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Effects of biological soil crusts on surface roughness and implications for runoff and erosion

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ABSTRACT

Soil surface roughness has a strong influence on runoff and erosion, affecting surface storage capacity, water flow routing and velocity, and modifying runoff rates. It also reduces soil detachment by raindrops and the shear effect of water flow on the soil surface. In arid and semiarid ecosystems, biological soil crusts (BSCs) commonly appear in clearings between plants. Depending on the dominant component in the BSC community, the roughness of the soil surface may vary considerably, changing the hydrologic and erosive response of the soil. The aim of this study is to determine the effect of physical and biological crusts on soil surface roughness and their influence on runoff and erosion. For this purpose, we set up open plots containing different BSC types and treatments and recorded runoff and total erosion from all the events for 18 months. Micro-topographic indexes were calculated from high-resolution digital surface models of the plots built from terrestrial laser scanner height data. After comparing different spatial resolutions and indexes, we concluded that only the local Random Roughness index in a 40-mm moving window provided a precise estimation of the roughness induced by BSCs, though it did not have a direct effect on runoff response. The best relationship between microtopography and runoff on biologically crusted soils was found for surface storage capacity, which appears as a powerful predictor of the runoff coefficient on long temporal scales. Sediment yield was not well predicted by any of the micro-topographic indexes studied. The only index that was significantly related to sediment yield was the local Random Roughness in a 40 mm moving window, but even this explained only a third of the erosion variance.

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1. Introduction

Microtopography plays an important role in controlling exchanges of matter and energy between the soil and the atmosphere, and its effect is known to be extended from the plot to the hillslope scale and even to larger scales. It modifies the contact surface between the two systems and affects vertical (evapotranspiration and infiltration) and horizontal (runoff) water flows, conditioning soil water availability (Allmaras et al., 1966; Dunkerley, 2004). Its effect on runoff generation and erosion has been widely studied, especially in agricultural soils (Govers et al., 2000; Kamphorst et al., 2000), and is considered a key parameter governing these processes (Kirkby, 2002; Gaur and Mathur, 2003). Microtopography modifies overland flow, affects water storage in surface depressions, modifies the fraction of soil covered by water, regulates the amount of excess rainfall needed for runoff to start and affects hydraulic resistance which controls the flow velocity (Allmaras et al., 1966; Solé-Benet et al., 1997; Dunkerley, 2004; Sun et al., 2009; Smith et al., 2011). The presence or absence of soil surface roughness can also strongly influence water retention times at a given site (Dunkerley, 2004), modifying the connectivity of water sources (Armstrong et al., 2011). Moreover, it has been reported that rough surfaces absorb raindrop impact on the soil surface, and modifies significantly water flow and soil surface interactions (Dunkerley, 2004), reducing the shear effect and the speed and transport capacity of water flow (Helming et al., 1998; Planchon et al., 2000; Gaur and Mathur, 2003; Liu and Singh, 2004), and consequently, sediment yield.

Geomorphic evolution of arid and semiarid systems is highly dependent on the interactions and feedback-dominated processes at the fine and intermediate scales (Cammeraat, 2002). At these scales, dynamic processes are controlled by the hydrological and erosion behavior of the different surface covers, their spatial distribution in the landscape and all interactions among them (Cammeraat, 2002; Puigdefábregas, 2005; Boer and Puigdefábregas, 2005). In these systems, characterized by sparse vegetation cover, runoff and sediment yield are mainly generated in the intershrub spaces, while plants act as sinks of these resources (Ludwig and Tongway, 1995; Puigdefábregas, 2005). In most arid and semiarid ecosystems around the world, up to 70% of these inter-plant areas may be covered by biological soil crusts (BSCs) (Belnap et al., 2005), which are

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