 1.7, 1.8, 2.0, 2.1 and 2.1 times of that by the control plot, respectively. The total accumulations reached a maximum of 2.5 g m^{-2} day^{-1} at 75% coverage and remained stable with further increasing vegetation coverage. The particles in the dust trapped by treatment without vegetation coverage were significantly coarser than those by treatments with vegetation. In addition, the dust trapped by treatments with vegetation contained more organic carbon, nitrogen and phosphorus content than that by the control plot. This finding indicates that areas with higher vegetation coverage can obtain more nutrients by trapping airborne dust in semiarid steppes.

1. Introduction

Dust transport pathways can range in scales from local (over a few hundred meters) to global (over thousands of kilometers) distance. This indicates that potential dust impacts upon ecosystems can operate over similar scales (McTainsh and Strong, 2007). On a global scale, a region or one major ecosystem type can be a large "dust collector"; the positive or negative effects of dust collection determine whether an ecosystem is a dust source or sink and can also directly reflect the loss and accumulation of soil resources. Therefore, it has been suggested that dust plays an important role in many biogeochemical processes (Prospero, 1999;Muhs et al., 2008).

In the past several decades, a large number of studies have shown that nutrient input is a function of aeolian dust and an important factor affecting soil nutrients, especially in those regions where winds often occur (Leys and McTainsh, 1999; Lv and Ma, 2003; Stoorvogel et al., 1997; Swap et al., 1996; Thomas and Dougill, 2011). Aeolian dust may often be higher in fertility than the existing soil where it is deposited. There is a net increase in soil nutrients when wind deposition is stronger than wind erosion, otherwise, a net loss of nutrients will occur (Lv and Ma, 2003; Thomas and Dougill, 2011). Stoorvogel et al. (1997) showed that 50% of the nutrients in a humid tropical rainforest along the Ghana coast were derived from the dust carried by dry and hot winds from the Sahara. Swap et al. (1996) drew more startling conclusion in that a particularly strong sandstorm was capable of blowing 4.8×10^5 t dust at one event from the Sahara in Africa to the Amazon Basin in South America, with an annual transport of settled dust of up to 1.3×10^8 t, corresponding to 190 kg·ha^{-1}. Through dust fall, the Amazon Basin has obtained 1–4 kg P·ha^{-1}·yr^{-1}, which is greatly distributed to the nutrient pool of the rainforest ecosystem. Leys and McTainsh (1999) also showed that the filtration effect of vegetation on the dust is a crucial process,

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estimating that shelterbelts in Australia can reduce downwind dust sedimentation by more than 50%. A large number of studies have confirmed that dust deposition played an important role in soil formation of semi-arid and semi-humid lands (Cattle et al., 2002; Derry and Chadwick, 2007; Gustavson and Holliday, 1999; Johnston, 2001; McIntosh et al., 2004; Tiller et al., 1987; Wen et al., 2002). Some studies have demonstrated that dust fall can enrich various nutrients (P, K, Mg, Na, Ca, Fe, Cu, Mn and Mo) in surface soil (Reynolds et al., 2001; Wen et al., 2002) and that the increase of certain elements indirectly influences the utility efficiency of other elements. For example, carbonate influences the biological efficiency of Na, P, K and Mg, while both Mo and P are essential to the N-fixation process (Reynolds et al., 2001).

Vegetation coverage is a crucial factor affecting wind erosion and airborne dust accumulation in semiarid steppes. Grasslands degraded by human activities have been a major dust source in northern China (Xu et al., 2005; Yan et al., 2010; Zhao et al., 2000). The wind tunnel test has shown that erosion of grassland soil by overgrazing and reclamation amounts to 14 and 4 kg m^{-2}, respectively, corresponding to 45 and 13 times of that of ungrazed grasslands (Xu et al., 2005). At the same time, a large area of grasslands receives and intercepts abundant dust fall. It was reported that the natural dust fall in typical steppe areas reaches 35.2 t km^{-2} month^{-1} in the Xilin River Basin of northern China (Wang et al., 2000). However, the balance between wind erosion and dust fall greatly influences steppe soils at the ecosystem level. The soils of restored grasslands in grazing exclosures contained finer particle materials with higher nutrient contents than those of continuously overgrazed grasslands (Yan and Tang, 2008). In degraded grasslands, low vegetation coverage could not trap the dust fall and thus became a source of dust. It is therefore necessary to quantify the trapping effect of different vegetation coverages on the aeolian dust to better understand the role of vegetation in aeolian dust accumulation in arid and semi-arid regions.

Most previous studies have focused on the relationships between vegetation coverage and wind erosion (Dong et al., 1996; Li et al., 2007; Mu and Chen, 2007). However, few studies have been conducted to quantify the function of vegetation in trapping dust. We here hypothesize that an increase in vegetation coverage would improve the efficiency of dust accumulation and add more organic carbon (OC) and nutrients to the degenerated grassland soil. To test this hypothesis, we conducted a field experiment by constructing five vegetation coverage treatments (15%, 35%, 55%, 75% and 95%) with 0% coverage as a control. The specific objectives were (1) to explore the effect of vegetation coverage on trapping aeolian dust and (2) to evaluate the effect of dust nutrient contribution on the vegetation-mulched fields.

2. Methods

2.1. Site description

This study was conducted in the north bank of the middle of the Xilin River, in Inner Mongolia of China (43°26′N, 116°04′E, Fig. 1). There is a fixed sand belt with 10 km width near the north of study site. The semiarid region was formed on basalt plateaus and mainly covered with fine-sand loess. Typical soil types are chestnuts and calcic chernozems. It is characterized by semiarid steppe climate: cold and dry in winters but mild and humid in summers, with an annual average rainfall of 285 mm (1961–2004). Precipitation is highly variable, with 75% occurring from June to September. Strong winds occur from March to May with an average monthly speed of up to 4.9 m s^{-1}. The annual average temperature is 2.4 °C. The average temperature was −22.3 °C in the coldest month (January) and 18.8 °C in the hottest month (July). After cold and dry winters, numerous strong storms result from high air pressure gradients between the Siberian mainland and eastern Asia in spring (Hoffmann et al., 2008). The natural dust fall in this area reaches 35.2 t km^{-2} month^{-1} (Wang et al., 2000). Wind erosion and dust storms are common phenomena in this area and contribute considerably to matter balances (Hoffmann et al., 2008).

2.2. Experimental design

We bound herbage into small clusters (20 cm height) with thin wires to mimic different vegetation coverage and used the treatment without any vegetation (0%) as the control. These clusters were fixed onto square-opening galvanized iron trays (side length = 90 cm, height = 5 cm). Five cover levels (15%, 35%, 55%, 75% and 95%) using herbage clusters of 10 cm^2 in a vertical projection area were simulated with a uniform arrangement. In total, 18 iron trays were mounted into the ground of grasslands which experience degradation because of serious wind erosion. Inter-treatment buffer zones of 1.2 m were left to minimize the interference between treatments. These trays were arranged in a vertical row against the main wind direction, and three replicates were set up for each treatment (Fig. 2). The field site was fence-protected to prevent interference during the experiment time.

2.3. Dust collection and physical and chemical analysis

The experiment started on May 28, 2009. We collected dust from the trays on May 22, 2010. We first removed herbage clusters in iron trays and then cleaned the trapped dust with brushes into plastic

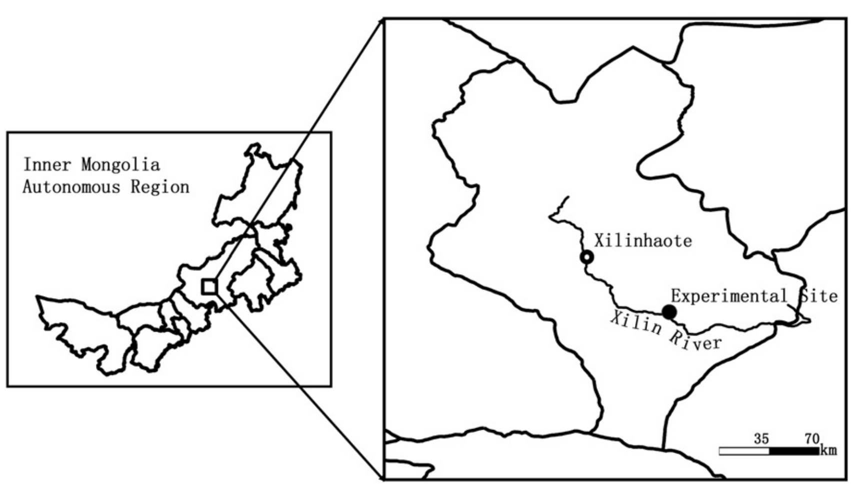

Fig. 1. Location of the experimental site.