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Dust fall and biological soil crust distribution as indicators of the aeolian environment in China's Shapotou railway protective system

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ABSTRACT

Spatial and temporal distributions of dust fall along with the spatial variation of the biological crust were measured along a cross-section in China's Shapotou railway protective system. The variation of the aeolian environment was evident from the spatial variation of near-surface wind flow and both grain size and accumulation rate of dust fall. These varied greatly along the selected cross-section that extended from the mobile dune through the straw checkerboards and vegetation zone to the gravel platform of the railway. On the temporal scale, the dust fall concentrated from March through May. The grain-size composition changed monthly. These temporal changes were related to the wind-force variation and surface condition. The surface conditions along the cross-section were characterized by crust type, crust thickness, and ground (0–5 cm) compaction. Crust could only be found in a relatively stable environment. The distribution of dust fall and crust indicated the intensity of aeolian activity and the stability of the aeolian environment. Further improvement of the aeolian environment by natural processes or by human construction would promote additional dust fall and accelerate the development of the crust.

1. Introduction

Research on dust fall includes reports on the intensity, particle composition, deposition speed, process, mechanics, movement, etc. Researchers also studied the dust sources and transfer routes, calculated the amount and seasonal distribution of dust fall, explored the significance to environmental pollution, analyzed the effects on ecology and environments, and determined their relationship to meteorological factors (Kimura et al., 2009; Klacka and Kocifaj, 2001; Li and Dong, 2010; Tainsh and Strong, 2007; Wen et al., 2001; X.M. Zhang et al., 2008; Yan and Dong, 2001). Previous research covered both spatial and temporal scales that included small areas and even larger regions (Duanmu, 2005; Fan et al., 2002; Wang et al., 2004), but studies now focus on cities (Tripathi et al., 1991; Zhang et al., 2010). The temporal scales range from monthly changes to multi-annual variations over long periods (Dethier et al., 2011; J.C. Li et al., 2008). Most dust fall research now couples both temporal and spatial scales (Irvine et al., 1989; Sun et al., 2003).

The Shapotou region of the Baotou–Lanzhou railway located on the southeastern edge of the Tengger Desert was once threatened by moving sand. Since the establishment in 1958 of the Shapotou railway protective system, sand dunes are prevented from moving towards the railway, because the mobile sand dunes in the protective system have changed into semi-fixed dunes and fixed dunes. The pattern of aeolian activity also has changed greatly (Mitchell et al., 1998), and deposition has become the main type of aeolian activity. The changes in aeolian environment and the subsequent survival of planted vegetation have promoted the development of biological soil crust.

Dust fall studies have continued in the changed aeolian environment. The results of Xiao et al. (1997) showed that the average grain size of surface sediments in the protective system was finer than 250 μm in diameter. The deposition rate was 4358 kg hm^{-2} a^{-1} on average and was significantly higher in the inter-dunes than that on the dune tops. The source of deposited material was fine particles transported mainly from the deserts. Almost half of the dust fall was silt, and the other half was clay-size particles. Vegetation cover was favorable for capturing dust fall, and it intercepted 30–60% of the total dust fall in this area. Fan et al. (2002) reported similar results. They found that the grain size of dust fall in the protective system ranged from 2 to 250 μm and that the average deposition rate was 4866 kg hm^{-2} a^{-1}, both of which differed spatially. The inter-dunes were the major deposition positions.

Prior studies of biological soil crust include mainly the development of mechanics and processes along with categorizing of the physical and chemical properties. Some studies also include the significance of the crust to the ecosystem and environment and its response to

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disturbances (Belnap, 1990; Bolton et al., 1993; Tarchitzky et al., 1984; Z. Zhang et al., 2008; Zhang, 2005). After straw checkerboards and vegetation, crust has been treated as a key factor in stabilizing the sandy ground. It takes on an important role in the protective system due to its ability to enhance the stability of the surface soil (Belnap and Gillette, 1998; Verrecchia et al., 1995; Williams et al., 1995) by binding fine particles together into large ones (Belnap and Gardner, 1993; Shields and Durrel, 1964), thus entrapping the fine particles (Reynolds et al., 2001).

The study presented here was conducted on a section across the railway protective system along the prevailing wind direction. The purpose of this study was: i) to determine the spatial and temporal distribution characteristics of the dust fall and spatial distribution of soil biological crust across the protective system. ii) To evaluate the effects of the near-surface wind flow field, sand dune topography, and vegetation on dust fall. iii) Finally to analyze the relationships among dust fall, biological soil crust and the aeolian environment.

2. Material and methods

2.1. Study area

The Shapotou section of the Baotou–Lanzhou railway is located southeast of the Tengger Desert (37°27′N, 104°59′E; Fig. 1a), where network dunes, barchan dunes, and barchan chains are the main dune types. The prevailing wind directions are northwest (NW) and west-northwest (WNW), with an important secondary wind direction from the east-northeast (ENE). Compared to the other seasons, spring has the longest duration of high wind speeds. This region has a typical arid climate. The mean annual precipitation is 186 mm, most of which (83%) falls from May to September. The mean annual evaporation is more than 3000 mm, and the mean annual temperature is 9.6 °C. The average maximum temperature is 24.3 °C in July, and the minimum is −6.9 °C in January. The average annual wind speed is 3.5 m s^{-1}. Frequent blowing sand events occur with a cumulative duration of more than 1177 h $year^{-1}$.

The railway protective system consists of four parts: an upright sand fence at the windward edge of the system, straw checkerboards within the vegetation zone without irrigation downwind of the fence, an irrigated vegetation area, and a gravel platform (Fig. 1b). The upright sand fence used to block sand is 1.2 m tall and has a porosity of about 30%. Generally the fence was installed along the upper parts of the windward slope on the mobile dune close to the vegetation zone. This position was selected as the beginning of the protective distance in this study (protective distance equals to 0 m). Straw checkerboards made of wheat and rice straw embedded in the sand form a rough 1 × 1 m grid, with the straw protruding 10 to 15 cm above the ground surface (Fig. 2). Seedlings of xerophytic shrubs such as *Caragana korshinskii* (Leguminosae), *Hedysarum scoparium* (Papilionaceae), *Elaeagnus angustifolia* (Elaeagnaceae) and *Calligonum arborescens* (Polygonaceae) were then planted. The first 5 years after planting, the vegetation was lightly irrigated to encourage survival, and then the irrigated program ended. The mean vegetation cover currently is around 20%. The gravel platform still has shrubs growing. The protective system was established in 1956 and has continued to improve and stabilize the surface since its establishment. The straw checkerboards and the vegetation zone without irrigation represent the main and most important parts of the system.

2.2. Methods

The desert influences the protective system and the railway more along the prevailing wind direction than all other directions. Therefore, we selected a cross-section along the prevailing wind direction (NW–SE)that transects is from the windward toe of the upwind mobile dune with an upright sand fence through the adjacent straw checkerboards and the vegetation zone without irrigation to the gravel platform at the north side of the railway. Dust fall containers were installed along the cross-section. The dust fall containers are cylindrical glass tanks that were widely used in previous research (Naddafi et al., 2006; Yan and Dong, 2001). The inner-diameter is 17.5 cm, and the height is 35 cm. They were set on the ground with 5 cm underground;

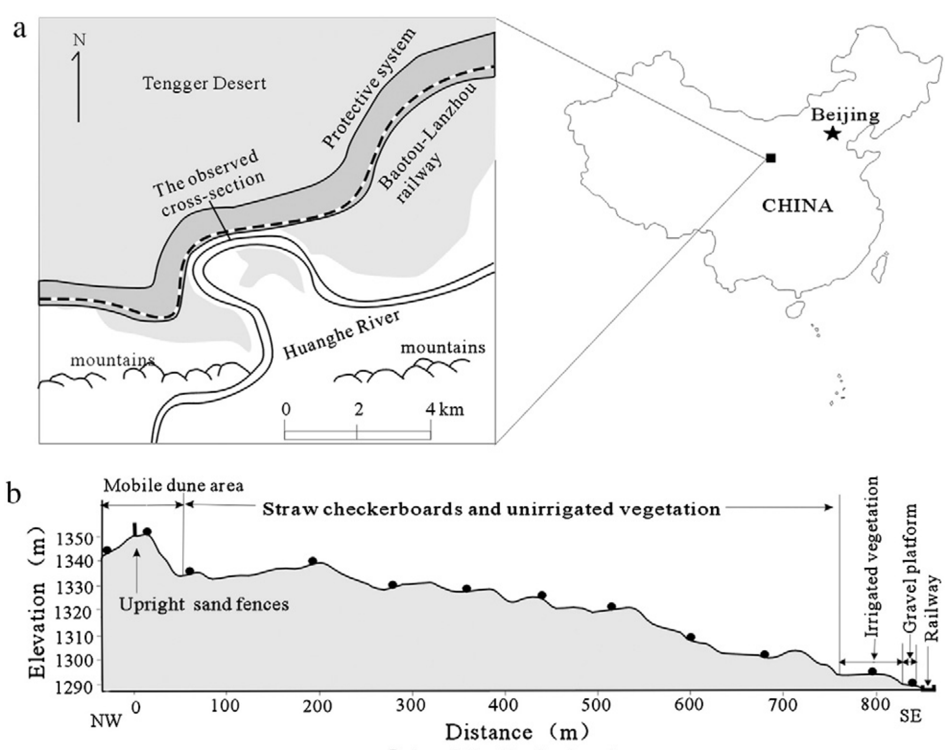

Fig. 1. The study area and the collection sites of dust fall.