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Overland flow generation mechanisms affected by topsoil treatment: Application to soil conservation

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ABSTRACT

Hortonian overland-flow is responsible for significant amounts of soil loss in Mediterranean geomorphological systems. Restoring the native vegetation is the most effective way to control runoff and sediment yield. During the seeding and plant establishment, vegetation cover may be better sustained if soil is amended with an external source. Four amendments were applied in an experimental set of plots: straw mulching (SM); mulch with chipped branches of Aleppo Pine (*Pinus halepensis* L.) (PM); TerraCottem hydroabsorbent polymer (HP); and sewage sludge (RU). Plots were afforested following the same spatial pattern, and amendments were mixed with the soil at the rate 10 Mg ha^{-1}. This research demonstrates the role played by the treatments in overland flow generation mechanism. On one hand, the high macroporosity of SM and PM, together with the fact that soil moisture increased with depth, explains weak overland flow and thus low sediment yield due to saturation conditions. Therefore, regarding overland flow and sediment yield, RU behaves similarly to SM and PM. On the other hand, when HP was applied, overland flow developed quickly with relatively high amounts. This, together with the decrease downward in soil moisture along the soil profile, proved that mechanisms of overland flow are of the Hortonian type.

1. Introduction

Various factors account for soil hydrology and erosion including soil texture and aggregate stability (Boix-Fayos et al., 1998; Brevik, 2009); gravel content (Van Wesemael et al., 1996); vegetation cover (Cerdá, 1998; Lavee et al., 1998; Calvo et al., 2003); land use and land management which are markedly affected by agricultural use and land abandonment (Lasanta et al., 2000); and particularly soil wettability during rainfall events (Castillo et al., 2003; Shakeby and Doerr, 2006). Soil moisture affects infiltration capacity and the capacity of soils to store new rainfall, as reflected in many physical-based hydrological models (Bronstert, 1994; Bronstert et al., 1998; Seeger et al., 2004). For this reason, the various runoff generating processes (saturation excess overland flow, infiltration excess overland flow, and return flow) are highly regulated by soil moisture (Castillo et al., 2003). In humid areas, overland flow is generated only when and where saturation conditions have been reached (Lavee et al., 1998; Ward and Robinson, 2000). However, Hortonian overland flow can occur when rainfall intensity exceeds the infiltration capacity (Horton, 1933; Ferreira et al., 2000; Calvo et al., 2003, 2005).

Hortonian overland flow is responsible for significant amounts of soil loss in Mediterranean geomorphological systems (Puech and Chabi-Gonnie, 1984; Rao et al., 1998; Beven, 2002; Stomph et al., 2002; Garcia-Ruiz et al., 2013). As a consequence of climatic conditions and human activities, soil is not sufficiently protected by vegetation and is thus subject to loss of organic matter and nutrients (Marqués et al., 2005), which creates a positive feedback process that can lead to desertification (Lavee et al., 1998). Restoration of native vegetation is the most effective way to regenerate soil health, and control runoff and sediment yield production (Inbar et al., 1998; Alegre et al., 2004; Boix-Fayos et al., 2007). The seeding and plant establishment stages are critical (Cerdá, 1998; Adekalu et al., 2007; Smets et al., 2008; Macci et al., 2012), but during these stages the beneficial effects of the vegetation may not be apparent and the soil is highly susceptible to the erosion and depletion of soil quality (Will et al., 2011). Under these conditions, vegetation cover in areas having degraded soils may be better sustained if the soil is amended using an external source of organic matter (Jordán et al., 2010; Chaudhuri et al., 2013; Shazana et al., 2013; Srinivasarao et al., 2013).

Various residue types have been investigated in erosion control studies under Mediterranean climate conditions. The results show that the application of crop mulch, sewage sludge or animal manure positively affects plant cover (Montgomery, 2007) and improves soil properties (Ferreras et al., 2006; Franco-Otero et al., 2011; González-Ubierna et al., 2012; Hueso-González et al., 2014). Where no vegetation is established, organic amendments can be used to rapidly protect the soil surface against the erosive forces of rain and runoff (Smets et al.,

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2008; Bark et al., 2012; Gholami et al., 2012). Similarly, other studies have shown that the amendment of soil with polymers including gypsum and polyacrylamide (PAM) prevented seal formation, and reduced overland flow and soil loss (Ben-Hur and Keren, 1997; Flanagan et al., 1997a,b; Yu et al., 2003; Abrol et al., 2013). The studies noted above have also shown that geomorphological processes respond to various soil amendments. However, further studies are needed, given that few comparative studies of amendments have been carried out, particularly in relation to the mechanisms generating overland flow following their addition, simultaneously in time and for afforestation purposes.

In this study we investigated the hydrological effects of five soil treatments in relation to the soil moisture content. The specific objectives of the study were to: 1) analyze the soil moisture profile under various soil management regimes; 2) determine the overland flow mechanisms affected by various topsoil treatments; and 3) determine the sediment yield from amended afforested soil.

2. Study area

The El Pinarillo experimental site is located in the Sierra Tejeda, Almijara and Alhama Natural Park (southern Spain) (Fig. 1). The site is located at 470 m a.s.l., in the upper part of an alluvial fan (calcareous conglomerates) surrounded by mountains with marble as the primary bedrock material, and the climate is dry Mediterranean (mean annual temperature: 18 °C; mean annual rainfall: 589 mm). The study plots were located in an abandoned agriculture field recolonized by shrubs since the 1950s. The current vegetation consists of an open pine forest with typical degraded Mediterranean scrubs and tussocks; the area was affected by a fire that occurred in 1991. The vegetation cover is >70% and includes *Chamaerops humilis* L., *Cistus albidus* D., *Rosmarinus officinalis* L., *Thymus capitatus* L., *Rhamnus alaternus* L. and annual plants. The soils are classified as lithic and eutric leptosols, according to FAO (2006). They are characterized by a high level of rock fragment cover

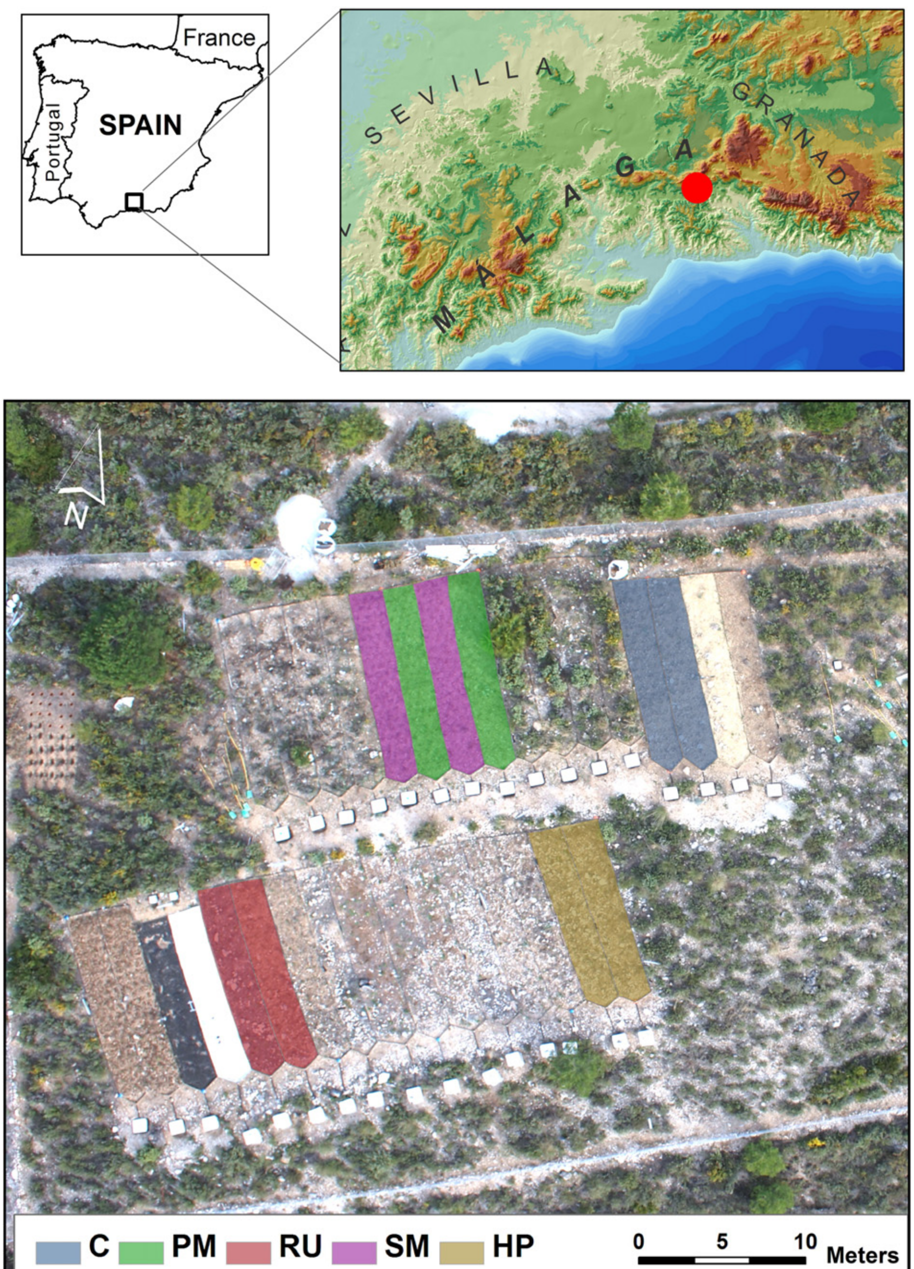

Fig. 1. Location of the experimental site. C: soil afforested, no amendment; PM: mulch with chipped branches of Aleppo Pine (*Pinus halepensis* L.); RU: sewage sludge; SM: straw mulch; HP: TerraCottem hydroabsorbent polymer.