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Pedogenic and microbial interrelations to regional climate and local topography: New insights from a climate gradient (arid to humid) along the Coastal Cordillera of Chile

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Abbreviations: AZ, Pan de Azúcar; SG, Santa Gracia; LC, La Campana; NA, Nahuelbuta; MAT, mean annual temperature; MAP, mean annual precipitation; PET, potential evapotranspiration; LAI, leaf area index; CAM, Crassulacean acid metabolism; BD, bulk density; TOC, total organic carbon; BS, base saturation; CEC_{eff}, effective cation exchange capacity; Al_{ex}, exchangeable aluminum

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A B S T R A C T

The effects of climate and topography on soil physico-chemical and microbial parameters were studied along an extensive latitudinal climate gradient in the Coastal Cordillera of Chile (26°–38°S). The study sites encompass arid (Pan de Azúcar), semiarid (Santa Gracia), mediterranean (La Campana) and humid (Nahuelbuta) climates and vegetation, ranging from arid desert, dominated by biological soil crusts (biocrusts), semiarid shrubland and mediterranean sclerophyllous forest, where biocrusts are present but do have a seasonal pattern to temperate-mixed forest, where biocrusts only occur as an early pioneering development stage after disturbance. All soils originate from granitic parent materials and show very strong differences in pedogenesis intensity and soil depth.

Most of the investigated physical, chemical and microbiological soil properties showed distinct trends along the climate gradient. Further, abrupt changes between the arid northernmost study site and the other semi-arid to humid sites can be shown, which indicate non-linearity and thresholds along the climate gradient. Clay and total organic carbon contents (TOC) as well as Ah horizons and solum depths increased from arid to humid climates, whereas bulk density (BD), pH values and base saturation (BS) decreased. These properties demonstrate the accumulation of organic matter, clay formation and element leaching as key-pedogenic processes with increasing humidity. However, the soils in the northern arid climate do not follow this overall latitudinal trend, because texture and BD are largely controlled by aeolian input of dust and sea salts spray followed by the formation of secondary evaporate minerals. Total soil DNA concentrations and TOC increased from arid to humid sites, while areal coverage by biocrusts exhibited an opposite trend. Relative bacterial and archaeal abundances were lower in the arid site, but for the other sites the local variability exceeds the variability along the climate gradient. Differences in soil properties between topographic positions were most pronounced at the study sites with the mediterranean and humid climate, whereas microbial abundances were independent on topography across all study sites. In general, the regional climate is the strongest controlling factor for pedogenesis and microbial parameters in soils developed from the same parent material. Topographic position along individual slopes of limited length augmented this effect only under humid conditions, where water erosion likely relocated particles and elements downward. The change from alkaline to neutral soil pH between the arid and the semi-arid site coincided with qualitative differences in soil formation as well as microbial habitats. This also reflects non-linear relationships of pedogenic and microbial processes in soils depending on climate with a sharp threshold between arid and semi-arid conditions. Therefore, the soils on the transition between arid and semi-arid conditions are especially sensitive and may be well used as indicators of long and medium-term climate changes. Concluding, the unique latitudinal precipitation gradient in the Coastal Cordillera of Chile is predestined to investigate the effects of the main soil forming factor – climate – on pedogenic processes.

1. Introduction

Soil forms at the interface between the atmosphere and lithosphere sustaining Earth's life and biogeochemical cycles (Amundson et al., 2007). Excluding anthropogenic effects, soils and their properties are commonly regarded as forming from interactions between five factors including: climate, biota, topography, parent material and time (e.g. Dokuchaiev, see Glinka, 1927; Hilgard, 1914; Jenny, 1994). Climate has a strong effect on soil properties via biological and hydrological processes, as the changing water flow, vegetation and soil biological activity affects soil physical and chemical properties, including BD, soil organic matter, clay formation, pH value and the degree of leaching or accumulation of base cations and pedogenesis in general (Bojko and Kabala, 2017; Jenny, 1994; Lin, 2010; Pastalkova et al., 2001; Smith et al., 2002).

Previous studies on latitudinal and elevational soil-climate gradients with similar parent materials (including granites, loess, basalts, paragneiss) demonstrated that increasing precipitation and decreasing temperature result in a decrease of silt contents, soil pH and BS, whereas TOC, acidity and exchangeable aluminum (Al_{ex}), electrical conductivity and clay contents increase (Bardelli et al., 2017; Bojko and Kabala, 2016; Khomo et al., 2011; Khormali et al., 2012; Raheb et al., 2017; Smith et al., 2002; Xu et al., 2014). Specific thresholds for the occurrence of shifts in these properties, like a certain elevation, e.g. > 1000 m a.s.l. or a mean annual precipitation (MAP) of 1400 mm were suggested (Bojko and Kabala, 2017; Chadwick et al., 2003). According to Slessarev et al. (2016), the pH value has a threshold with a steep transition from alkaline to acidic when MAP exceeds potential evapotranspiration (PET). Regarding the soil microflora, microorganisms are highly responsive to their environment and the composition of microbial communities is shaped by a wide range of soil properties. For example, several studies highlighted the influence of pH (Lauber et al., 2009), particle size (Sessitsch et al., 2001; Wagner et al., 1999), organic carbon content (Fierer et al., 2007; Goldfarb et al., 2011; Zhou et al., 2002) and nutrient availability (Fierer et al., 2003) on microorganisms. In general, microbial abundances tend to be lower under arid climate conditions, increase with increasing precipitation (Bachar et al., 2010; Fierer et al., 2012; Ollivier et al., 2014) and decrease with soil depth (Agnelli et al., 2004; Fierer et al., 2003; Goberna et al., 2005; Schulze-Makuch et al., 2018; Will et al., 2010). The previous studies show that the study of pedogenic characteristics and microbial abundances along latitudinal gradients is a promising approach to explore the interactions between climate effects on soils and microorganisms, and to identify the thresholds involved.

In addition to climate, the topographic position of soils is regarded as an essential factor in soil formation ever since Milne (1935) published the concept of a catena. A catena describes soils along a landscape sequence, where soil properties change gradually depending on geological, geomorphic, atmospheric, or biological processes with upslope mobilization, downslope redistribution and transfer of solutes, colloids and particles (Sommer and Schlichting, 1997; Wysocki and Zanner, 2006). Bojko and Kabala (2016) reported finer soil textures and higher contents of base cations downslope as a result of the selective transport of material along the slope for soil developed from granitic