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Review

Microbiology of wind-eroded sediments: Current knowledge and future research directions

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A B S T R A C T

Wind erosion is a threat to the sustainability and productivity of soils that takes place at local, regional, and global scales. Current estimates of the cost of wind erosion have not included the costs associated with the loss of soil biodiversity and reduced ecosystem functions. Microorganisms carried in dust are responsible for numerous critical ecosystem processes including biogeochemical cycling of nutrients, carbon storage, soil aggregation, and transformation of toxic compounds in the source soil. Currently, much of the information on microbial transport in dust has been collected at continental scales, with no comprehensive review regarding the microbial communities, particularly those associated with agricultural systems, redistributed by wind erosion processes at smaller scales including regional or field scales. Agricultural systems can contribute significantly to atmospheric dust loading and loss or redistribution of soil microorganisms are impacted in three interactive ways: (1) differential loss of certain microbial taxa depending on particle size and wind conditions, (2) through the destabilization of soil aggregates and reduction of available surfaces, and (3) through the reduction of organic matter and substrates for the remaining community. The purpose of this review is to provide an overview of dust sampling technologies, methods for microbial extraction from dust, and how abiotic, environmental, and management factors influence the dust microbiome within and among agroecosystems. The review also offers a perspective on important potential future research avenues with a focus on agroecosystems and the inclusion of the fungal component.

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1. Introduction

Wind erosion processes produce a significant impact upon global sustainability, health and environmental quality with estimates of global mineral dust emissions varying from 500 to about 3300 Tg yr^{-1} (or 5.0×10^8 to 3.32×10^9 Mt yr^{-1}) (Shao et al., 2011). Although the majority of these emissions occur from non-anthropogenically influenced desert surfaces, agricultural soils can also represent significant regional dust sources (e.g. Lee et al., 2012; Ginoux et al., 2012). Tegen et al. (2004) postulated that about 10% of the total dust load is derived from agriculturally modulated sources alone, producing estimates of at least 50 million Mt of dust contributed to the global budget per year. Downwind transport of eroded sediment is often over great distances (Prospero et al., 2005, 2014) and carries with it a variety of mineral and organic materials including geochemicals, biochemicals, xenobiotics (e.g., pesticides), and microorganisms. Of these components, the microbial composition of dust is the least understood, in part due to the vast abundance and diversity of microorganisms found in soils. For example, one gram of an agricultural soil with relatively high contents of organic matter and clay (i.e., Iowa, USA) was found to contain 1.34 ± 0.38 μg DNA within the 0–0.3 m depth, with respective fungal and bacterial estimates of 1.03×10^5 or 6.19×10^7 colony forming units (Taylor et al., 2002). In terms of the variety of bacterial species, Roesch et al. (2007) estimated that up to 8.3 million species were present per gram of soil based on over 50,000 sequences of 16S rRNA evaluated for a forest soil from Canada and three agricultural soils from Brazil and the USA. By having the potential to remove vast numbers of soil microorganisms, wind erosion events on agricultural land such as Fig. 1 can exert profound impacts on the sustainability and productivity of soils that are subject to deflation by aeolian processes.

Microorganisms carried in dust are important in local, regional, and global processes including biogeochemical cycling of nutrients (Gardner et al., 2012; Li et al., 2007, 2008), pathogenicity (Griffin et al., 2001; Hara and Zhang, 2012; Prospero et al., 2005), and microbial biogeography (McTainsh and Strong, 2007; Smith et al., 2010, 2013) and there are discussions of their role in climate interactions and the formation of clouds (Konstantinidis, 2014). In his epic travels on *H.M.S. Beagle*, Charles Darwin and his associates collected airborne dust near the island of Santiago in Cape Verde and showed that it contained organic material subsequently identified by Darwin's associate, Professor Ehrenberg, as many forms of Infusoria, which are minute aquatic organisms (Darwin, 1845). Recent analysis of this dust shows that it most likely originated from the Sahara (Gorbushina et al., 2007). Darwin's pioneering study was one of the earliest to demonstrate the movement of microbial-rich dust as a result of aeolian entrainment and subsequent transport, and the potential wind-driven biodiversity loss of some ecosystems and enrichment of others.

Microbial communities lost from agricultural soils when carried away in dust are essential to the ecosystem functions, services and productivity of the source soil (Fig. 2). Microorganisms, for instance, play key roles in protecting soils from erosion and reduce soil erodibility potential through their influence in organic matter build up and aggregate stability. Thus, management practices that increase soil microbial biomass, C content and sequestration, will contribute to enhanced soil structure and reduce the erodibility of soils. Fungal growth, for instance, leads to the physical binding of aggregates and the production of cementing agents referred as glomalin, which glue soil particles together (Wright et al., 1996). Increases in soil organic matter that consequently lead to improved aggregate stability and increases in soil water holding capacity are the result of decomposition processes by both fungi and bacteria. Fungi, and to certain extent actinomycetes, degrade complex compounds to more simple forms that are sequentially used by bacteria (G+, G−), and these series of reactions not only incorporate and recycle several nutrients in soil, but will also lead to soil C sequestration. Bacterial species involved in symbiotic associations of N fixation (i.e., rhizobia) and fungal species (e.g., members of the

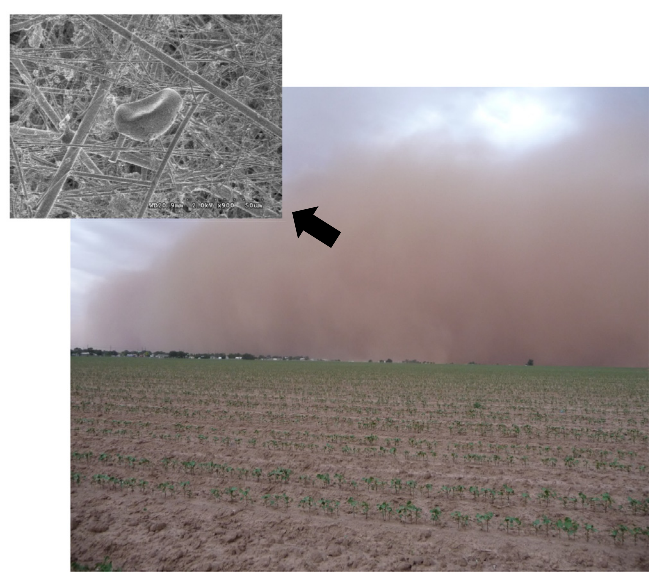

Fig. 1. Dust storm seen in September 3, 2011 in a semiarid agricultural region in the USA within the Southern High Plains in Texas. This region experiences high intensity rain events and high wind speeds (>9 m/s) particularly at planting time in the spring and at harvest in the fall when the crops and the soil are more susceptible to damage. The dust image (50 μm in size) shows polen, fibers and fungal hyphae. The image was taken using a scanning electron microscope at *The Imaging Center of Texas Tech University* using a Hitachi S-4300SE/N (NSF MRI 04-511 The Texas Tech University A&S EOX Imaging Facility, Texas Tech University) by a Texas Tech graduate student Chenhui Li.