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Soil changes associated with land use in volcanic soils of Patagonia developed on dynamic landscapes

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ABSTRACT

This paper aimed to identify indicators of soil degradation in volcanic soils developed in the ecotone between the Andean Forests and the Patagonian steppe. The study area is located in the Percy River Basin, Argentine, on alluvial fans with volcanic soils. Sampling was conducted in two adjacent hillslopes where native forest was replaced by a rangeland with grass-shrub vegetation and a 32-years old *Pinus radiata* plantation. Sectioned and bulk soil samples were collected along three transects in each land cover up to 40 cm depth. Two forest patches of *Maytenus boaria* were selected as controls. Physical, chemical and magnetic properties were analyzed. Native forest soils were rich in silt fraction, organic matter and non-crystalline minerals, and presented the lowest values of magnetic susceptibility. Rangeland and plantation soils differed from forest soils in these properties. Soil changes were mainly associated to changes in mineralogy resulting from soil desiccation and to the selective removal of fine particles by erosion, together with differences in the effects of recent volcanic events on the soils. Changes in soils associated with land use affected key properties related to pedogenetic processes. Magnetic susceptibility, organic matter content, texture, and pH NaF were key for understanding soil degradation processes in this dynamic environment.

1. Introduction

Worldwide, land use change, driven by the need to provide goods and services to human populations, have deeply affected land health by accelerating the soil degradation processes (Gaspar et al., 2013). In different forest ecosystems, the change of land use was proved to diminish soil quality (Cerri et al., 1991; Navas et al., 2008). While chemical soil properties changes, driven by the transition from forest to rangeland, can be highly variable and even positive (Guo and Gifford, 2002; Murty et al., 2002), different authors agree that overgrazing causes physical soil degradation (Belsky and Blumenthal, 1997; Mekuria et al., 2007). Changes occurring in the soil depend, among other factors, on intrinsic soil properties, initial fertility and also domestic animals stocking rates (Binkley et al., 2003; Álvarez-Yépiz et al., 2008).

Nowadays there is a tendency to increase forest cover in some countries, and forest plantations are being established across the globe for commercial and restoration purposes (Chazdon, 2008). However, the effects of afforestation in ecosystem and soil are under discussion. Changes in biodiversity, hydrological cycle and soil properties are the most challenged when natural vegetation is replaced by exotic conifers. Changes in soil properties may include chemical, biological, physical and morphological modifications in the soil profile (Amiotti et al., 2000; Broquen et al., 2000; Guo and Gifford, 2002).

The Patagonian Andean Region, despite being seen as a conserved and natural area, is subjected to intense land use changes. Deforestation, livestock grazing, agriculture and urbanization have triggered several land degradation processes (Carabelli and Scoz, 2016). The subhumid sector, corresponding to the transition (ecotone) between the Andean Forests and the Patagonian steppe, is a fragile ecosystem with the highest anthropic pressure and high losses of native forests (Veblen et al., 1999). Livestock grazing has accelerated the soil degradation processes in different environments of Patagonia (Ares et al., 1990; Chartier et al., 2013), and the most drastic changes were found in the sub-humid sector (Bertiller and

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Bisigato, 1998), where rangeland soils are supposed to have a very slow recovery, with no change in organic carbon 15 years after grazing exclusion (Nosetto et al., 2006).

Nowadays, plantations with exotic conifers are also concentrated in the sub-humid sector, being promoted as an economic activity while a palliative to erosion (Irisarri and Mendía, 1997). Although there is little local available information, it was shown that soil fertility is depleted where exotic conifers are planted in very fertile soils, both, replacing native forests (Gobbi et al., 2002) or even degraded rangelands (La Manna et al., 2016a).

The landscape of the Patagonian Andean Region is dominated by glacial geoforms covered by volcanic ash deposits. In the subhumid sector, with precipitations around 600–800 mm per year, the volcanic ash weathered to imogolite, a non-crystalline aluminosilicate with strong affinity for water, metal cations and organic molecules (Besoain, 1985; McDaniel et al., 2012). In this xeric environment, imogolite may dehydrate to crystalline clays such as halloysite, which is a 1:1 layer silicate (Besoain, 1985; Parfitt and Wilson, 1985). The presence of non-crystalline aluminosilicates is key not only for determining land productivity but also resistance to erosion (McDaniel et al., 2012). Overgrazing, mainly if soil loses its cover, might results in desiccation of soil, allowing non-crystalline materials to evolve to halloysite (Parfitt and Wilson, 1985). On the other hand, in a landscape with a rugged topography, the slope position might modify the soil water regime, altering the degree of weathering processes and, thus, the formation of non-crystalline minerals. The influence of land use and slope position on volcanic soils has been poorly addressed in Patagonia.

Several studies around the world have considered physical and chemical soil properties to assess soil quality in response to degradation processes (Bastida et al., 2008; Zucca et al., 2010; Moebius-Clune et al., 2011). Soil organic carbon content has been considered to be a good indicator of environmental quality for mineral soils because of the influence that organic matter has on key functional properties, such as fertility, soil structure and water relations (Ogle and Paustian, 2005). Soil organic carbon resulted a key variable for evaluating soil changes associated with different land use (Quijano et al., 2017) and slope positions (Powers and Schlesinger, 2002).

Magnetic susceptibility is also a soil property often considered in studies about soil degradation and erosion (De Jong et al., 1998; Royall, 2007; Quijano et al., 2014). Mass magnetic susceptibility (χ) is a fast and non-destructive technique to quantify the degree of induced magnetization of a soil sample in response to an applied magnetic field. Soil magnetic susceptibility depends on the concentration of the ferrimagnetic minerals and is sensitive to the magnetic mineralogy, grain size, shape and orientation of the mineral grains (Dearing, 1999; Magiera et al., 2006). Iron oxides and hydroxides in soils unaffected by anthropogenic pollution are valuable pedo-enviromental indicators due to its sensitivity to physico-chemical conditions in sedimentary environments, including soil forming processes (Torrent et al., 2010), degree of pedogenesis (Geiss and Zanner, 2006), weathering processes and biological activities (Dearing et al., 1996; Singer et al., 1996). Enhancement of magnetic susceptibility due to the secondary formation of iron compounds (i.e. magnetite and maghemite) through pedogenic processes (Mullins, 1977; Maher, 1986; Van Dam et al., 2004) is used to identify differences between topsoil and subsoil. Several soil studies have used magnetic susceptibility as a tracer of the topsoil movement to evaluate soil erosion and soil degradation (Gennadiev et al., 2002; Royall, 2007; Sadiki et al., 2009; Jordanova et al., 2014), however, magnetic susceptibility studies were never carried out in Holocene volcanic soils of Patagonia Argentina.

1.1. Objectives

The aim of this study was to identify indicators of soil degradation in volcanic soils developed on dynamic landscapes of the forest-steppe ecotone in the Patagonian Andean region. Two specific objectives were considered: i) to evaluate some physical, chemical and magnetic soil properties under different land use (native forest, forestation and rangeland); ii) to assess the effect of slope position on soil properties under different land uses (forestation vs. rangelands).

2. Materials and methods

The study was carried out in the Percy River Basin (42°54′00″ S; 71°22′12″ W), a rugged topography near to Esquel Town, in the forest-steppe ecotone of the Patagonian Andean Region. The Percy River Basin is one of the most fragile areas of the Chubut province in Argentina, with one of the oldest European settlements in Patagonia. This basin is characterized by large eroded areas, the degradation of riparian systems and high losses of native forests (Kutschker et al., 2009; Miserendino et al., 2016). Soils were developed from holocenic volcanic ashes and ecosystem degradation is worsened because of the high erodibility of volcanic soils in this area (La Manna et al., 2016a).

The geomorphology of the study area corresponds to alluvial fans (Andrada de Palomera, 2002), and soils have been mapped in a unique unit characterized as dissected phase of Entic Haploxerolls (Phaeozem vitric, according to the World reference base (WRB) of the International soil classification system) and Typic Vitrixerands (Andosol vitric) (Irisarri et al., 2000).

The original vegetation of the study area is composed of a forest dominated by *Maytenus boaria* Mol with a shrub stratum, which is still preserved as isolated patches in certain sectors. Throughout the last century, the forest matrix has been degraded and was mostly replaced by grass-shrub vegetation, as a result of overgrazing and fires. Two representative situations of forest replacement were considered: a) by rangeland; b) by afforestation with exotic conifers.

Sampling was conducted in two adjacent hillslopes with 10° mean slope and south-east aspect (155°) (Fig. 1). One of the hillslopes, present grass-shrub vegetation (80% covered), dominated by *Rumex acetosella* L., a perennial and invasive exotic herbaceous plant (Franzese and Ghermandi, 2012) accompanied by species indicative of degradation as *Acaena splendens* Hook. & Arn and *Mulinum spinosum* (Cav.) Pers. and grasses of low palatability as *Pappostipa speciosa* Trin. et Rupr. This rangeland has been used for grazing for the last 100 years. On the other hand, the adjacent hillslope corresponds to a 32 years *Pinus radiata* D. Don plantation from 1985. Two patches of native forests of *M. boaria* were also sampled. They are located near the rangeland and the plantation, in sites with moderate slope (8°) and south-east aspect (Fig. 1).

Three soil pits up to 150 cm depth were excavated to examine the soil profiles in each land use (Fig. 2) that were described according to USDA (Schoeneberger et al., 1998). Furthermore, in control forests and in the high, medium and lower parts of hillslopes of rangeland and plantation soil profiles were established to assess the vertical variation of soil properties as well as along the slope.

In the patches of the native forests, a total of 11 points were sampled up to a depth of 40 cm. Of these, five were sectioned at 5 cm depth increments and the other six were 0–40 cm depth bulk samples. Along the hillslopes, of forestation and rangeland, three transects placed 35 m apart and parallel to the main slope, were established for each land use. The lower part of the slope corresponded to the lowest portion of the plantation, which is not exactly the end of the topographic slope. Along the transects soil samples were taken to a depth of 40 cm in 10 points that were placed 25 m apart from each other. In the sample points, 0–40 cm depth bulk samples were collected. In each transect at three slope positions (the upper, middle and lower slope) soil samples were sectioned at 5 cm depth increments. Although this sampling was possible in most of the points, some soils were too loose in depth preventing an accurate fractioning. Where the samples could not be correctly sectioned up to 40 cm, 0–40 depth bulk samples were also taken. Where the samples could be appropriately sectioned up to 40 cm, the average of soil variables of the sectioned samples was considered for bulk sample data analysis. Thus, 11, 30 and 30 sampling points 0–40 depth were included for native forests, plantation and rangeland, respectively. A total of 39, 68 and 47 sectioned samples were obtained for native forests, plantation and rangeland, respectively. In all cases, metal tools were avoided in order to not contaminate samples with metals.

Soil samples were air-dried and passed through a 2 mm sieve. Total dry weight and percentage of coarse fragments were determined. Texture was