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Buried black soils on the slopes of Mt. Kilimanjaro as a regional carbon storage hotspot

Michael Zech [a,b,*], Claudia Hörold [a], Katharina Leiber-Sauheitl [a], Anna Kühnel [a], Andreas Hemp [c], Wolfgang Zech [a]

[a] Institute of Soil Science and Soil Geography, Department of Soil Physics and Institute of Geomorphology, University of Bayreuth, D-95440 Bayreuth, Germany
[b] Institute of Agronomy and Nutritional Sciences, Soil Biogeochemistry, Martin-Luther University Halle-Wittenberg, Von-Seckendorff-Platz 3, 06120 Halle, Germany
[c] Department of Plant Systematics, University of Bayreuth, D-95440 Bayreuth, Germany

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ABSTRACT

Mt. Kilimanjaro attracts much scientific and public attention due to its dramatically shrinking ice caps, still known as “the white top” of Africa. In this mountain system forming a type of island within the surrounding savannah, a new phenomenon has recently been discovered. On the slopes of Mt. Kilimanjaro, Late Quaternary paleosol sequences, composed of dark or black buried soils, are widespread in the montane rainforest zone (1800–3000 m a.s.l.). In this study we investigated in detail the soil organic carbon (SOC) content and SOC stocks in soil profiles (mostly Andosols) along two altitudinal transects, situated on both the humid southern slopes and on the drier northern slopes of the mountain.

In the montane forest zone, up to 3 m thick paleosol sequences are frequently found. SOC content is remarkably high, reaching values of up to more than 10%. This testifies to good preservation of soil organic matter (SOM) which may be due to such factors as rapid burial by dust, low temperatures alongside more resistant litter during glacial periods, formation of stable organo-mineral complexes and high black carbon (BC) content. The buried black soils are estimated to contain ~82 kg m^{-2} mean SOC stocks in the montane rainforest. As compared to the SOC storage in the surrounding savannah soils of the Maasai Steppe, the buried black soils constitute a distinctive regional carbon storage hotspot.

1. Introduction

For many years, the rapidly shrinking ice caps on Mt. Kilimanjaro have attracted much attention in the scientific community as well as among the general public (Cullen et al., 2006; Thompson et al., 2002). By contrast, the occurrence of buried and humus rich soils on the slopes of the ancient volcano was noticed only recently (Little and Lee, 2006; Zech, 2006; Zech et al., 2011b). However, it has in the meantime become clear that sequences up to 3 m thick of such buried soils developed almost area-wide, particularly in the modern rainforest zone at elevations ranging from ~1800 m to 3000 m a.s.l. These sequences comprise manifold buried horizons, including black and humus-rich, brown and clayey, gray and bleached, or rust-colored and iron-enriched horizons (Fig. 1). The soils can be classified as Andosols (WRB, 2006). Although recent studies (Zech, 2006; Zech et al., 2011b) pointed to the remarkably high soil organic carbon (SOC) content of up to more than 10%, especially in the black buried soils, none of these studies has highlighted the role of these paleosol sequences for SOC storage.

Due to global warming, carbon sequestration, carbon dioxide release and carbon storage in soils are highly relevant issues (Schaefer et al., 2011; Schmidt et al., 2011; Shaver et al., 2006). On a global scale and in terms of carbon storage per hectare, permafrost soils in high latitudes and Chernozems in mid-latitude steppe regions exhibit outstanding soil organic carbon (SOC) storage (Mikhailova and Post, 2006; Tarnocai et al., 2009; Zech et al., 2011c; Zimov et al., 2006), whereas Acrisols, Ferralsols, Lixisols, Nitisols and Vertisols, which prevail in East African savannah regions, typically have a much lower SOC content (Batjes, 2008; Zech and Hintermaier-Erhard, 2002). Notably, in previous studies conducted in other tropical volcanic regions such as Colombia, Central Mexico or South Japan it was pointed out that high SOC preservation in Late Pleistocene tephra-paleosol sequences is a common and widespread phenomenon (Fölster et al., 1977; Inoue et al., 2011; Sedov et al., 2001; Sedov et al., 2003b).

In this study we therefore investigate in detail the SOC content and stocks of sequences of buried soils which are situated along two altitudinal transects; one along the humid southern slopes and one along the drier northern slopes of Mt. Kilimanjaro. We discuss various possible factors contributing to the exceptionally high SOC stocks

* Corresponding author at: Institute of Soil Science and Soil Geography, Department of Soil Physics and Institute of Geomorphology, University of Bayreuth, D-95440 Bayreuth, Germany. Tel.: +49 (0)921 552172.
E-mail address: michael_zech@gmx.de (M. Zech).

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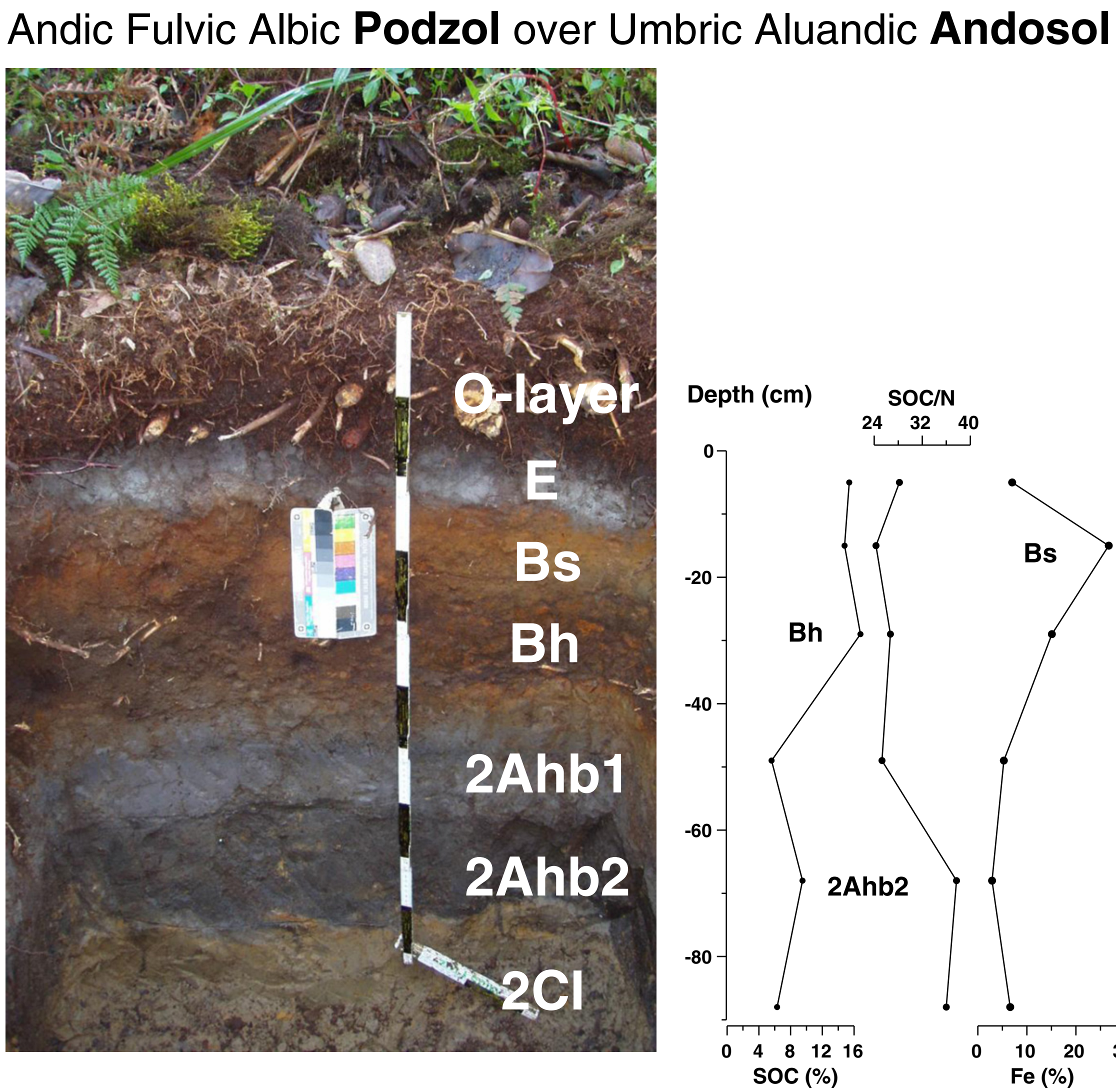

Fig. 1. Typical sequence of buried soils in the montane rainforest zone. It illustrates the soil profile investigated at 2650 m a.s.l. on the southern slopes of Mt. Kilimanjaro and its horizonation. It can be classified as Podzol over Andosol. To the right, the depth-function for SOC reveals maxima for the Bh and the 2Ahb2 horizon, a TOC/N maximum in the 2Ahb2 horizon (indicating ericaceous vegetation) and a Fe maximum in the Bs horizon.

achieved by the buried soils and compare them to those of the surrounding savannah soils.

2. Study area

2.1. Climate, vegetation and soils

Mt. Kilimanjaro, the "white roof of Africa", is located in Tanzania, equatorial East Africa, close to the border to Kenya (2°45′ and 3°25′ S, 37°00′ and 37°43′E). The ancient volcano comprises three formerly active eruption centers, with Kibo peak, the youngest volcanic cone, rising from the surrounding savannah plains at an elevation of ~700 m a.s.l. to 5895 m altitude. The parent rock consists of basalts, olivine basalts, trachytes and phonolithes (Dawson, 1992). As it is influenced by the Innertropical Convergence Zone (ITCZ), Mt. Kilimanjaro experiences two rainy seasons; a weak one in November/December and a strong one in April/May (Rohr and Killingtveit, 2003). Furthermore, precipitation depends on exposure, with the northern leeward slopes being more arid and the southern slopes, capturing the southeast trade winds coming from the Indian Ocean, being more humid. Precipitation maxima of up to 3000 mm/year occur between 2000 and 2400 m a.s.l.; above and below this, precipitation decreases considerably within a short distance.

As a result of the climatic zonation, vegetation as well is strongly differentiated along the altitudinal gradient, similar to other East African mountains (Hedberg, 1951); a recent detailed description of the vegetation zones on Mt. Kilimanjaro is provided by Hemp (2006). In brief, the savannah and cultivated land extend up to ~1800 m a.s.l. (Fig. 2). This zone is used intensively for cropping and grazing. The savannah soils can be classified as Acrisols, Ferralsols, Lixisols, Nitisols and Vertisols (WRB, 2006), whereas at higher altitudes Andosols predominate (Zech et al., 2011b). Above ~1800 m a.s.l., different submontane and montane forest types follow (e.g., lower and middle montane *Cassipourea* forest and upper montane *Hagenia-Podocarpus* forest, Hemp, 2006). Human impact decreases, but still exists, in the form of timber logging and gathering firewood. Soils are mostly Umbric and Aluandic Andosols characterized by the frequent occurrence of buried soils. Between 3100 and 3500 m a.s.l., *Erica excelsa* forests are replaced by subalpine *Erica trimera* heathland. Hemp and Beck (2001) noted that the modern occurrence and expansion of *E. excelsa* can be attributed partly to its fire tolerance due to rapid regeneration by sprouting. Topsoils are typically folic, histic or umbric horizons (WRB, 2006).