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Enriched Stable Isotope Tracer Techniques to Quantify the Fate of Fertilizer-Applied Trace Metals in Agroecosystems

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Enriched stable isotope tracer techniques have been demonstrated to provide precise information regarding nutrient use efficiency from fertilizers, as well as the fate of fertilizer-applied contaminants in agroecosystems. While these techniques have been extensively utilized for major nutrients such as nitrogen, their application to trace metals remains limited. A set of plant growth and lysimeter experiments were conducted to explore the potential of enriched stable isotope techniques in examining the fate of the contaminant cadmium (Cd) and the micronutrient zinc (Zn) in agroecosystems. To this end, mineral and complex organic fertilizers containing Cd and/or Zn were applied to arable and grassland soils typical for Switzerland. Initial methodological tests demonstrated that simplified purification procedures in conjunction with single collector ICP-MS analytics facilitate the adequate resolution of enriched $^{111/110}$Cd and $^{67/66}$Zn isotope ratios while ensuring a high sample throughput. The application of these fit-for-purpose workflow demonstrated that less than 3% of the Cd that was applied with mineral phosphorus fertilizer reached the plant. The remaining 97% of the Cd was mostly deposited in mobilizable soil pools, while only a minor fraction was immobilized in the soil or leached out of the soil profile. A similar phenomenon was observed for Zn, where less than 12% of the Zn applied with mineral and different organic fertilizers was directly transferred from the fertilizers to the plant. Consequently, most of the Cd and Zn applied with mineral and organic fertilizers accumulated in the soil as a residual pool. This residual pool can contribute to a critical accumulation of these trace metals in the soil, thereby threatening soil functions in the mid- and long-term. While these pioneering studies have demonstrated the feasibility of precisely quantifying the fate of fertilizer-applied trace metals using enriched stable isotope tracer techniques, their scope can be further expanded. To this end, enriched stable isotope tracer techniques could be combined with isotope-sensitive imaging (e.g., NanoSIMS) and speciation methods (e.g., SEC-ICPMS) to gain novel insights into the biogeochemical processes that control the fate of fertilizer-applied trace metals in agroecosystems.