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Utilizing strontium isotopes to trace fertilizer-derived metal(loid) accumulation in the soil-wheat system

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The application of mineral and organic fertilizers is a routine agricultural practice to optimize crop yield by supplying essential nutrients required for plant growth. Mineral fertilizer application causes unintended negative impacts on soil quality such as soil acidification. Additionally, mineral fertilizers are often enriched in contaminant trace metals, such as uranium, cadmium, chromium, and vanadium, which have associated long-term environmental and human health risks. Therefore, the reintegration of organic fertilizers into agricultural management is of ongoing interest to improve soil and crop quality. However, the extent to which different fertilizers contribute to metal(loid) enrichment remains insufficiently explored. In this study, we analyzed soil and wheat grain samples collected between 2000 and 2021 from the Static Fertilization Experiment (SFE) in Bad Lauchstädt, Germany. This site has maintained constant fertilization regimes since 1902, including no fertilization, mineral fertilization, organic fertilization, and mixed mineral+organic fertilization. Using crop yields, soil parameters, and metal(loid) concentrations, we examined the movement of select metal(loid)s from soils to crops and utilized the $^{87}Sr/^{86}Sr$ ratio as a fingerprinting tool to trace fertilizer-derived metal(loid)s' enrichment.

We found that fertilization increased the soil concentrations of Cd, Pb, As, and U in fertilized soils. While mineral and mixed fertilization increased concentrations of U and As, organic and mixed fertilization increased concentrations of Cd and Pb. Moreover, the mobile soil fractions showed significant increases for Cd due to mineral fertilization, while As and V significantly increased in all fertilization practices. In the wheat grain, mineral fertilization significantly increased Cd contents, while mixed fertilization significantly increased As contents. The $^{87}Sr/^{86}Sr$ ratio of both the total and mobile soil fraction, were affected by fertilization management and indicative of the fertilizer applied. Consistently, wheat grains inherited the $^{87}Sr/^{86}Sr$ ratio of the fertilizer applied, where the $^{87}Sr/^{86}Sr$ signature of mineral fertilizer was detected and dominant in the mixed fertilization treatment. Overall, we demonstrated unique metal(loid) enrichment trends arising from fertilization and the utilization of $^{87}Sr/^{86}Sr$ as a tracer for fertilizers impact in the soil-wheat system. These findings emphasize the need for careful fertilization strategies to mitigate contaminant accumulation in agricultural soils and products.