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Effects of flooding on phosphorus and iron mobilization in highly weathered soils: Short-term effects and mechanisms

Deejay Maranguit
Department of Soil Science, Visayas State University, Baybay, 6521-A Leyte, Philippines (maranguitdeejay@gmail.com)

The strong affinity of phosphorus (P) to iron (Fe) oxides and hydroxides in highly weathered tropical soils limits P availability and therefore plant productivity. In flooded soils, however, P fixed by Fe oxides and hydroxides can be released and transformed to a more available form because of Fe^{3+} reduction to Fe^{2+}. These P dynamics in flooded soils are well documented for rice paddies. Such effects are much less studied in other land-use types under the influence of seasonal flooding, especially in the tropics during heavy monsoon rains. The aim of this study was to investigate the mobilization of P during flooding leading to anaerobic conditions in topsoil and subsoil horizons depending on land-use type. Samples were collected in highly weathered soils from four replicate sites under natural rainforest, jungle rubber, rubber and oil palm plantations in Sumatra, Indonesia. Topsoil and subsoil were taken to ensure a wide range of soil organic matter (SOM) and P contents. Soils were incubated under anaerobic, flooded conditions at 30 ± 1 oC for 60 days. Our results confirmed the hypothesis that soil flooding mobilizes P and increases P availability. Two distinct and opposite phases, however, were observed upon flooding. During the first three weeks of flooding, the dissolved P (DP) concentration peaked, simultaneously with a peak of dissolved Fe^{2+} (DFe^{2+}) and dissolved organic carbon (DOC) in the soil solution. After three weeks, P availability in soils decreased, although Fe-P and available P did not reach initial, pre-flooding levels. Accordingly, Fe dissolution and P mobilization were reversible processes. Furthermore, land-use type influenced the impacts of flooding on P and Fe forms mainly in the topsoil, where P dissolution and availability were generally higher under forest and, to a lesser extent, under jungle rubber. A positive correlation between DOC and DFe^{2+} ($R^2 = 0.42$) in topsoil indicates that the intensity of microbially-mediated Fe^{3+} reduction is limited by the amount of available carbon (C) as an energy source for microorganisms. Moreover, microbial mineralization of organic P from SOM also increases P availability, and this process requires available C. This interpretation was supported by the strong correlation ($R^2 = 0.58$) between available P and DOC, as well as between DP and DOC ($R^2 = 0.56$) in topsoil. The increasing soil solution pH in topsoil and subsoil after flooding of all land-use types may also influence the P release over time. In summary, the increase of available P and DP during flooding is due to three main mechanisms: (1) P release via the microbially-mediated reductive dissolution of Fe^{3+} oxides; (2) P release during SOM mineralization and (3) solubility of Fe phosphate due to increasing pH. These mechanisms are relevant not only in riparian areas, where flooding occurs, but also in well-drained soil that is partly waterlogged after regular heavy rainfalls during the wet season. Likewise, the P cycle turnover is faster in compacted, often anaerobic plantation soils. Here, more P is pumped by the vegetation and then removed from plantations due to yield export.