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Experimental determination of magnesium isotope fractionation during higher plant growth

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Magnesium is an essential element in biological systems: Mg regulates key enzymes implied in nitrogen and phosphorus metabolisms and binds different ribosome subunits during protein synthesis. It is also the central core of the chlorophyll molecule. Plants mobilize Mg mainly from silicate rocks and take it up as Mg^{2+} ion from soil solutions. 70% of this Mg remains mobile in plants, ie constantly recycled between the various organs (roots, stem and shoots). Plants contain typically $\sim$2000 ppm; representing about 2.5 Gt Mg worldwide. For comparison, this is equivalent of what the Amazon exports to the ocean during 400 yrs. The biological cycle can therefore affect Mg availability for clay formation in soils and for its transport in natural waters.

Precise Mg isotope measurement is a new tool to quantify the role of biological processes such as root uptake, Mg translocation and distribution within plant organs on the continental Mg cycle. δ^{26}Mg of commercial and natural chlorophylls range from -3.55 per mill to 0.09 per mill and δ^{26}Mg measured recently for bulk plants fall within this range. In this study, two plant species, clover and rye-grass, were experimentally grown on two substrates highly enriched in Mg (phlogopite, nutritive solution). Some of the roots harvested at the end of an hydroponic culture were leached using $CaCl_2$ (0.1M) in order to analyze the adsorbed Mg. A second experiment was performed using dead and living clover and rye-grass roots: roots were first immerged in HCl (0.5N) in order to remove all potential adsorbed ions, and then in a pure Mg solution for 1, 5, 30 and 60 min at pH 6. Mg isotope compositions ($\delta^{25}Mg_{DSM3}$ and $\delta^{26}Mg_{DSM3}$) were measured using the Nu Plasma MC-ICP-MS after separation by ion exchange resin.

For both species and both substrates, bulk plants are significantly enriched in the heavy isotope relative to the Mg source ($\Delta^{26}Mg_{plant-source}$range from 0.40 per mill to 0.60 per mill for rye-grass and 0.60 per mill to 0.90 per mill for clover). Both species also exhibit a similar trend from roots to shoots: roots are significantly enriched in heavy isotopes relative to the solution ($\Delta^{26}Mg_{root-source}$ = 0.59 per mill to 0.77 per mill), and shoots are systematically slightly lighter than roots ($\Delta^{26}Mg_{shoot-root}$ = -0.10 per mill to -0.60 per mill). Mg desorbed from plant roots grown hydroponically is significantly enriched in the heavy isotope (by $\sim$0.70 per mill). Similarly, adsorption experiments using living roots leads to a significant depletion in heavy isotopes of the residual solution (from $\delta^{26}Mg_{DSM3}$= -1.12 per mill at t= 0 min to $\delta^{26}Mg_{DSM3}$= -4.24 per mill and -3.45 per mill at t=60 min for rye-grass and clover respectively). In plants in general, 10 to 15% of leaf Mg is located within the chlorophyll, 35% is associated with proteins and 50% is free as Mg^{2+}. Postulating that protein synthesis is associated with Mg isotope fractionation in favor of heavy isotopes, a simple model has been developed for fitting the measured isotope compositions, considering (1) constant isotope composition of the Mg source (2) Mg distribution between plant organs and (3) internal Mg recycling from shoots to roots. Further investigations include studies of the role of plants in the Mg biogeochemical cycle and water isotope compositions on a catchment scale.