Use of the (228Ra/226Ra) isotopic ratio to quantify timescales and biogeochemical cycle of alkaline earth cations in soil-plant ecosystems

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Résumé

The alkaline-earth nature of radium leads to behavior similar to calcium in ecosystems. Beyond its relevance as a radioactive nuclide posing radiation hazards, understanding the biogeochemical cycle of Ra can provide insights into the calcium cycle. This study aims to establish the biogeochemical cycling, including timescale information, of Ra among the organo-mineral compartments of forest ecosystem. The study was conducted at the experimental Montiers (INRAE-Andra site, France) and Strengbach watershed (OHGE site, France) beech-forested site. The activities of 228Ra, 226Ra, 230Th and 232Th were measured across various ecosystem compartments (soil solutions, vegetation, and mineral soil fractions). Radium isotopic ratio can provide crucial insights due to the short half-life of 228Ra (5.7 y). The decay of 228Ra isotope produces significant variations in the (228Ra/226Ra) ratio throughout the biological cycle that enabled quantification of slow Ra translocation from roots to leaves, which ranged from 1 to over 16 years, increasing with the age and/or the size of the tree. This range of values was consistent with the previously assessed long ascent time estimation for Ca and Mg that did rely on injection studies of marked isotopes. These previous studies required a lengthy waiting time, i.e.: the transfer duration. The use of the (228Ra/226Ra) isotopic ratio provides a convenient means to determine alkaline earth cations transport time without waiting several years. In addition, the (228Ra/232Th) disequilibrium within the soil profile enabled estimation of Ra leaching fluxes and subsequent vegetation uptake. Allocation of this flux among tree compartments revealed that 34–80% of Ra taken up by vegetation was stored in long-lived, perennial tree structures rather than in annual or newly formed biomass. This pattern underscores the persistence of active tree compartments over years, and highlights the necessity of detailed analyses across all tree compartments, including radial variations in sapwood, to avoid underestimating vegetation uptake of alkaline-earth cations. This study demonstrates the value of Ra isotopes for investigating the alkaline-earth cations cycle, elucidating the origins of fluxes and soil leaching rates that govern vegetation uptake and providing valuable timescale information that is difficult to obtain for Ca or other nutrient-related alkaline-earth cations.

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