Geoderma 264 (2016) 103–116

Contents lists available at ScienceDirect

Geoderma

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

Unexpected calcium sources in deep soil layers in low-fertility forest soils identified by strontium isotopes (Lorraine plateau, eastern France)

Lea Bedel [a,b], Anne Poszwa [b,*], Gregory van der Heijden [a], Arnaud Legout [a], Luc Aquilina [c], Jacques Ranger [a]

[a] INRA UR BEF 1138 Biogéochimie des Ecosystèmes Forestiers, 54280 Champenoux, France
[b] Université de Lorraine, CNRS UMR 7360 LIEC Laboratoire Interdisciplinaire des Environnements Continentaux, 54500 Vandœuvre-lès-Nancy, France
[c] Université de Rennes 1, CNRS UMR 6118 Géosciences, 35000 Rennes, France

ARTICLE INFO

Article history:
Received 2 March 2015
Received in revised form 11 September 2015
Accepted 22 September 2015
Available online 24 October 2015

Keywords:
Forest soils
Tree nutrition
Polycyclic soils
Ca and Mg cycles
Sr isotopes
Groundwater

ABSTRACT

Forest ecosystems are often found on acid soils where calcium availability depends on two main inputs (atmospheric deposition and the weathering of soil minerals) and on the biological cycling of nutrients. In the context of global change (decreasing atmospheric inputs, increasing biomass exportation, climate change), it is important to determine calcium sources to the ecosystem and tree nutrition to better understand how forest ecosystems will respond to these changes over time. The aim of this study was to study and compare Ca pools and cycling in two mature forest ecosystems (Clermont en Argonne and Azerailles) developed on two contrasting polycyclic soils (Lorraine plateau, eastern France) and identify the Ca sources contributing to ecosystem functioning. At both sites, soil Ca pools were measured; atmospheric deposition of Ca was monitored from bulk precipitation and throughfall chemistry; Ca biological cycling was assessed by measuring litterfall and by a litter decomposition experiment; strontium ($^{87}Sr/^{86}Sr$) isotope data in the soil profile (fine roots, exchangeable pool, bulk soil) was used to estimate the distribution of Sr and Ca uptake in the soil profile and the relative contribution of mineral weathering in the soil layers to total ecosystems inputs. Despite important differences in Ca availability in the topsoil between both sites, tree growth and nutrition indicators showed no significant difference. This discrepancy is not explained by the biological cycling of Ca but may be partly explained by higher Ca deposition at the Ca-poorer site. Strontium isotope data enabled to show important differences of Ca sources for tree uptake. At the Ca-poorer site, deep soil layers (>105 cm) potentially represent from 32% to 100% of total Sr uptake. At the Ca-richer site, results suggest that uptake is more evenly distributed in the soil profile. Sr isotope data coupled with a modeling approach suggest that two different mineral sources exist in the soil profile: a radiogenic Sr source in the topsoil ($^{87}Sr/^{86}Sr > 0.717$) and a less radiogenic source in depth ($^{87}Sr/^{86}Sr < 0.717$). The deep mineral source may represent from 40% to 86% of total Sr inputs at the poorer site and from 25% to 86% at the richer site. The origin of this deep strontium source is unclear but soil mineralogy suggests an allochthonous origin. We hypothesize that this deep source originates from capillary rise of the groundwater aquifer. This nutrient input to forest ecosystems is not commonly taken into account but may strongly participate in maintaining the chemical fertility of soils over time.

1. Introduction

Bioavailable Ca and Mg pools in extensively managed ecosystems are assumed to originate from two dominant sources: atmospheric deposition and weathering of soil minerals (Ranger and Turpault, 1999). The biological cycling of nutrients (returning nutrients taken up from the soil profile to surface soil horizons) supports tree nutrition and limits impoverishment of the most sensitive soils (Attiwill and Adams, 1993; Legout et al., 2008). Understanding Ca and Mg cycling in forest ecosystems is essential to characterize the sustainability and impacts of different forest practices in order to optimize the management of soil and forest resources.

In many case studies, discrepancies between conventional approaches and indicators have been observed. Low available Mg and Ca pools and Ca and Mg depletion were not reflected in tree growth, nutrition and health indicators (van der Heijden et al., 2013). Over studies have shown discrepancies between measured soil nutrient pool change and predicted change using nutrient input–output budgets (Hazlett et al., 2011; Johnson et al., 2008; van der Heijden et al., 2011; van der Heijden et al., 2014). These discrepancies suggest that tree access nutrient sources which are not currently taken into account and highlight the limits of conventional approaches to study nutrient cycling and identify nutrient sources.

The use of isotope ratio data, in either natural abundance variation (Bolou-Bi et al., 2012; Fantle and Tipper, 2014) or isotopic labeling studies (van der Heijden et al., 2015), coupled with conventional approaches has proven to be a powerful tool to trace sources and processes in forest

* Corresponding author at: LIEC, Faculté des Sciences et Technologies, Boulevard des Aiguillettes, BP 70239, 54506 Vandoeuvre-les-Nancy, France.
E-mail address: anne.poszwa@univ-lorraine.fr (A. Poszwa).

http://dx.doi.org/10.1016/j.geoderma.2015.09.020
0016-7061/© 2015 Elsevier B.V. All rights reserved.

ecosystems. The use of $^{87}Sr/^{86}Sr$ ratios is a useful tool to trace Sr and Ca sources and to estimate the relative contributions of weathering and atmospheric deposition to soil bioavailable stocks and to tree nutrition (Capo et al., 1998). Strontium isotope ratios are more easily measured than Ca isotope ratios and although isotopic fractionation of the $^{88}Sr/^{86}Sr$ isotope ratio has been observed (de Souza et al., 2010; Halicz et al., 2008), no measurable fractionation between ^{87}Sr and ^{86}Sr isotopes has been observed during biological, physical and chemical reactions. The use of strontium isotope data enables to trace Sr and therefore Ca sources for tree nutrition in forest ecosystems. For example, in two mixed beech and oak forests in Belgium, (Drouet et al., 2005) showed that atmospheric deposition contributes from 75 to 78% of total Ca annual tree uptake. Sr isotope data has also been used to study the distribution of tree uptake in the soil profile (Drouet et al., 2015) and compare uptake distribution between tree species (Poszwa et al., 2004). Sr isotope data has also enabled to study the sources of Sr in soil solutions: (Wiegand and Schwendenmann, 2013) showed in a study of four geographically close watersheds in Costa Rica that rainfall contributes up to 95% of soil solution Sr in one watershed while in the other three watersheds bedrock groundwater contributes up to 60% of soil solution Sr.

The aim of this work was to study and compare Ca pools and cycling in two mature forest ecosystems developed on two contrasting polycyclic soils (Lorraine plateau, eastern France) and identify the Ca sources contributing to the biogeochemistry of the ecosystem. The classic approach of measuring stocks and fluxes was supplemented with the use of Sr isotopes to trace Ca origins in both ecosystems.

2. Material and methods

2.1. Site description

Two experimental sites were set up in deciduous forests of the Lorraine plateau (North-East of France — Fig. 1). The first stand (mixed beech and oak), located in the “Grand Pays” forest at Clermont en Argonne (49° 06′ 23″ N, 5° 04′ 18″ E), is developed on a “gaize” bedrock (Gaize d'Argonne, Cenomanien), a permeable silicate sedimentary rock, poor in weatherable minerals. The second stand (beech, oak, birch and maple), located in the “Hauts-Bois” forest at Azerailles (48° 29′ 19″ N, 6° 41′ 43″ E), is developed on marls (Triasic/Keuper) with completely decarbonated in surface, covered by a quaternary alluvial loamy deposit about 50 cm thick. The elevation of the Clermont en Argonne (CA) and Azerailles (AZ) sites are respectively 270 and 300 m a.s.l. The mean annual temperatures are 9.5 °C (CA) and 9 °C (AZ) and mean annual rainfall (average over 30 years) approximately to 900 (AZ) and 1000 mm (CA) (Kessler and Chambraud, 1986).

2.1.1. Soil description

Soils of the two sites are classified as Luvisols according to the World Reference Base for Soil Resources (WRB., 2014) and polycyclic Neoluvisols according to the Référentiel Pédologique (Baize and Girard, 2008). At both sites, soils have an analogous physical structure. They are constituted of two clear different units: one is dominated by silt in the first fifty cm, the second, corresponding to deeper horizons, is characterized by a strong increase in clay content. This causes a temporary perched water table to invade the loamy horizon during wet periods. The materials composing the different units are different at both sites. At Clermont en Argonne, the existence of these two units is illustrated by a soil texture discontinuity around 40 cm depth (15% clay [0–40 cm] and 30% [40–110 cm]). The nature of clays varies with depth (with vermiculites in the soil surface layers and smectite in deep horizons in addition to kaolinite, illite and interstratified clays present throughout the profile (Figure A in supplementary material). Another discontinuity exists for sodium Na and titanium Ti and for trace elements (such as Y or Pr). At Azerailles, in addition to a soil texture discontinuity (25% of clays in the [0–40 cm] layer and more than 50% [40–110 cm]), a layer of round pebbles of quartz from the Vosges

Fig. 1. Location of experimental sites in the north-east of France. The Clermont en Argonne site is shown in red and the Azerailles site in blue.