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Effect of forest floor characteristics on water repellency, infiltration, runoff and soil loss in Andisols of Tenerife (Canary Islands, Spain)

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ABSTRACT

Given its singular properties and location, forest floor (litter + duff) is a key factor in hydrological processes. Water infiltration research was carried out for the present study in Andisols at ten sites, six of which had coverings of pine forest and four of rainforest. Rainfall simulations were conducted on gentle, moderately-steep and steep slopes (10, 30 and 50%) to determine infiltration, runoff and soil loss as a function of the forest floor characteristics. The duff on the pine forest soils consists of moderately porous, extremely hydrophobic and consistent semi-decomposed organic material, which is rich in fungi hyphae. The duff on the rainforest soils is formed by highly porous, loose, semi-decomposed organic material. The study results highlight the influential role played by the forest floor in infiltration and runoff. Infiltration barely reaches 20 mm h^{-1} in pine forest, compared to 50 mm h^{-1} in rainforest. As a consequence, the pine forest runoff is twice that recorded in rainforest sites. The wetting front on gentle and moderately-steep slopes evidences the influence of the duff on infiltration. In pine forest, most of the rainwater remains in the duff and infiltration depends little therefore on the underlying mineral soil properties. In rainforest, the wetting front extends below the duff and the well-developed soil structure is a major factor in water infiltration. The differences noted in the two parameters are not found on the steep slopes. No soil loss differences are observed between the two vegetation covers and forest floors despite the greater runoff in pine forest. The results demonstrate the protective effect of the organic covering and how the stability of the Andisols helps combat water erosion processes.

1. Introduction

As the interface between the mineral soil and the atmosphere in many land ecosystems, the forest floor – a surface horizon mainly comprising decomposing plant material – plays a crucial role in hydrological processes (Keith et al., 2010a). Forest floor is divided into two differentiated layers (litter and duff) following a gradient of decomposition (Keith et al., 2010b). As the above authors note, litter (L or A_{00} horizon) is formed by fresh leaves from the surrounding vegetation and is located on the surface. Duff (A_0) comprises two distinct layers: a top fermentation layer (F horizon) and bottom humus layer (H horizon). The layers are formed, respectively, by partly or wholly decomposed plant remains.

Several authors have drawn attention to the physical particularities of the forest floor and note how they differ to those of the underlying mineral soils (Keith et al., 2010b; Lauren and Mannerkoski, 2001; Lauren et al., 2000). Due to its location and properties, the presence of forest floor can modify the amount of rainwater available for infiltration and runoff (Guevara-Escobar et al., 2007). Consequently, it can alter the hydrological response of the soils compared to their response when no forest floor is present (Keith et al., 2010a). According to Descroix et al. (2001), surface features play a pivotal role in soil hydrology. However, most hydrological studies in forest zones focus on the mineral soil and few take the forest floor into consideration (Buttle et al., 2000, 2005). Furthermore, it is well known that the presence of water-repellent soil surface horizons inhibits infiltration and promotes runoff (DeBano, 1971; Doerr et al., 2000; Robichaud and Waldrop, 1994). However, most studies concern themselves with the underlying mineral horizons and few with the forest floor (see e.g. Martínez-Zavala and Jordán-López, 2009; Poulenard et al., 2001; Zehetner and Miller, 2006).

Andisols (Soil Survey Staff, 1999) are the most characteristic soils found on Tenerife (Canary Islands, Spain) due to the island's volcanic nature, the relatively young age of some of its materials and its appropriate climate conditions. These are soils with high structural development and high porosity, properties which explain their high water infiltration rate under natural conditions (Harden, 1991; Nanzyo et al., 1993; Perrin et al., 2001). Most authors consider that the singular mineralogical properties and high organic carbon content of these soils are decisive factors in their structural properties (Fernández Caldas and Tejedor Salguero, 1975; Hoyos and Comerford, 2005; Quantin, 1994; Warkentin and Maeda, 1980). Nonetheless, previous

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field observations show that, in pine forest, some of the soils do not become moist until the end of the rainy season. This wetting delay would appear to be in contradiction with the theoretically high infiltration of Andisols. Studies of Andisols have highlighted the structural degradation and reduction in infiltration capacity produced by a change in land use (see e.g. Jiménez et al., 2006; Poulenard et al., 2001; Rodríguez Rodríguez et al., 2002; Warkentin and Maeda, 1980; Zehetner and Miller, 2006). Meanwhile, various authors have drawn attention to the influence exerted on soil hydrological behaviour by surface features, including plant cover (Cerdà, 1998, 1999; Molina et al., 2007), rock fragments (Descroix et al., 2001; Martínez-Zavala and Jordán, 2008) and even ash (Cerdà and Doerr, 2008; Woods and Balfour, 2008, 2010; Zavala et al., 2009) and pine needles following a fire (Cerdà and Doerr, 2008). However, few studies have examined the influence of the forest floor on the water repellency and hydrological behaviour of Andisols.

The present work aims to contribute to resolving the discrepancies that exist with respect to the wetting process in certain Andisols under forest vegetation. In order to do so we will: (a) characterise the forest floor and soil for two different vegetation covers; (b) study the infiltration, water repellency, runoff and erosion in the Andisols under both covers using simulated rainfall events; and (c) analyse the influence of the forest floor and soil properties on the hydrological processes in the study soils.

2. Methodology

2.1. Site description

Tenerife (Canary Islands, Spain) is an island in the Atlantic Ocean. It is situated between 27º 55′ and 28° 35′ north latitude and between 16° 05′ and 16° 55′ west longitude (Fig. 1). Its geographical position (near the Tropic of Cancer and under the influence of the trade winds), elevation (highest point: 3718 m.a.s.l.) and the orientation of its mountain systems give rise to a wide variety of meso- and micro-climates and vegetation (del Arco et al., 2006). It also boasts a diversity of volcanic materials of different ages. The combination of all these factors accounts for the presence of different soil orders on the island (Tejedor et al., 2007).

The study area is situated between 850 and 1400 m.a.s.l. on the north face of the island (Fig. 1). It is dominated by moderately-steep hillsides (20–50%) according to the slope classification given in the Soil Survey Manual (Soil Survey Division Staff, 1993). Bedrock consists of basaltic pyroclasts and lava flows (0.7–0.01 M yrs) with subsequent rejuvenations by analogous ashes (<0.01 M years). Average annual precipitation is between 600 and 1000 mm. The amount of water from condensation is very significant in this altitudinal strip. According to Marzol Jaén (2005), water from condensation can amount to five times rainfall, depending on the vegetation and location. The natural vegetation consists mainly of pine forest (*Pinus canariensis*) and rainforest (*Laurus novocanariensis*, *Apollonias barbujana*, *Persea indica*, *Ilex canariensis*, *Myrica faya*, *Erica arborea*, and *Erica scoparia*, among other species).

The study area lies on the ustic–udic boundary (Soil Survey Staff, 1999). The soils are mostly Andisols (Ustands and Udands). Some Inceptisols and Entisols (Soil Survey Staff, 1999) are also found although they occupy much smaller areas. The type of vegetation determines the characteristics of the forest floor, particularly the duff properties. The litter in both the pine forest and rainforest consists of a covering of loose leaves in the early stages of decomposition. The pine forest duff comprises semi-decomposed organic material, which is rich in macroscopic fungi hyphae (Fig. 2). In contrast, the rainforest duff is a loose, semi-decomposed organic material which appears to be free of fungi hyphae (Fig. 2).

2.2. Site selection

Six pine forest sites and four rainforest sites were selected for the study. All the soils are Udands or Ustands (Soil Survey Staff, 1999). The sites are located at heights between 900 and 1200 m.a.s.l. Bearing in mind the influence of vegetation cover on forest floor characteristics, care was taken to select sites with homogeneous vegetation composition, both in the pine forest and rainforest. *Pinus canariensis* is the main species present in the pine forest sites, while the vegetation in the rainforest sites comprises laurifolia tree species (*Myrica faya* and *Persea indica*). The limited extent of rainforest on the island, its location in areas that are difficult to access and its wide botanical composition prevented further rainforest sites from being selected. 3 plots with similar forest floor characteristics were selected in each site for each of the study slopes: 10% (30 plots), 30% (30 plots) and 50% (15 plots). Only 5 sites with slopes of 50% were identified (2 in pine forest and 3 in rainforest). In line with the Soil Survey Division Staff (1993) slope classes, the terms gentle, moderately-steep and steep were used for slopes of 10, 30 and 50%, respectively. The

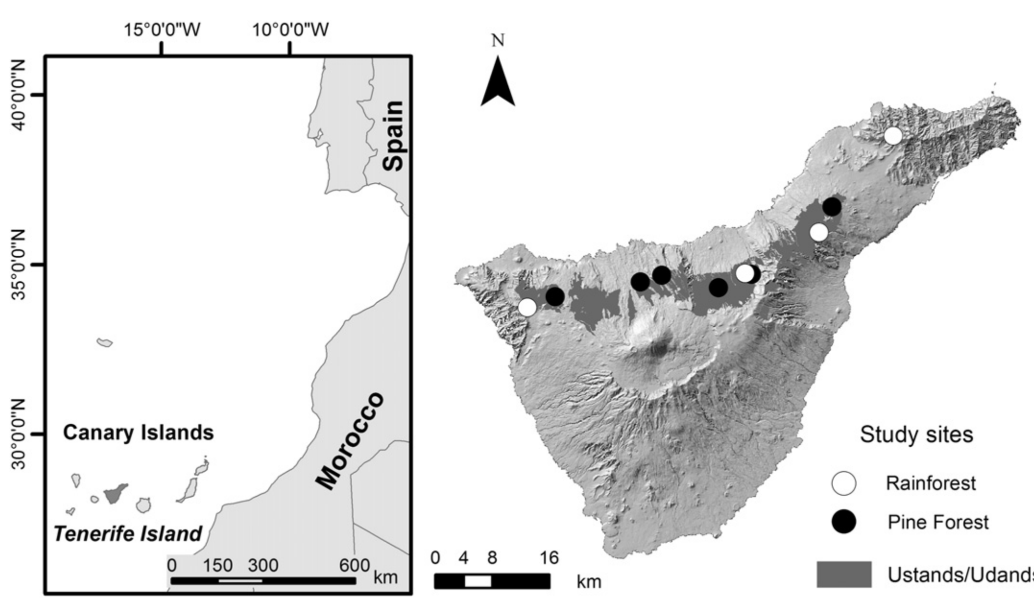

Fig. 1. Location of the island of Tenerife; Andisols (Udands and Ustands) and study sites.