Transformation of phosphorus precipitates in manure to vivianite for recovery

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Motivation

Phosphorus (P) is crucial for the cellular processes of all living organisms. Therefore, the modern global food production system is dependent on supply of P fertilizer usually produced from mined rock. However, phosphate rock sources are dwindling, giving rise to geopolitical constraints and endangering food security. Moreover, P is used in excess on agricultural soils leading to its run off into water bodies. This leads to increased algae bloom, hypoxia and acceleration of eutrophication, endangering aquatic ecosystems [1].

Fig.1: Three matrices containing phosphorus for recovery (left to right): manure, sewage sludge and lake sediment.

Sources of P that are of interest (*Fig.1*) include:

1. Livestock production: Manure accounts for 1.75 million t P a year in the EU [2]. High phosphate concentrations in European soil coincide with areas of intense agricultural activity such as the Netherlands, Belgium, Denmark and Northern Germany. Manure spreading is considered to provide a significant amount of P input [3].
2. Human waste: P in wastewater treatment in the EU is about 450,000 t P a year. Wastewater treatment plants there have to remove P and accumulate the P in sewage sludge. A significant amount of the P in the sludge can not be used effectively and is lost [2].
3. Lake sediments: In the EU, 200,000 t P per year are lost to the hydrosphere [2]. Due to high P influent into lakes, P is loaded into the sediment. Even when external P sources are restricted, P from sediment is released back into the lake leading to a slow recovery from eutrophication [4].

Technological Challenge

Manure spreading restrictions in countries like the Netherlands lead to its export implicating extra cost and loss of valuable organic matter. In manure, P is mostly bound to magnesium (struvite) and calcium phosphates. To allow better local use of organic matter in manure, P could be recovered, but it is rarely done so far. A possible approach to recover P proceeds via acidification and precipitation using alkaline magnesium or calcium salts. This implicates a high use of chemicals and a challenging extraction of the precipitated phosphate minerals making this approach not ideal. Overall, there is a need to further study chemical interactions between iron (Fe), P, sulfur (S) and organics in manure to develop P recovery procedures [5].

One possibility to remove P during wastewater treatment is precipitation with Fe. Under anaerobic conditions in sludge digesters, an iron phosphate mineral, vivianite $(Fe(II)_3(PO_4)2 \cdot 8\ H_2O)$, is formed. The magnetic recovery of vivianite due to its paramagnetic characteristic has been demonstrated at pilot scale [5]. A similar approach may hold potential for manure treatment. Yet, about three times more Fe in comparison to sewage sludge had to be added to manure to convert all P into vivianite [6]. Based on knowledge from soil sciences, Fe- binding to organics could explain the high dose of iron required for vivianite formation. In addition, Fe is known to bind S more preferentially than P. A way of restricting Fe-organic as well as Fe-S interactions should be found in order to favour Fe-P binding. Knowledge of chemical interactions in lake sediment and sewage sludge could serve as reference and inspiration (*Fig.2*).

Research Goals

- Investigate and compare the interactions between Fe, P, S and organics in manure, sewage sludge and lake sediment
- Find possibilities of minimizing Fe binding to organics and S using previously elucidated relationships and hence favour Fe-P binding
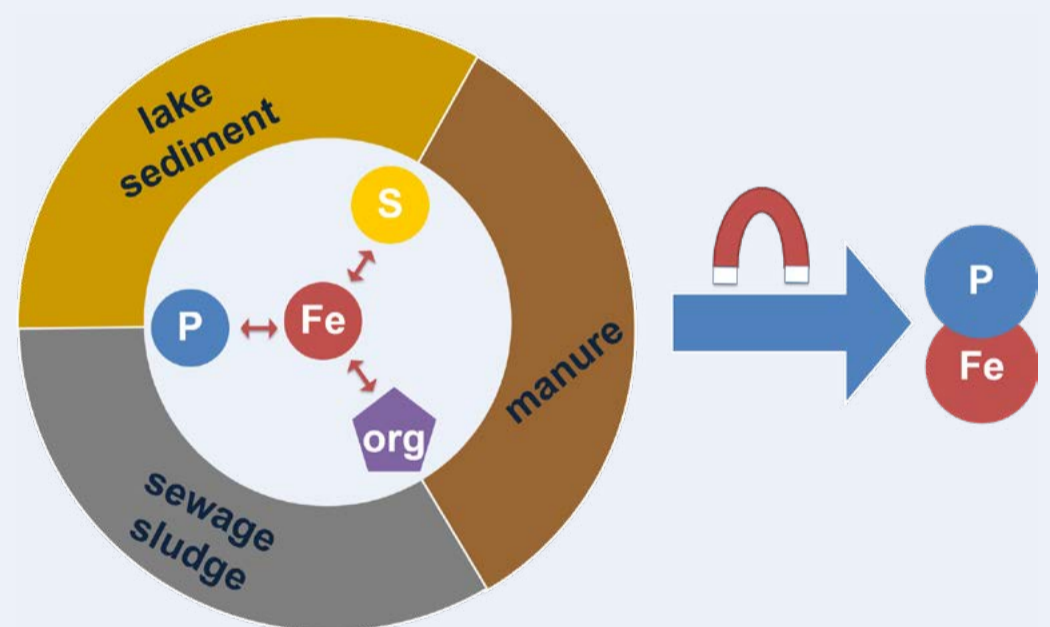

Fig.2: Fe-P, Fe-S and Fe-org (organic) interactions in three different matrices (left), the goal of improving Fe-P interaction using that knowledge and magnetically recovering vivianite (right).

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