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Titel
Extractability of different forms of mineral-associated phosphorus

Abstract
The sequential extraction scheme introduced by Hedley et al. (1982) and modified by Tiessen and Moir (2008) has become the preeminent measure for estimating biological availability and binding forms of phosphorus in soil. However, the method's underlying assumptions, especially on the binding forms, have never been subjected to rigorous testing under defined conditions. We reacted different forms of phosphorus (orthophosphate, phytic acid, RNA) with several potentially phosphorus-binding mineral phases (kaolinite, montmorillonite, goethite, ferrihydrite, amorphous Al hydroxide, allophane) at pH 4. Then, the phosphorus-loaded mineral phases were rinsed for removal of excess phosphorus compounds, shock-frozen in liquid N_2 and freeze dried. Each 1 g of phosphorus-loaded samples was then mixed with 9 g of purified quartz (sieved to <63 µm) to mimic relations of reactive and nonreactive mineral phases in soil. All samples were then subjected to sequential extraction in line with the Hedley fractionation scheme (water?resin extraction, extraction with 0.5 M $NaHCO_3$, extraction with 0.1 M NaOH, extraction with 1 M HCl, extraction with concentrated HCl at 80°C). All extracts were analysed for orthophosphate and total phosphorus. The minerals retained different amounts of phosphorus compounds, with the hydrous metal oxides and allophane binding orthophosphate and most of the organic species most strongly. Clay minerals showed the weakest binding of phosphorus compounds. The water?resin extraction mobilised surprisingly large portions of orthophosphate from all mineral phases and also some of the organic compounds. The $NaHCO_3$ and NaOH extracts removed increasing portions of phosphorus compounds. Amorphous Al hydroxide largely dissolved in 1 M NaOH; the iron oxides and allophane, however, withstood the alkaline extraction. Treatment with 1 M HCl resulted in further release of phosphorus compounds from all minerals, especially from ferrihydrite. The assumption of the Hedley fraction that the 1 M HCl extraction represents exclusively Ca-bound phosphorus, thus, is obviously wrong. In summary, phosphorus forms bound to different minerals contribute to all extracts. Thus, the individual extraction steps of the Hedley do not represent phosphorus bound to certain compounds but phosphorus bound to various mineral phases via bonds of different strength.

Literatur
Hedley MJ, Stewart JWB, Chauhan BS (1982) Changes in inorganic and organic soil phosphorus fractions induced by cultivation practices and by laboratory incubations. Soil Science Society of America Journal 46, 970-976.
Tiessen H, Moir JO (2008) Characterization of available P by sequential extraction. In: Carter MR, Gregorich EG (eds) Soil Sampling and methods of analysis. CRC Press, Boca Raton, pp 293-306.