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Rare earth elements as potential tracers of carboxylate-based plant nutrition strategies

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Phosphorus (P) and iron (Fe) are limiting nutrients in many (agro-)ecosystems. Due to P-sorption under most soil conditions, the current P-fertilization practices are inefficient, since large quantities of the P fertilizer applied remain in the soil as a residual part. Therefore, the development of sustainable agricultural practices urgently needs to improve nutrient-acquisition efficiencies of crop species through rhizosphere engineering and breeding of low-input strains. The availability of nutrients in the rhizosphere, especially that of P, is dependent on the activity of roots and associated microbes, particularly their ability to acidify the surrounding soil and release chelating compounds such as carboxylates. Therefore, there is a growing interest among plant ecologists, breeders and agronomists in "easily-measurable" tools to trace belowground functional traits in nutrient acquisition under soil conditions. Here, we explore the idea to use rare earth elements (REEs) in plant material to evaluate the nutrient-acquisition strategy, particularly under nutrient limitation. The rationale behind this hypothesis is that i) REEs are present in almost all soils at quantities similar to some plant nutrients such as Cu and Zn, ii) REEs interact with nutrient-bearing soil phases (phosphates, Fe-oxyhydroxides), iii) root exudates released under P/Fe deficiency strongly mobilize REEs in soil, and iv) the uptake of mobilized REEs in plants depends on their chemical form, which is a function of rhizosphere chemistry. Preliminary results from greenhouse and large-scale field experiments indicate that P-inefficient species show different REE-concentrations in their leaves than P-efficient species, and that the pattern of REEs is related to the composition of root exudates. In ongoing experiments, this hypothesis will be rigorously tested by coupling a field sampling campaign of plant material from species with contrasting nutrient-acquisition strategies along soils with changing nutrient availability (Western Australian chronosequences) as well as controlled greenhouse experiments for mechanistic elucidation of processes involved.