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Phosphorus-bearing particles in agricultural drain water: Synchrotron XRF microscopy, P *K*-edge XANES and X-ray diffraction

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Particulate forms constitute a large part of phosphorus (P) leached from agricultural soils. We applied spectroscopic and traditional chemical analyses on drain water from five experimental fields in Sweden. Flow-proportional sampling in tile drains was performed fortnightly during winter and spring 2019. Soil parent material was Quaternary clayey–silty (four fields) and sandy (one) deposits, formed under brackish or marine water in the early Holocene, and emerging 11,000–2,400 years before present during postglacial rebound.

Most drain-water P was associated with particles >0.45 µm, which were isolated and characterised as follows. According to P *K*-edge XANES, P-associations with Al and organic matter were dominant in waters from all fields; each of the two categories represented 25–50 % of particle-bound P. Organic P was further indicated by spatial co-occurrence of P with organic S according to µ-XRF imaging and S *K*-edge µ-XANES. Fe-bound P was less abundant, at most 25 %, and typically occurring in slightly acidic waters high in dissolved sulphate, suggesting that pyrite oxidation in the soil resulted in formation of Fe(III)-colloids that sequestered P from the solution. Ca–P associations, typically 10–30 %, were low in the acidic waters but more prominent in more alkaline waters, which were not far from equilibrium with respect to apatite and calcite.

The drain-water particles were otherwise dominated by crystalline phases quartz, feldspars and 2:1 clay minerals, of which the latter generally made up a larger proportion, 40–80 %, than found in soil clay fractions isolated from the corresponding soil profiles and analysed by X-ray diffraction of parallel-oriented specimens. Drain-water particles furthermore contained 3–6 % organic matter and up to 2 % non-crystalline Al-, Si- and Fe-phases (oxide basis) according to oxalate extractions. Although a small percentage, the latter phases generally represented a sufficient nominal sorption capacity to explain the Al- and Fe-bound P forms found by P *K*-edge XANES. Oxalate-extractable P in leached particles was similar to the maximum concentration in the corresponding soil profile; apparently particles rich in P were not filtered off during passage through the soil.