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Characteristics of aeolian sediment transport over different land surfaces in northern China

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ABSTRACT

Differences among regions in the meteorological, surface, and vegetation cover characteristics lead to differences in sediment transport. In this paper, field data were measured above five surface types in the arid zone of northern China to analyze the vertical distribution of sediments in the near-surface transport layer (0–50 cm) and total sediment transport. We were able to express the sediment flux in this zone as an exponential function for all surface types. Sediment transport differed among the surfaces, with the greatest transport above mobile dunes, followed by cultivated land, semi-fixed dunes, fixed dunes, and a shrub community. Vegetation coverage is important for reducing wind erosion and increasing the proportion of the creep sediment transport. With increasing vegetation cover, the soil erosion decreased; the amount for the mobile dunes was 659 times that of the shrub community, and 8 times for fixed dunes. The proportion of sediment transported by creeping differed among the five surface types, with a minimum of 33% for the mobile dunes, and maximum of 44% for the shrub community.

1. Introduction

Wind erosion is a common phenomenon in arid and semi-arid regions, where it results from complex interactions among a wide range of natural factors (e.g., rainfall, evaporation, wind, soil erodibility, and vegetation cover) with human activities such as agriculture and grazing (McTainsh 1998). Although wind erosion is a natural process, it has increased with the expansion of agriculture and pastoralism. Wind erosion can remove the most nutrient-rich fractions of the soil, which are often concentrated in the near-surface layers (Gomes et al., 2003; Michels and Bielders 2006; Visser et al., 2005). When these materials are transported in the air, they can affect human health, reduce visibility, and even disrupt electricity supplies (Tegen and Fung 1995; Sterk et al., 1996; Buschiazzo et al., 2007; Maurer et al., 2010).

During wind erosion, soil particles at the surface are entrained by the wind and transported via one of three main modes: suspension, saltation, and creeping, which is also referred to as "reptation" (Bagnold, 1941). The relative importance of each mode depends on the wind characteristics and the physical and aerodynamic properties of the particles. Suspension is the transport mode in which grains are lifted farthest from the surface, so that they are transported over long distances without touching the surface again. In contrast, saltation is the transport mode in which entrained grains are lifted a short distance above the surface, then fall again, rebounding and often freeing other grains from the surface to also undergo transport. Finally, grains whose displacement occurs primarily along the surface are said to undergo creeping (reptation). Because the threshold wind speed above which sediment transport occurs depends on both soil and vegetation characteristics (Raupach et al., 1993), the surface characteristics are a major constraint on movement and transport of sediments. Creep, saltation, and suspension are inter-related (for example, abrasion caused by saltation commonly produces fine particles that travel by suspension), so the extent to which these processes occur individually vs. simultaneously can influence the type and degree of wind erosion and the potential loss of sediment and nutrients from soil that occurs. Previous study indicated that the saltation fraction account for 50–70% of the total sand transport (Wu 2003), the suspension fraction account for 30–40% and the creep fraction account for 5–25% of the total sand transport (White, 1997).

Many field and modeling methods have been used to study aeolian sediment transport above the surface of arid and semi-arid land (Fryrear et al., 1991; Stout and Zobeck 1996; Gillies and Berkofsky 2004; Wang and Zheng, 2004; Ellis et al., 2009; Mertia et al., 2010; Panebianco et al., 2010; Dong et al., 2006, 2011, 2012; Mendez et al., 2011; Sankey et al., 2013). However, most previous

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research has focused on the sediment transport saltation processes and the most accepeted models are power function (Mertia et al., 2010), an exponential function or a modified exponential function (Namikas 2003; Ellis et al., 2009; Panebianco et al., 2010; Mendez et al., 2011; Dong et al., 2011), and combined power and exponential functions (Sterk and Raats 1996). In such models, the sediment transport creeping was considered as a part of overall sand flux or ignored (Stout and Zobeck 1996; Ellis et al., 2009; Dong et al., 2012). For the aeolian sediment transport suspension and creeping processes, there was just little research (Wang and Zheng, 2004; Zhang et al., 2014).

Aeolian sediment transport works over different spatial and temporal scales; thus, in studying aeolian sediment transport, the most appropriate scale for the measurement objectives must be considered. For example, a large portion of northwestern China is subject to wind erosion, but the nature of the sediment transport differs from region to region because of spatial and temporal variation in the controlling factors. Although Li et al. (2005); Dong et al. (2011) and Hoffmann et al. (2011) have studied aeolian sediment transport over different land surfaces in northern China, some parts of this area remain relatively unstudied. Likewise, little work has been performed to compare transport above different land surfaces within the same region. In the present study, we performed research in 2006 in a little-studied region of northwestern China to compare aeolian sediment transport over different land surfaces; our overall goal was to provide information that could be used to support efforts to protect the region's soils from excessive wind erosion.

2. Study region and methods

2.1. Study region

Our study was conducted in Yanchi County (37° 39′ N, 107°13′ E), which is in the eastern portion of China's Ningxia Province (Fig. 1). This area is a desertified steppe zone, a transitional zone between desert and low mountains, and with a mean elevation of 1560 m a.s.l. The climate follows a typical continental monsoon pattern, with mean annual precipitation of 249.6 mm (with about 60% of the total falling during the growing season, between June and August), mean annual potential evapotranspiration of 2179.8 mm, and an average temperature of 7.6 °C, with mean monthly temperatures ranging from a minimum of 8.9 °C in January to a maximum of 22.3 °C in July. The average wind speed is 2.8 m/s and the wind direction is primarily from the northwest. Strong wind days (days with wind speeds in excess of 17 m/s) occur more than 30 days each year, and sand storms and blowing dust occur about 20 days per year. Since 1960, the mean annual temperature has increased significantly, at a rate of 0.38 °C/10 years (Qu and Wang 2006); the winter temperature has increased more than the summer temperature. However, annual rainfall has not changed significantly.

Most of the study area consists of hilly and gently sloping terrain covered by fixed, semi-fixed, and mobile dunes. The prevalent sandy Sierozem soils are susceptible to wind erosion and have low natural fertility. The sparse vegetation, which is adapted to the arid desert conditions, is typified by a single plant

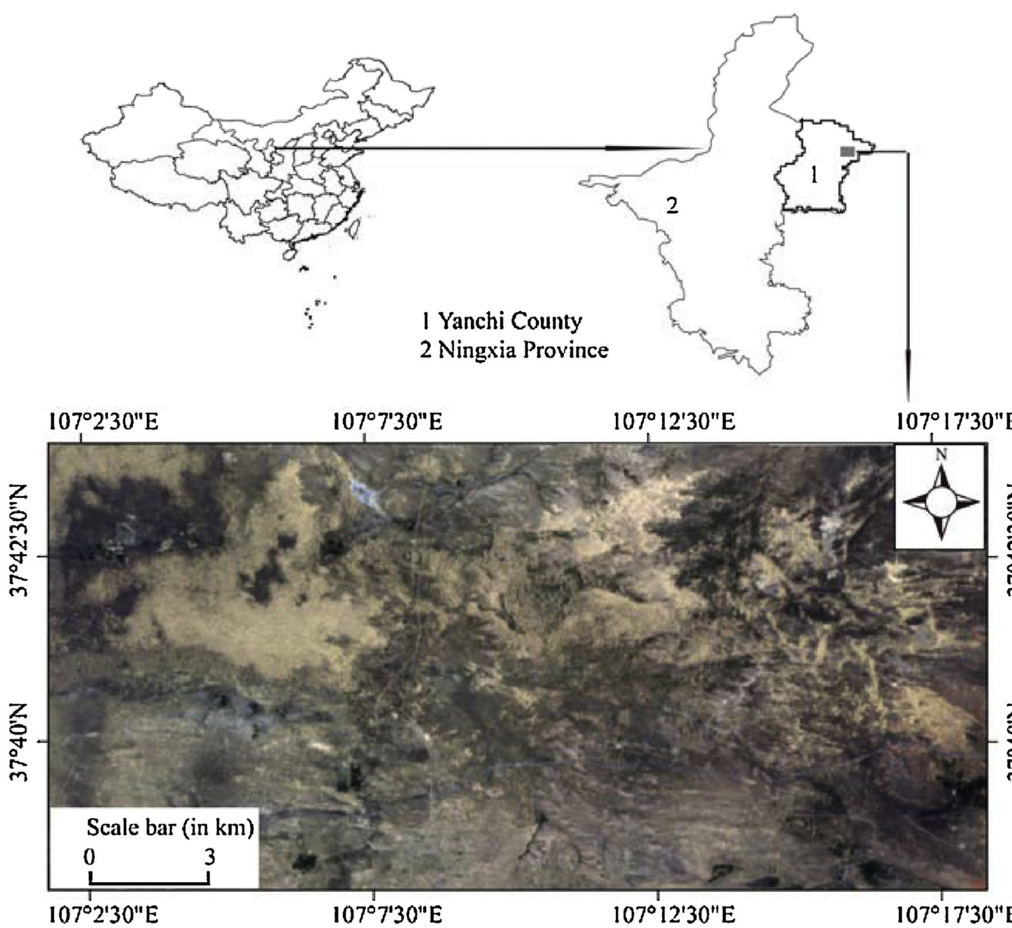

Fig. 1. The location of the study area, and satellite image.