Geoderma 217–218 (2014) 212–224

Contents lists available at ScienceDirect

Geoderma

journal homepage: www.elsevier.com/locate/geoderma

High exchangeable calcium concentrations in soils on Barro Colorado Island, Panama

Tobias Messmer [a], Helmut Elsenbeer [b,c], Wolfgang Wilcke [a,*]

[a] University of Berne, Geographic Institute, Hallerstrasse 12, 3012 Bern, Switzerland
[b] University of Potsdam, Institute of Earth and Environmental Sciences, Karl-Liebknecht-Strasse 24-25, 14476 Potsdam, Germany
[c] Smithsonian Tropical Research Institute, Balboa, Panama

A R T I C L E I N F O

Article history:
Received 19 February 2013
Received in revised form 28 October 2013
Accepted 29 October 2013
Available online 22 November 2013

Keywords:
Panama
Cation-exchange capacity
Exchangeable Ca
Clay mineralogy
Weathering indices

A B S T R A C T

The soils on four lithologies (basaltic conglomerates, Bohio; Andesite; volcanoclastic sediments with basaltic agglomerates, Caimito volcanic; foraminiferal limestone, Caimito marine) on Barro Colorado Island (BCI) have high exchangeable Ca concentrations and cation-exchange capacities (CEC) compared to other tropical soils on similar parent material. In the 0–10 cm layer of 24 mineral soils, pH values ranged from 5.7 (Caimito volcanic and Andesite) to 6.5 (Caimito marine), concentrations of exchangeable Ca from 134 $mmol_c\ kg^{-1}$ (Caimito volcanic) to 585 $mmol_c\ kg^{-1}$ (Caimito marine), and cation exchange capacities from 317 $mmol_c\ kg^{-1}$ (Caimito volcanic) to 933 $mmol_c\ kg^{-1}$ (Caimito marine). X-ray diffractometry of the fraction <2 μm revealed that smectites dominated the clay mineral assemblage in soil except on Caimito volcanic, where kaolinite was the dominant clay mineral. Exchangeable Ca concentrations decreased with increasing soil depth except on Caimito marine. The weathering indices Chemical Index of Alteration (CIA), Plagioclase Index of Alteration (PIA) and Weathering Index of Parker (WIP) determined for five soils on all geological formations, suggested that in contrast to expectation the topsoil (0–10 cm) appeared to be the least and the subsoil (50–70 cm) and saprolite (isomorphically weathered rock in the soil matrix) the most weathered. Additionally, the weathering indices indicated depletion of base cations and enrichment of Al-(hydr)oxides throughout the soil profile. Tree species did not have an effect on soil properties. Impeded leaching and the related occurrence of overland flow seem to be important in determining clay mineralogy. Our results suggest that (i) edaphic conditions favor the formation of smectites on most lithologies resulting in high CEC and thus high retention capacity for Ca and (ii) that there is an external source such as dust or sea spray deposition supplying Ca to the soils.

1. Introduction

It has long been accepted by soil scientists that the soils of the tropics are as diverse as the landscapes in which they developed (Sanchez and Logan, 1992; Sollins et al., 1994). One of the misconceptions that persist is the presumed general infertility of tropical lowland soils (Sollins et al., 1994) on account of their advanced degree of weathering. Strong weathering results in the depletion of cationic nutrients, such as Ca, and in the prevalence of typical suites of low-activity clay minerals. This misconception, which Richter and Babbar (1991) traced back to the early 19th century, tacitly but wrongly assumes that tropical lowland soils neither receive any atmospheric input from volcanic, oceanic, anthropogenic or dryland sources (Boy and Wilcke, 2008; Kurtz et al., 2001; Likens et al., 1998; Wiegand et al., 2005), nor experience any denudation. While the former assumption was safely put to rest (Muhs et al., 1990; Pett-Ridge et al., 2009; Prospero et al., 1981), the latter received overdue scrutiny only recently (Bern et al., 2005; Porder and Chadwick, 2009; Vitousek et al., 2003; Zimmermann et al., 2012).

The macronutrient Ca in soil can have two sources: (i) minerals of the parent material like calcite or plagioclase (Plg) and (ii) deposition from the atmosphere resulting from external sources such as sea spray, volcanic exhalations, desert dust, or anthropogenic emissions (Boy and Wilcke, 2008; Kurtz et al., 2001; Likens et al., 1998; Wiegand et al., 2005). Central America is influenced by winds transporting Sahara dust over the Atlantic Ocean and depositing dust on Caribbean islands (Muhs et al., 1990; Pett-Ridge et al., 2009; Prospero et al., 1981). To our knowledge, there is no reported evidence for dust input in Panama yet, although Golley et al. (1976) reported a high flux of 37 $kg\ ha^{-1}\ yr^{-1}$ of Ca in throughfall in the Darién region.

Studies of toposequences of tropical soils on basaltic parent material revealed that the occurrence of smectite and kaolinite is related to topographic positions and drainage conditions. Smectites were identified on footslope positions with poor drainage and kaolinite on topslope positions with good drainage. On positions with intermediate drainage, interstratified kaolinite/smectite clay minerals occur with CEC of 250–1100 $mmol_c\ kg^{-1}$, depending on the proportion of kaolinite in the clay mineral (Bühmann and Grubb, 1991; Herbillon et al., 1981; Kantor and Schwertmann, 1974; Righi et al., 1998, 1999; Vingiani et al., 2004). In many mature tropical soils, pH-depending variable charge of organic matter is the major contributor to CEC (Sollins, 1987). However, Yavitt

* Corresponding author. Tel.: +41 316313896; fax: +41 316318512.
E-mail address: wolfgang.wilcke@giub.unibe.ch (W. Wilcke).

0016-7061/$ – see front matter © 2013 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.geoderma.2013.10.021

and Wright (2002) measured a point of zero net charge (PZNC) of pH <2 and showed that soils with a permanent charge dominate on BCI. This is corroborated by Baillie et al. (2007) who concluded from field evidence that smectites dominate in soils on Caimito marine and Bohio, and that kaolinitic clays dominate in soils on Andesite and Caimito volcanic. The report of Baillie et al. (2007) is based on 484 auger observation and 30 detailed soil profile descriptions. Johnsson and Stallard (1989) identified smectite as dominant clay mineral in stream sediments on Caimito marine and Bohio and to minor extent on Andesite and Caimito volcanic by XRD measurements of the fine-earth fraction.

Individual tree species affect nutrient cycling and thus soil properties in mixed forests in temperate climates because of different nutrient demands, rooting depths and litterfall characteristics as shown by Fujinuma et al. (2005), Dijkstra and Smits (2002) and Dijkstra et al. (2003). The fig species *Ficus insipida* Willd. and the cashew *Anacardium excelsum* (Bertero & Balb. ex Kunth) Skeels on BCI show contrasting Ca concentrations in fruits. Fruits of the figs had an average concentration of 11.9 ± 3.5 mg g^{-1} Ca in dry matter of pulp. On the other hand, fruits of cashew had an average concentration of 0.80 ± 0.25 mg g^{-1} Ca in dry matter of pulp (L. Albrecht, M. Tschapka and E. K. V. Kalko, personal communication). Because these data suggest a different Ca demand, we expected contrasting impacts of fig and cashew trees on the nutrient status in soils near these tree species.

On BCI, exchangeable Ca concentrations of around 300 $mmol_c$ kg^{-1} were reported and attributed to the marine facies of the Caimito formation (Yavitt and Wright, 2002; Yavitt et al., 1992) and to frequent rejuvenation of soil material (Johnsson and Stallard, 1989). These rejuvenation processes are likely either induced by tectonic uplift associated with high erosion rates (Nichols et al., 2005) or by a combination of near-surface flow induced by shallow impermeable soil layers and unprotected soil surface because of rapid decomposition of nutrient-rich leaf litter and a sparse understory caused by closed canopies (Zimmermann et al., 2012).

To investigate the reasons for the high CEC and base metal concentrations, our objectives were i) to evaluate two competing hypotheses regarding the origin of soil Ca in this lowland humid tropical environment — i.e. lithogenic vs. eolian, ii) to explain the mechanism of Ca retention, and iii) to assess the role of recycling in maintaining high soil Ca levels.

2. Material and methods

2.1. Study site

The study sites are located at latitude 9°08′–9°11′ N and longitude 79°49′–79°52′ W on Barro Colorado Island (BCI) in the Gatún Lake which was created in 1914 when the Panama Canal was dammed (Fig. 1). The island has a size of 15 km^2. The highest point of the island is 168 m above sea level and 138 m above lake level. The climate is classified as Tropical Monsoon [Am] in the Koeppen Climate Classification with a mean annual precipitation (MAP) of 2600 mm and a pronounced dry season between January and April with an average rainfall of around 90 mm (Windsor, 1990). Mean annual temperature is about 27 °C with a diurnal range of 8–10 °C and a monthly deviation of 2 °C (Leigh, 1999). Vegetation is classified as a Tropical Moist Forest in the Holdridge system (Holdridge and Budowski, 1956). Barro Colorado Island consists of three geological formations of Oligocene to Miocene age. Two are of sedimentary origin (the Bohio and Caimito formations), while the third is an andesitic lava flow capping the center of the island. The oldest formation is the Bohio formation dating back to the early Oligocene, which forms the northwestern part and stretches from north to south through the center of the island. Of the 300 m-thick formation, only the uppermost 125 m are exposed on BCI. This formation consists mainly of coarse basaltic conglomerates, set in a sandy matrix of volcaniclastic origin. Clasts are spherically weathered and attain diameters of cm to meters; most clasts range from 5 to 10 cm (Johnsson and Stallard, 1989; Woodring, 1958). The andesite lava flow is of early Miocene age and caps the central part of the island. It is a resistant, non-vesicular, phenocrystic andesite reaching a thickness of 85 m (Woodring, 1958). The mineral assemblage mainly contains plagioclase,

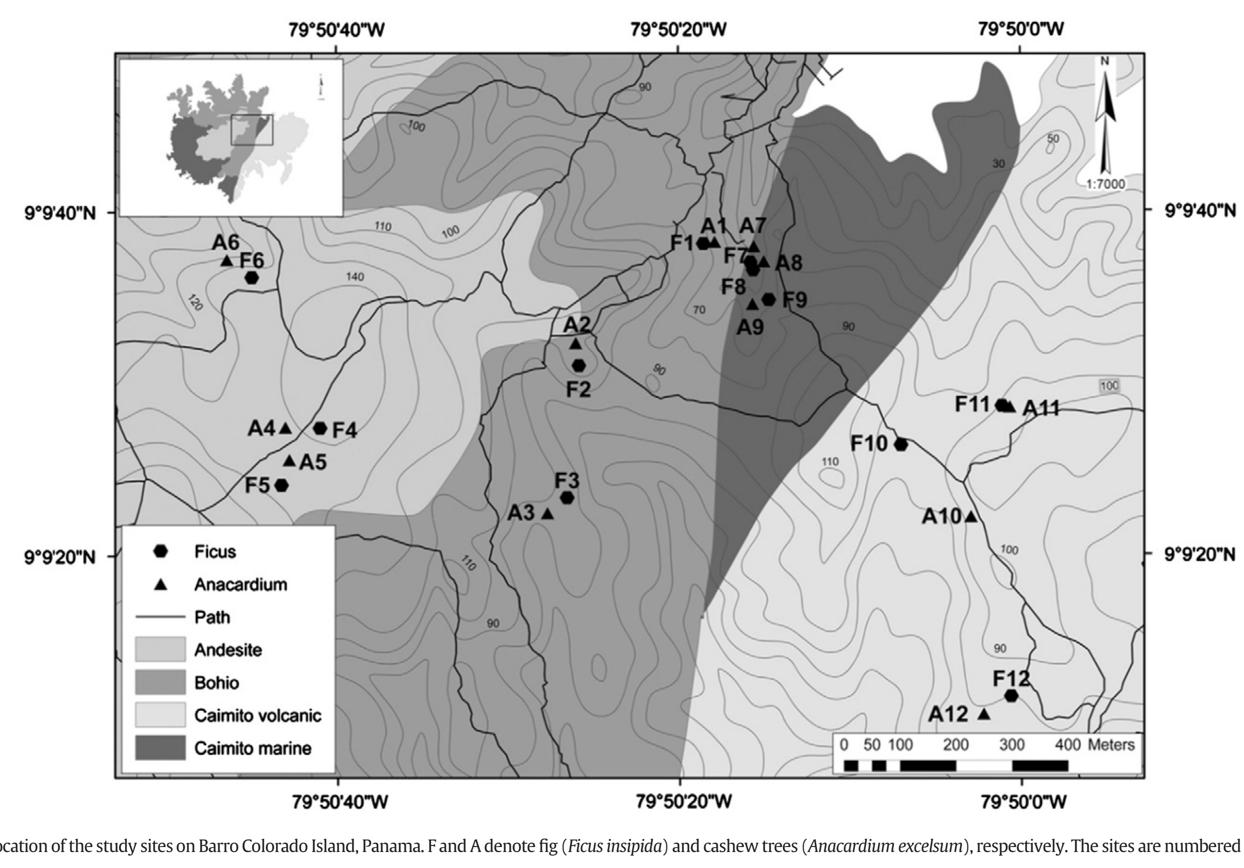

Fig. 1. Location of the study sites on Barro Colorado Island, Panama. F and A denote fig (*Ficus insipida*) and cashew trees (*Anacardium excelsum*), respectively. The sites are numbered from 1-12.