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# Land degradation in drylands: Interactions among hydrologic–aeolian erosion and vegetation dynamics

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ABSTRACT

Land degradation in drylands is one of the major environmental issues of the 21st century particularly due to its impact on world food security and environmental quality. Climate change, shifts in vegetation composition, accelerated soil erosion processes, and disturbances have rendered these landscapes susceptible to rapid degradation that has important feedbacks on regional climate and desertification. Even though the role of hydrologic–aeolian erosion and vegetation dynamic processes in accelerating land degradation is well recognized, most studies have concentrated only on the role of one or two of these components, and not on the interactions among all three. Drawing on relevant published studies, here we review recent contributions to the study of biotic and abiotic drivers of dryland degradation and we propose a more holistic perspective of the interactions between wind and water erosion processes in dryland systems, how these processes affect vegetation patterns and how vegetation patterns, in turn, affect these processes. Notably, changing climate and land use have resulted in rapid vegetation shifts, which alter the rates and patterns of soil erosion in dryland systems. With the predicted increase in aridity and an increase in the frequency of droughts in drylands around the world, there could be an increasing dominance of abiotic controls of land degradation, in particular hydrologic and aeolian soil erosion processes. Further, changes in climate may alter the relative importance of wind versus water erosion in dryland ecosystems. Therefore acquiring a more holistic perspective of the interactions among hydrologic–aeolian erosion and vegetation dynamic processes is fundamental to quantifying and modeling land degradation processes in drylands in changing climate, disturbance regimes and management scenarios.
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## 1. Introduction: dryland degradation

Drylands of the world are of critical concern as they cover over 41% of the surface of the earth with over 2 billion inhabitants, mostly in the developing world (MEA, 2005). Land degradation in drylands is one of the major environmental issues of the 21st century because of its impact on food security and environmental quality (MEA, 2005). The United Nations Convention to Combat Desertification (UNCCD) defined desertification as "land degradation in arid, semi-arid and dry sub-humid areas resulting from various factors, including climatic variations and human activities". The causes and consequences of dryland degradation, sometimes arguably referred to as "desertification", remain controversial and poorly understood (Hutchinson, 1996; Thomas, 1997; Veron et al., 2006). Some authors even consider desertification as a potential but not necessarily an outcome of land degradation processes. Desertification results in environmental and socio-economic-political changes through a complex interplay of biophysical and anthropogenic factors that act at different scales (Geist and Lambin, 2004). Because desertification is considered to be a cause and a consequence of poverty, the mitigation of desertification could aid in reducing poverty in dryland areas (MEA, 2005). In the case of many dryland systems, severe climatic conditions (e.g., the series of droughts such as those that affected sub-Saharan Africa since the late 1960s) combined with weak economies and unsustainable use of marginal resources, have increased the levels of stress in dryland ecosystems, which were often unable to sustain the pressure of the increasing human population (Darkoh, 1998). Collectively, these factors caused famine and large-scale human migrations that have had important regional-scale socio-economic and political consequences (Mabbutt and Wilson, 1980; Darkoh, 1998).

Human activities have a profound influence on the degradation trends and patterns in drylands (Reynolds et al., 2007). A classic example of anthropogenic degradation of drylands is the "Dust Bowl" period that occurred in the Great Plains of the United States during the 1930s, when dramatic soil loss and dust emissions were triggered by poor land management practices and concurrent dry climatic conditions

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(Worster, 1979). Anthropogenic disturbances of dryland soils after the European colonization and consequent shifts in vegetation patterns have also been reported in the southwestern United States, Australia, Southern Africa, and South America (Pickup, 1998; Van Auken, 2000; Ravi et al., 2009a). Anthropogenic pressures include the overgrazing of rangelands, which comprise around 70% of drylands, and conversions to cropland. These pressures are exacerbated by climatic changes, urbanization and management factors. A notable example is the Sahel region of Africa (Nicholson et al., 1998; Taylor et al., 2002), where a feedback between vegetation and climate can induce the existence of two alternative stable states: a stable dry (desertified) and a stable moister (vegetated) climate regime (Charney, 1975; Xue and Shukla, 1993; Zeng and Neelin, 2000). In this system a decrease in vegetation cover may result into a highly irreversible shift to a dry climate state, in which rainfall would be insufficient to allow for the recovery of vegetation (Brovkin et al, 1998).

Degradation of soil and vegetation can lead to substantial reduction in ecosystem functions and services, perhaps in as much as 70% of drylands (Dregne and Chou, 1992). Regardless of the actual amount, land degradation is clearly occurring at an alarming pace, threatening the food security and environmental quality in drylands (UNCCD, 1994; MEA, 2005). Notably, soil erosion is the most widespread form of land degradation in these landscapes. Recent studies indicate that triggering factors of land degradation, such as global climate change, have resulted in drier conditions in arid and semi-arid regions (Held et al., 2005; Burke, et al., 2006; Seager et al., 2007). An increase in aridity can result in an increase in relative importance of abiotic factors that propagate land degradation, such as aeolian and hydrological transport processes. Indeed, wind and water erosion are considered to have contributed to 87% of the degraded land (Middleton and Thomas, 1997). Grazing pressure, loss of vegetation cover, and the lack of adequate soil conservation practices render soils in these regions more susceptible to processes of soil erosion, which in turn can have important impacts on regional climate and desertification (Nicholson et al, 1998). Even though the role of hydrologic–aeolian erosion and changing vegetation dynamics in accelerating land degradation is well recognized, our understanding of how the interactions among different forms of soil erosion and vegetation dynamic processes contribute to desertification is generally still uncertain. Many studies have concentrated only on the role of one or two of these components, and not on the interactions among these processes (Fig. 1). Based on a more holistic perspective of relevant studies, here we review recent studies on the interactions between wind and water erosion processes in dryland systems, and discuss how these processes affect vegetation patterns and how vegetation patterns, in turn, affect these abiotic processes. We focus on (1) interrelationships between wind and water erosion; (2) hydrologic–aeolian erosion and changing vegetation dynamic processes; and (3) applications, including the increasing need to estimate long-term changes in food and fodder supply, to design and evaluate soil conservation and land reclamation programs, assessment of the rate of entrainment of dust into the atmosphere and its contribution to global climate change, and the effect of climate change and land management scenarios on arid and semi-arid regions.

## 2. Wind and water erosion in drylands

Soil erosion can be defined as the detachment and transport of soil particles and subsequent redeposition in near or distant areas mainly by the action of wind and water. Soil erosion is a natural land surface process, which can be accelerated and exacerbated by anthropogenic and biophysical factors with adverse effects on soil resources, crop productivity, environmental quality and climate (Lal, 1994).

Archeological evidences indicate that accelerated soil erosion emerged as a serious environmental issue as early as 8000 years ago. Since then, it has often threatened the existence of civilizations (e.g., Redman, 1999; Rolett and Diamond, 2004; Montgomery, 2007). On a global scale, 1094 million ha are affected by water erosion and 550 million ha by wind erosion (Middleton and Thomas, 1997). Even though, globally, water is the major contributor to soil erosion, in many arid and semi-arid systems, erosion by wind can be substantial and even the dominant (Breshears et al., 2003; Field et al., 2009). For example, the cultivated soils in the Great Plains of North America are particularly prone to the action of winds, and rates of wind erosion may exceed those of water erosion. In this region, dramatic soil losses and dust emissions were induced in the 1930s (the "dust bowl" period) by poor land management and drought conditions (Worster, 1979).

Soil erosion is often considered as a cause and an effect of desertification (Nicholson et al 1998; Lal, 2001; MEA, 2005) and important feedbacks have been shown to exist among erosion, biodiversity loss and climate change (Fig. 2). An increase in rates of soil erosion because of climatic changes that increase aridity could result in enhanced loss of soil resources and a loss in biodiversity, which can further increase rates of soil erosion and result in loss of vital services from drylands, including the possible reduction in primary production and carbon sequestration (e.g., Chapin et al., 1997). Moreover, biodiversity loss has been related to a decrease in ecosystem resilience—the ability of the ecosystem to recover from disturbances (e.g., Elmqvist et al., 2003). Therefore, less diverse ecosystems are more prone to highly irreversible shifts to a desertified state induced by anthropogenic factors or climate fluctuations (Fig. 2). Soil erosion affects the productivity and spatial pattern of dryland vegetation

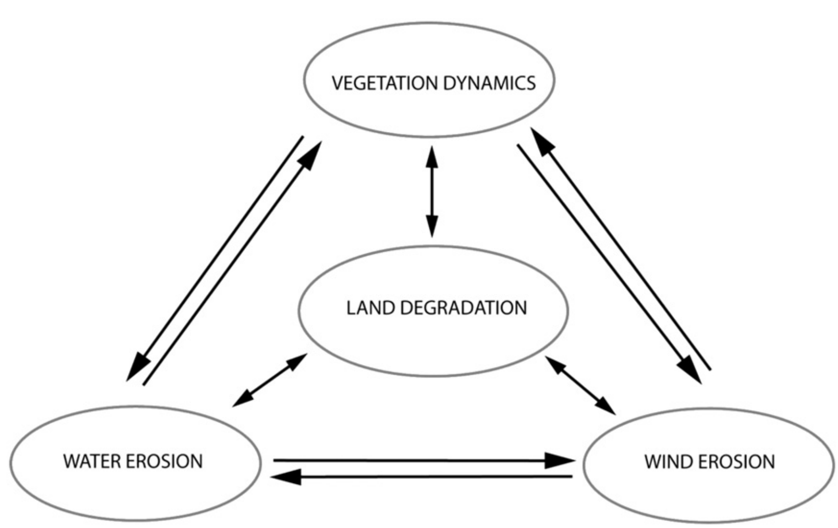


**Fig. 1.** A holistic perspective of land degradation dynamics by considering the interactions among wind–water erosion and vegetation dynamic processes.

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