ESPC4 & PERM5 – Book of Abstracts

TABLE OF CONTENTS

Insight into direct phosphorus release from simulated wastewater ferric sludge: influence of physiochemical factors

Phosphorous (P) recovery from wastewater treatment plants utilizing chemical phosphorus removal (CPR) is limited. CPR plants generate an iron phosphate (Fe-P) rich sludge due to the interaction of iron with phosphate in wastewater when iron is added for phosphorus. This study investigates the effects of Fe/P molar ratio, pH, aging time, and NaCl concentration on direct release of phosphorous and iron, from lab simulated Fe-P sludge in the absence of wastewater interferences. Phosphorus and iron release at pH values ranging between 2 and 11, for sludges that had been aged for times between 0 and 11 days was determined at different time intervals. The results showed that at elevated pH values (10 and 11) phosphorus release from fresh sludge was consistently high (92.1 ± 1.3 *and* 94.4 ± 1.6 respectively), while iron release at the same pH values was low (3%). Aging time did not affect phosphorus release from Fe-P sludge at ages less than 5 days. However, a remarkable decrease in the percent release of phosphorous (i.e., 50% reduction) was observed at ages of 9 and 11 days for pH values of 9-10. Modeling with the PHREEQC geochemical software was conducted to simulate the release of phosphorus and iron from the Fe-P sludge.

"**Al NIMER** Aseel"

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Thermal behaviour of sewage sludge aiming at white phosphorus recovery

The FlashPhos project will recover high-quality white phosphorus and other raw materials at a large scale using sewage sludge as input material. In order to detail the expected behaviour during combustion, melting and reduction, this study investigates the thermal behaviour of sewage sludge samples, both theoretically as well as experimentally. The experimental investigations were performed in DSC-TGA, to establish starting temperatures and rates for the different process steps. The initial steps consist of drying, volatilization, and combustion reactions, allowing to recover the chemical energy stored in the organic part of the sludge. This energy is used for heating and melting the ash, which is studied separately. Finally, the required temperature and reaction rate of the reduction of the molten ash with carbon is investigated. These insights are crucial for the design and optimization of the thermal process. The obtained values could be compared and complemented with theoretical insights from thermodynamic calculations, such as the expected melting point, solubilities, and enthalpies.

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Phosphorus balance, release rates and mechanisms in a eutrophic coupled - reservoir system

The Franconian lake country is an artificial reservoir system that suffers from high phosphorus inputs. Measures taken to reduce external loading did not improve the water quality sufficiently. Here we investigate the role of the sediment as a source and sink of phosphorus. A phosphorus mass balance was set up over the system to calculate average annual burial rates and sediment incubations were performed for the three main reservoirs to investigate seasonal phosphorus release rates and mechanisms. The reservoirs differ strongly both in bathymetry and trophic status.

The mass balance showed that 66-80% of external phosphorus was immediately buried and could not be retrieved in the lake water. Sediment incubation at summer temperatures showed a release of 45 mg $P*m^{-2}*d^{-1}$ for the deep eutrophic reservoir and 23 mg $P*m^{-2}*d^{-1}$ for the hypertrophic shallow lake. Interestingly, for the shallow lake no iron release was observed, indicating a different control on the anoxic phosphorus release. The sequential extraction protocol SEDEX indicated a higher proportion of organic and humic-acid-bound phosphorus in the shallow lake sediment. Possibly these fractions were responsible for the observed phosphorus release. The differential controls on anoxic phosphorus release will be the subject of further research.

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Use of vivianite obtained from water purification as phosphorus fertilizer

Vivianite is a Fe(II) phosphate that can be obtained from phosphorus (P) removal in water purification. In calcareous soils, it has proved an effective iron (Fe) fertilizer for overcoming Fe deficiency chlorosis. However, there is no information about its potential use as P fertilizer. Its efficiency as P source for plants may be constrained by its low solubility, in particular in basic soils, and fast oxidation. To assess its potential as P fertilizer, we performed a pot experiment with wheat involving the use of soluble mineral fertilizer (superphosphate), vivianites and struvites from different origin. All fertilizer were tested at two rates (50 and 100 mg P kg^{-1}).

Overall, the two tested struvites yielded similar dry matter than soluble mineral fertilizer, significantly higher than all vivianites at both rates. One of the vivianites from water purification did not lead to increased yields relative to non-fertilized control. The best performance with vivianites were obtained with that from industrial effluents and the synthetic one. This two vivianites were the only ones that increased Olsen P in soil after harvest relative to non-fertilized control. Soluble P fertilizers and struvite were the most effective products in increasing Olsen P after harvest.

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Effect of rain variability and water retention measures on phosphorus loads at the farm scale

Water is a stress factor for crop growth and climate change is causing greater rainfall variability (Masson-Delmotte et al., 2021). To adapt against rain variability farmers often adopt water retention measures (WRM). However, the effect of WRM on phosphorus transport is still not fully understood. This study aims to quantify the effects of WRM on phosphorus transport at the farm scale.

We collected 4 years of high-frequency data (groundwater levels, discharge, EC, phosphorous, turbidity, nitrate) of a farm in the east of The Netherlands where the phosphorus routes from the soil to the surface water were previously studied (Barcala et al., 2020). On the 4th year WRM were implemented. To complete missing data we used random forest algorithm, Breiman (2001), with 0.98 R^2. Before WRM were introduced, the yearly phosphorus loads increased linearly with rainfall. Turbidity was the most important predictor for phosphorus i.e. most phosphorus was transported with particles. Although WRM were expected to reduce peak discharge and particulate phosphorus transport, more phosphorus was transported. This increase could be explained by the rise in groundwater levels that mobilized more phosphorus from the topsoil towards the surface water system.

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LCA of the multiple scenarios of dairy wastewater treatment and P-recovery processes

In 2015, after the abolishment of the dairy quota, the European Union's milk production became the largest producer of dairy products in the world, with an increase in the volume of dairy wastewater (DWW) that needs to be treated. A sustainable solution to manage the huge volume of DWW, consists of considering it as a resource. In recent years, there has been a strong interest in technological development for phosphorus (P) recovery from DWW. Phosphorus is a finite resource, which will be limited in the future. So, in order to treat the huge volume of DWW and simultaneously respond to the upcoming P crisis, the interest in technological development for P-recovery from DWW streams has increased. This work aims to analyses which are the environmental impacts of the DWW treatment, and how different scenarios of P-recovery from DWW could influence these environmental impacts, using a commonly used tool for the estimation of environmental impacts: Life Cycle Assessment. The assessed scenarios are a combination of different DWW treatments, conventional and innovative, and innovative P products recovery processes. The recovery processes consist of technologies which use ash or liquids, by products obtained from the wastewater treatment process, to produce struvite or phosphoric acid.

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P-recycling from sewage sludge with fluidized bed incineration applying in-situ heavy metal removal

Thermochemical conversion of sewage sludge enables i) the destruction of harmful organic compounds, ii) sustainable energy provision, and iii) recycling of phosphorus from the resulting fuel ash for downstream fertilizer application. Heavy metals can be simultaneously removed from the fuel ash during fluidized bed combustion and gasification by adjusting the operating conditions or using additives.

This approach was investigated experimentally with a fluidized bed test rig in two test campaigns. In the first test campaign, we investigated the influence of operating conditions such as temperature, air-fuel ratio, and $CaCl_2$ addition on heavy metal removal during incineration. Produced ashes were analyzed with ICP-OES. After the first test campaign, the test rig was equipped with a hot gas cyclone and a cold gas filter to investigate the temperature-selective separation of individual elements. Experimental results were compared with thermodynamic equilibrium calculations.

Heavy metal contents in the ash fractions were compared to thresholds according to the corresponding Austrian and German regulations for fertilizer applications. Higher temperatures and the addition of $CaCl_2$ were beneficial for heavy metal removal from the phosphorus-rich main ash fraction. These results show a promising way of in-situ recycling of phosphorus, which can be used with little or no further processing step for fertilizer production.

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Multiple resource recovery from dairy processing waste. A circular economy approach for downstream valorization

European dairy industry is the largest milk producer in the world usually regarded as the major agro-industrial wastewater source. Dairy processing wastewater (DPWW) is characterized by high concentrations of organic matter and nutrients (mainly Nitrogen and Phosphorus (P)). DPWW presents high potential of causing severe environmental problems like eutrophication. Despite its environmental threat, DPWW is certainly a valuable source of materials and energy which can be recovered. Considering all the available valorization opportunities, the main objective of the present work is to evaluate the potential multiple resource recovery from DPWW by applying a novel Enhanced Biological Phosphorus removal (EBPR) operation strategy. Resources which can be recovered from DPWW by means of EBPR include polyhydroxyalkanoates (PHA), nutrient rich biosolids, bioenergy and biofuels. Our results show satisfactory water quality effluents levels and underpin the opportunity for producing PHA and methane while principally obtaining biosolids with high calorific value along with high-quality P rich biosolids. Based on the yearly generation of DPWW and the obtained yields in our study, a recovery of about 17000 ton/year of P (1.5% of EU consumption) could be achieved. Recovery of P and other value-added products from DPWW allows dairies to comply with the circular economy principles.

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Assessment of P availability and efficiency of recycled P fertilizers - Recommendations for pot trial standardisation -

Two pot trials were set to investigate the most adequate conditions (P dose, test duration, low P substrate) to characterise plant P availability from recycled P products. A seven-month pot trial was carried out to evaluate the efficiency of two struvites (STRSL and STRLQ), two ashes (ASH1 and ASH2) and iron-phosphate (FeP)), using triple superphosphate (TSP) as a positive control. Ryegrass was grown in river sand fertilized at three incremental doses (30, 60 and 90 kgP_2O_5 ha^{-1}). Besides, a four-month pot trial was conducted to test the P availability of microalgae (MA), crab carapace material (CCM), P salt produced by chemical leaching of sludge (PsaltCL), and sewage sludge ash produced by pyrolysis and incineration of sludge (SSAPI) in two growing substrates (S1 and S2) planted with ryegrass. Phosphorus uptake efficiency varied among the products in the following order: first trial - STRSL≥STRLQ≥TSP>ASH1≥FeP>ASH2; second trial - PsaltCL=TSP=MA>CCM>SSA PI>Zero P in S1, and PsaltCL=TSP≥SSA PI>MA≥CCM≥Zero P in S2. It was concluded that the high efficiency of the recycled P fertilizers can be observed using i) the P dose of 60 kgP_2O_5 ha^{-1} ii) minimum four and optimally seven months of plant growth iii) and the slightly acidic S1 substrate over alkaline S2.

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Granular iron-based materials for phosphate removal from waters

Phosphorus is a scarce element which can cause eutrophication of water. This creates a high demand for P removal from waters. Iron-based materials and residuals exhibit high efficiency for P removal from waters due to their strong affinity with P, low-cost and accessibility.

Iron residuals in raw form are very fine and to be used in filters must be agglomerated. We have produced adsorbents from iron-based raw materials mixed with an organic polymer.

Our study aims at the production of filter-stable materials from iron residuals for phosphate removal, optimization of the production, and investigation of the kinetics of phosphate adsorption at filter-stable materials. Adsorption isotherms and kinetic data were obtained to determine the adsorption capacity and the mechanism of phosphorus removal. XRD, FTIR, BET were used to determine the size and structure of the adsorbents.

Our first tests present that produced materials maintain 97% of mass after shaking for 30 minutes and a phosphate uptake of 1.1 mmol/g versus FerroSorp (0.52 mmol/g) and Bayoxide (0.33 mmol/g).

Our laboratory results indicate that the granular iron-based filter materials exhibit promise for phosphate removal from water. Future research will be dedicated to adsorption capacity at low phosphate concentrations, regeneration and reuse of materials.

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Agronomic effectiveness of Actinobacteria-based biofertilizers on cereal plant growth under phosphate / potassium rocks fertilization

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Abstract

Soil fertility and plant nutrition require an adequate management of essential macronutrients such as potassium (K) and phosphorus (P), which are mandatory for plant development, crop yield and quality. However, the availability of P and K is too low to meet plant's need. Therefore, exploiting soil P and K mineral reserve by using beneficial microorganisms as biofertilizer can improve their availability and, consequently, crops yield in a sustainable way. In this context, experiments were conducted in greenhouse to evaluate the potential of Actinobacteria strains belonging to *Streptomyces* and *Nocardiopsis* to solubilize P and K rocks using wheat and maize plants. Results showed that rock P and K combined with these microorganisms consistently increased all the agronomic parameters as well as soil mineral availability. The most performing strains were P18, BC3, BC10, and BC11 since they have a broad spectrum of RP and RK solubilization as well as the capacity to produce IAA, HCN, ammonia, and siderophores. Moreover, inoculation with these strains improved soil enzymatic activities such as acid and alkaline phosphatase in plant rhizosphere. These findings showed that the selected strains are promising candidates for the implementation of an efficient biofertilization strategy to valorize sustainably low reactive RP and RK in agriculture.

Keywords: Actinobacteria –Phosphate and Potassium Rock – Biofertilizers – Wheat– Maize - Greenhouse

Bio-based fertilizers as efficient alternative phosphorus sources for closing nutrient cycles

A wide range of bio-based fertilizers (BBFs), belonging to different Product Function Categories (PFC) and Component Material Categories (CMC) according to EU Fertilising Product Regulation (EU 2019/1009), was evaluated with respect to P availability in three sets of pot experiments in Finland, Austria and Switzerland. Barley and wheat were grown up to maturity in P deficient soils, while three consecutive cuts of ryegrass were obtained in a mixture of sand and a commercial peat-based potting substrate as a growth media. Increasing levels of triple superphosphate were used as a reference P fertilizer. Mineral fertilizer equivalents of 90-100% were reached for about a third of all BBFs. These BBFs originated from CMCs 10 (animal by-products), 12 (precipitated phosphate salts), 13 (thermal oxidation materials), and from sewage sludge, showing the potential to develop effective BBFs from a range of nutrient-rich side-streams. At the same time, some BBFs had very low mineral fertilizer equivalents, while others were intermediate. The dataset therefore offers the possibility to determine which BBF characteristics can indicate P use efficiencies of a wide range of BBFs.

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TerraNova®ultra: P-recovery and energy efficient sludge drying as integrated, decentralized solution

TerraNova®ultra applies continuous hydrothermal hydrolysis to dewatered sludge at a temperature level of 175°C. Acid is added to the hydrolyzed sludge to transfer the Phosphorous into the liquid phase that is subsequently separated in a mechanical press. Due to the change of the sludge's physical structure over the thermal treatment process dewatering can reach 70% dry matter content in the cake which allows for 60-80% P-recovery rates from the sludge.

The TerraNova®ultra P-product is based on CSH (Calcium Silicate Hydrate) and complies both to the German and the European Fertilizer regulations. Since most of the sludge water is removed within the process the dry sludge cake can be utilized to replace fossil fuels in cement kilns or waste incineration while minimizing transportation volume, offering a novel, energy efficient alternative to thermal sludge drying.

The presentation includes the operation results of a demonstration project at Ruhrverband Duisburg/Germany as well as data from pot trials about the agronomic efficiency of the P-product.

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Improved soil testing system in the Czech Republic, valuation of P-content in carbonate soils

Summary

The sufficient soil phosphorus supply is necessary for normal growth and development of plants. The extraction procedure Mehlich 3 is the official analytical method presently used (since 1999) in regular soil testing system in the Czech Republic for the determination of soil macronutrients including phosphorus. Extraction method Mehlich 3 usually doesn´t indicate real phosphorus content in carbonate soils (i.e soils with pH value higher than 7.3 and Mehlich 3 extractable calcium higher than 3500 mg/kg of soil). Mehlich 3 extractable phosphorus is more or less undervalued according to valid limits (criteria) for all soils.

The results of research unambiguously confirm the distribution of soils based on pH, Ca and P content on non-carbonate and carbonate soils, and furthermore the newly proposed adjustment of the P content criteria for carbonate soils.

For carbonate soils presently valid criteria (limits) for valuation of available phosphorus (in all soils) are reduced by ca 10 - 35 $mg.kg^{-1}$ depending on detected phosphorus amount in soil. New criteria for valuation of available phosphorus in carbonate soils (including optimalization of phosphorus rates for crops) can be already presently used in the Czech soil testing system.

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MSCA H2020 REFLOW (Grant Agreement number 814258) project website: https://etn-reflow.eu/

Simulating long-term phosphorus, nitrogen, and carbon dynamics to advance nutrient assessment in dryland cropping

Soil chemical fertility has steadily declined in tropical and subtropical agriculture with depleted stocks of phosphorus (P), nitrogen (N), and carbon (C). Assessing the dynamics of these elements and their effects on crop productivity in dryland cropping are complex because climate often dictates crop nutrient response. This results in under- or over- fertilising crops, and thus suboptimal crop yield and fertiliser inefficiency. The Agricultural Productions Systems sIMulator (APSIM) model accounts for C x N x climate interactions, but simulation of P dynamics is largely constrained by a dearth of suitable data. To address this problem, we used a novel approach to simulate P, N, and C dynamics at a 35-year long-term field trial where different N (0, 40, 80, 120 kg ha^{-1}) and P (0, 10, 20 kg ha^{-1}) fertiliser rates were consistently applied. The soil P model was parameterised with quantified adsorption isotherms and by assuming correspondence between conceptual soil P pools and Hedley fractionation pools. Soil N and C dynamics were parameterised with measured organic N, C and charcoal content to estimate organic matter decay coefficients, pool sizes and C:N ratios. APSIM accounted well for variation in mean N export (94 %), crop yield (88 %) and of P export (62 %) across the 12 different treatments and satisfactorily reproduced interannual variation in N and P treatment effects for crop yield and N export. APSIM generally identified the long-term depletion or accumulation of soil P, N, and C in all treatments. While fractionation and isotherm measurements are labour intensive, future efforts to consolidate a database for various soil types would be a worthwhile investment to not only to inform modelling efforts, but to provide insights into the effects of climate variability on soil fertility.

Presenter DAS Bianca

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How phosphorus removal technologies in WWTP can impact the phosphorus recovery from sludge?

Bioacidification is an efficient way to increase the Phosphorus (P) recovery rate from WWTP sludge by dissolving P as a result of *in situ* biological lactic acid production. Up to 75% of P are dissolved depending on P removal technology (PRT) applied. Even if the best results were obtained from sludge produced by WWTP combining biological (EBPR) and chemical (CPR) P removal, large fluctuations could be observed even in sludge coming from the same type of PRT probably because of different Iron -phosphate compounds formed[1]

The aim of this study was first to explore the correlation between PRT and P speciation in sludge and second to assess and discuss the mechanisms of P dissolution by bioacidification.

A combined P and Fe fractionation method was developed and applied to characterize the forms of Fe and P compounds in ten sludge coming from five WWTP, before and after bioacidification.

- Whatever the type of technology, P was mainly linked to Fe(III) even if Fe(II) was dominant.
- The P composition of EBPR +CPR sludge were different from all other technologies (figure 1).
- The contribution of each of the four P dissolution mechanisms induced by bioacidification differed from a type of sludge to another (figure 2).

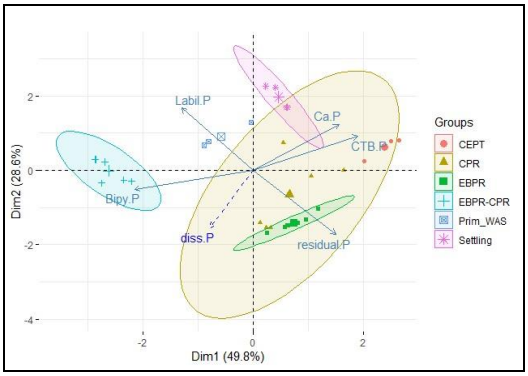

Figure1: ***Principal Components Analysis biplots of the P fractions in sludge and PRT.*** *CEPT: Chemically Enhanced Primary P removal; CPR: chemical P removal; EBPR: Enhanced Biological P removal; Prim-WAS: mixture of primary sludge and waste activated sludge (40:60 weight ratio); Settling: primary sludge without Fe addition; diss.p: dissolved P; Bipy.P; P extracted by bipyridine (linked to Fe(II)); CTB.P: P extracted by citrate thiosulfate bicarbonate (linked to Fe(III)); Ca.P: P linked to calcium and residual P: intracellular P or mineral forms very hard to dissolve.*

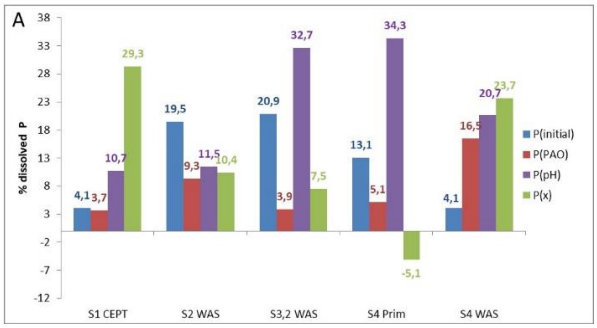

Figure2: ***Percentage of P dissolution by the different mechanisms induced by bioacidification***. *Sn: WWTP identification; CEPT: Chemically Enhanced Primary P removal; S2-WAS: EBPR+CPR activated sludge; S3-WAS: CPR activated sludge; S4-prim: primary sludge without Fe addition; S4-WAS : EBPR+CPR activated sludge; P(initial): P dissolved before BA; P(PAO): P released by the Phosphate Accumulating Organisms; P(pH): P released due to pH decrease; P(x): P released by other metabolisms (iron reduction)*

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BioPhree: next generation solution to remove and re-use phosphate in surface & effluent waters to ppb-level.

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In many places in the world, lake eutrophication causes dangerous situations were blue algae release toxins, threatening beaches, swimming waters as well as drinking water reservoirs. Aquatic ecosystems become anoxic, making it impossible for fish and other aquatic life to survive and leading to less diverse and instable ecosystems. Getting phosphorous concentrations in surface water down to a level where it cannot cause harm through eutrophication calls for radical new solutions.

BioPhree is a process developed at Aquacare and Wetsus and is based on adsorption. Dissolved phosphate is adsorbed using an adsorbant material, and the effluent contains less than 10 ug/l phosphate, low enough to prevent eutrophication. The adsorbant can be regenerated for re-use, during which a very concentrated phosphate stream is produced that can be used as a resource. Aquacare and Wetsus have became finalists using this technology in several large contests such as the George barley water prize in the US and the Baltic sea challenge. A new fully automated system is now being demonstrated in the EU project “Water Mining”. This system is operational for a year as a polishing step for the waste water treatment plant in Larnaca Cyprus. An overview of the different pilot tests will be given, including performance data and lessons learned.

Iron coated sand filters for efficient P removal from agricultural drainage waters

Given that the Water Framework Directive (WFD) demands fast water quality improvements and most of the actual P mitigation strategies tend to work on the long run, new short-term mitigation measures are urgently needed. We report on the development of small scale field filters to remove P at the end of tile drains, starting from the screening of potential P sorbing materials (PSM): iron coated sand (ICS), acid pre-treated natural minerals (biotite, glauconite and olivine) and bauxite. Initial batch (ad)sorption experiments revealed following order in both, P sorption capacity and speed: ICS > bauxite > glauconite > olivine ¼ biotite. Because of the presence of significant amounts of lead and/or nickel, we excluded bauxite and olivine from further experiments. In subsequent lab scale flow through systems with P filters containing mixtures of ICS and glauconite, we found a significant relationship between Ksat and the filter mixtures particle size distribution and bulk density, and a significant effect of the filter mixture composition on P removal efficiency and stability of Ksat. Long term testing of different types of such filters at the outlets of field drains showed consistent P removal efficiencies (typically 60-95% of ortho-P) over different years. These filters seem extremely promising in helping to achieve meaningful short term reductions in P inputs into surface waters.

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Background information:

NuReDrain project: https://northsearegion.eu/nuredrain/

Soil phosphorus mining in agriculture – Impacts on P availability, crop yields and soil organic carbon stocks

Soil phosphorus (P) leaching is one of the major causes of diffuse P losses towards the environment in north-west Europe. In order to cut back these P losses over the long term, soil P stocks need to be drastically reduced. We set up two P mining experiments at sites with a very high initial soil P status (P saturation degree > 30%), comparing the effect of 0 P fertilization on crop yield, soil P status and SOC level to a business as usual scenario, for two crop rotations. Seven consecutive years of 0 P fertilization had no significant effects on neither the crop yield nor the crop P uptake. Further, English ryegrass, silage maize, celeriac and Chinese cabbage made the largest contribution to P removal. Although 0 P fertilization reduced the P balance at field level with 170–211 kg P ha-1 over seven years, this had no significant (measurable) effect yet on the soil P stocks. Simulations of the evolution of the SOC levels over a thirty-year period showed that the use of grass as green manure or as main crop only allows to partially maintain the SOC levels in the absence of any organic fertilizers. These results indicate that P mining is a challenging task, that will take a long time to reduce the soil P stocks and that will come at a cost for the farmer.

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ASSESSING PHOSPHORUS SOIL STATUS AND FERTILIZERS MANAGEMENT IN THE EBRO RIVER INTENSIVE IRRIGATED AREA (SPAIN)

The European “Farm to Fork” strategy puts forward the ambition to reduce nutrient losses to the environment from both organic and mineral fertilizers by at least 50% for 2030. In irrigated semi-arid areas, nutrients losses via irrigation return flows (IRF) is one of the most important surface water quality problems. The objectives of this study were to assess the P fertilizers management and determine its relation with the soil P status in La Violada Irrigation District (Spain), in which IRF annual average disolved P concentration reached 0.49 mg L^{-1} (2018-2020 period); surpassing the critical level of eutrophication (0.02 mg L^{-1}). This work is based on 94 farmer’s surveys and crop monitoring conducted in the different soils types and for the main irrigated crops during 2015, 2016, 2020 and 2021 irrigation seasons. Soil samples were taken before sowing and just after harvest for maize, alfalfa, sunflower and barley to determine soil P-Olsen evolution and P balance at field scale. The results indicate that there is a tendency to an increase of P soil status mainly in maize plots due to organic and/or mineral fertilizers application excess. Detailed results and P fertilizers management recommendations will be presented for improving IRF water quality.

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Resin-in-Pulp technology - an adapted holistic approach for nutrient and P-recycling from sewage sludge ash

- Summary:

The so-called Resin-in-Pulp technology (RIP) presents a holistic technological approach for the recovery of plant nutrients (incl. P) from sewage sludge ash (SSA) suspensions while eliminating heavy metals. The hydrometallurgical process is based on the direct usage of cation exchangers in a batch system containing the ash suspension with dissolved metal ions. Heavy metal sensitive cation exchangers are able to absorb the positive charged heavy metal ions while the ions of plant nutrients like K, Mg, Na and P in form of phosphate stay in the suspension and therefore will be preserved. The phosphorous and nutrient rich suspension can be granulated to a plant fertilizer. In that way this approach reduces the waste stream of SSA to a minimum in form of the absorbed heavy metals. This approach describes also a flexible and robust process which is adaptable to variating input streams of ashes. It resigns expensive application steps like liquid solid separation. Furthermore, acids, ion exchangers and metal salts for waste water treatment (e.g. $FeCl_3$) are regenerable.

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- Research-project „abonocare“: https://www.mfpa.de/files/documents/Projektsteckbriefe/2019-05-05%20Abonocare%20VP3%20Steckbrief%20Poster.pdf

Slow-Release Fertilizers Based on Dispersed Struvite in Thermoplastic Starch Matrix

Improving plant nutrition is key for higher crop yields and could be achieved with environmentally-friendly fertilizers. Phosphorus (P) is especially limiting to plant development, yet, conventional P fertilizers have been increasingly associated with eutrophication of freshwater systems. Struvite (St) is an alternative source for P, recycled from urban wastewaters. Its low water solubility reduces environmental impacts; however, efficiency can be considerably low in granular form for field application. Therefore, fertilizer design plays a critical role that should be addressed. In the present work we prepared slow-release fertilizers based on St fine dispersion in a biodegradable matrix of thermoplastic starch (TPS). Herein, we unveiled P dissolution patterns of St-TPS composites and their effect on maize growth. The results showed the potential of St-TPS to achieve a desirable agronomic efficiency for maize while also reducing P runoff losses in highly permeable or acidic soils.

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Sugarcane bagasse ash and its blends with triple-superphosphate reduce the dependency on rock phosphate

Optimal crop production depends on a supply of phosphorus. Sugarcane bagasse ash (BA), a by-product of sugarcane processing, contains up to 1.6 wt% phosphorus. BA use in agriculture can reduce the dependency on rock phosphate.

The potential of BA as phosphorus fertilizer was tested for soybeans on Oxisol soil under Brazilian field conditions. Fertilizing effects of 40, 80 and 160 kg/ha P_2O_5 from BA were compared to conventional fertilization with 40 kg P_2O_5 from triple-superphosphate (TSP). Additionally, BA/TSP blends consisting of 70% P_2O_5 from BA and 30 % from TSP (resulting in 32, 65 and 130 P_2O_5 kg/ha) were evaluated with respect to fertilizing efficiency.

The bioavailability of P_2O_5 from BA to soybeans was lower than from TSP, so that doubling of P_2O_5 dose was necessary to compensate for the lower offtake. Grain yields following BA- based fertilizations did not statistically differ compared to TSP fertilization, albeit tended to increase by 11% when fertilized with BA/TSP blend supplied at 65 kg P_2O_5/ha.

Thus, while 80 kg P_2O_5/ha in form of BA could replace 40 kg P_2O_5/ha in form of TSP, fertilization with 65 kg P_2O_5/ha in form of BA/TSP could save 50% of TSP and increase the grain yield.

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Sugarcane bagasse-based ashes as fertiliser for soybeans and the relevance of ash mineral composition on plant phosphorus availability

Sugarcane bagasse, the lignocellulosic remains of sugar cane processing is commonly burnt to generate electricity. Recycling strategies for the resulting ashes rarely take the remaining plant nutrients into account. The objective of this study was to investigate the potential of ashes sourced from combustion and gasification of bagasse alone and in combination with chicken manure and sewage sludge, respectively, as fertiliser for soybeans. The analyses were based on chemical ash characterisation, ^{31}P NMR, X-ray diffraction, sequential phosphorus (P) extraction, P extraction in citric acid and greenhouse pot experiments with soybean plants.

Fertilization effects were lower than those of triple-superphosphate and K_2SO_4 and depended on plant P availability. Calcium-based phosphates dominated in all ashes and determined plant P availability. XRD analyses revealed whitlockite ($Ca_9M(PO_4)_7$) and $CaK_2P_2O_7$ in all ashes, while $AlPO_4$ was detected only in an ash with low plant P availability and two undefined P phases and $Ca(Na,K)PO_4$ in ashes with high plant P availability.

In conclusion, plant P availability was highest in alkali-rich ashes, as observed in ashes from co-processing bagasse with chicken manure. To increase plant P availability in ashes, we recommend co-combustion of the biomass with sodium and potassium rich biofuels.

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A material flow model for the implementation of phosphorus recovery in a model region

In the Ruhr region, five water associations cooperate to build a phosphorus recovery technology and to create a holistic approach for this project. The region includes 139 waste water treatment plants and four mono-incineration plants. Since the sewage sludge already becomes incinerated, the phosphorus is supposed to be recovered from the ash. For this purpose, it is planned to create a sewage sludge and ash management by using a material flow model.

The model is created with the software Umberto LCA+ and contains all relevant flows and treatment plants. Furthermore, three technologies for phosphorus recovery are integrated. As first step, all flows are evaluated according to their quality. Variants of sludge distribution are calculated and will be used to show which cooperation arrangements make sense. In addition to this, research is being conducted to determine which adjustments might improve overall ash quality.

First results show, that the material flow management could have a big impact on the subsequent steps. Aimed management allows for a significant part of the ashes to use less costly technologies. This reduces the overall financial effort enormously. The fluctuations of the sewage sludge composition have to be further investigated, as they can have a considerable influence.

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Quinoa agricultural waste recycling: Evaluation of agronomic and physicochemical quality of quinoa compost.

Abstract

In Morocco, *Chenopodium quinoa* has been introduced as an alternative crop because of its nutritional value and adaptability to harsh existing conditions. However, quinoa production increases significantly, leading to an increase in the amount of post-harvest by-products. Therefore, finding sustainable ways to valorize these wastes is crucial. The main objective of our study is to valorize quinoa for further agricultural application. In this sense, compost was produced from quinoa by-products. The evolution of physicochemical parameters, germination test, and plant growth assay were monitored to assess its stability and maturity. The quinoa compost showed a richness in soluble P (0.12%), Cl (1.7%), and Mg (0.81%), with the C/N ratio shifting from 35.89 to 13.65 at the end of the process. The germination index exhibited a biostimulant effect on the majority of used plants; tomato (104.77%), lentils (128.32%), lucerne (90.77%), and cress (147.8%). All these analyses confirm the stability and the maturity of the compost produced from quinoa compost. Compost application improves the plant agro-morphological parameters in comparison to the control. Results showed that plant growth at 50t/ha of our compost gave better growth performance than those grown in the presence of commercial compost. Therefore, quinoa compost can be an excellent solution for valorizing quinoa biomass after the seed harvest. Besides, it could be used as hight quality biofertilizer for organic farming.

Keywords: Quinoa, Valorization, Compost, Physicochemical characterization, Biofertilizer.

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Structural Study on The Chemical Environment Surrounding Phosphorus in Ash Fractions Suitable for Nutrient Recovery

Abstract

Nutrient recovery is an integral part of sustainable clean energy production where one of the most important nutrients is phosphorus (P). Phosphorus recovery from biomass and waste ashes has been a hot topic for research and development activities for decades. However, the chemical speciation of heavy metals (HM) that may be included in recovered phosphates is yet to be resolved. Numerous trial and error approachs have been applied to lower the amount of HM content by fuel design and/or additives. Nevertheless, the connection between P and HM is theses complex phosphate systems on the atomic level is not fully understood.

Therefore, exploring if HM are associated with phosphates is paramount for creating a natural link between sustainable energy production and primary production of biomass. This study aims to examine the formation of different phosphates found in ashes and the potential inclusion of HM in their structures. The inclusion of Zn and Cu in whitlockite phosphates is investigated by powder X-ray diffraction and FTIR/RAMAN spectroscopy to identify possibilities and challenges with direct application of P-rich ash fractions as a nutrient source for plants. These measurements will be complemented by synchrotron-based X-ray absorption spectroscopy analysis in future work.

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Microbial phosphate solubilization: A potential alternative for increasing soil phosphorus sustainability

Phosphorus (P) is the second most important nutrient for plant development and yield increase. However, P availability in most agricultural soils is often limited because P strongly binds to soil particles and divalent cations forming insoluble P-complexes. Therefore, there is a constant need to sustainably improve soil P availability. This may include, among other strategies, the application of microbial resources specialized in P cycling, such as phosphate solubilizing bacteria (PSB). Phosphate solubilizing bacteria increase P availability in soil by transforming the insoluble P to soluble P that plants require. In addition to P solubilization, PSB directly improve plant growth and yield through the production of plant growth-promoting (PGP) substances (nitrogen fixation, phytohormones, nutrient availability, etc.), or indirectly by increasing plant resistance against the effects of pathogens. This P-mediating bacterial component can improve soil biological fertility and crop production, and should be integrated in well-established formulations to enhance availability and efficiency in use of P. This is of importance to P fertilization, including both organic and mineral P such as rock phosphate (RP) aiming to improve its agronomic efficiency within an integrated crop nutrition system where agronomic profitability of P and PSB can synergistically occur.

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Assessing the bioavailability of several recycled phosphorus forms in alkaline soils

Large portions of the agricultural P requirement end in wastewater treatment plants, usually in forms that have low bioavailability. Hence, P recovery from wastewater and biosolids is an emerging approach. Here, we aimed to test the final products from three different recovery processes: sewage-sludge ash (SSA), struvite, and hydrochar versus grounded rock-phosphate (RP) and synthetic P fertilizer (TSP). The five forms of P were tested in large pots with maize-tomato crop rotation. Later, we evaluated struvite performance in potato field under contrasting soil-P availability. We found that the bioavailability of the "alternative" P sources increased from the first to the second crop rotation, indicating prolonged release of P in the SSA, struvite and hydrochar but not in the RP and TSP. Of the four alternative P, hydrochar stood out as the most bioavailable P-source. In the field, potato yield increased with P supply. For any P level, replacing part of the synthetic P with struvite significantly increase tuber yield by an average of 0.4-ton ha^{-1}. The consistent positive effect of struvite in the field trial along with pronounced positive effect of hydrochar indicates these alternative P sources have an indirect positive impact, probably by enhancement of synergetic microbial activities.

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Strategies for optimizing the scalable microbial synthesis of vivianite

Vivianite *($Fe_3(PO_4)_2 \cdot 8H_2O$)* has been reported to form as a secondary mineralization product during the microbial reduction of phosphate-containing Fe(III) minerals. The phosphate-rich nature of vivianite makes it a suitable sink for phosphorus, which is a scarce and irreplaceable resource, and a major contributor to eutrophication in surface water bodies. There is, therefore, interest in synthesizing vivianite by Fe(III) reducing bacteria such as *Geobacter sulfurreducens* and *Shewanella putrefaciens,* to treat phosphate-rich waters, recovering the phosphate for re-use in agriculture.

In this study, factors including presence and absence of phosphate and electron shuttle, the buffer system, pH, microbial load, and the type of Fe(III)-reducing bacteria that influence the formation of vivianite under laboratory batch systems have been investigated. The rate of Fe(II) production, and its interaction with the residual Fe(III) and other oxyanions (e.g., PO_4^{3-}, CO_3^{2-}) was found to be the main driving factor for secondary mineral formation. Magnetite was formed in treatments with zero phosphates whereas vivianite and green rust were formed in treatments containing phosphate. No significant differences were observed in the extent of Fe(III) bioreduction between treatments with *Geobacter sulfurreducens* and *Shewanella putrefaciens.* However, vivianite and green rust were abundant in treatments with *Geobacter sulfurreducens* and *Shewanella putrefaciens* respectively.

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Heavy metal stabilization in sewage sludge ash with poultry litter ash to enhance phosphorus recovery

As known, sewage sludge ash (SSA) is a valuable secondary source of phosphorus (P), also proposed as a substitute for fertilizers [1]. Nevertheless, the variable composition of sludge from civil wastewater treatment plants, causes the presence of heavy metals (HM) in the derived ash. The wet-chemical extraction via acid leaching is a promising option to recover P from SSA [2] but the co-dissolution of HM must be controlled. For this reason, two SSA from an Italian pilot plant, bottom ash (BA) and cyclone fly ash (CYC) rich in lead and zinc, were investigated in this study. The relevant amount of P in the samples (circa 8% for BA and 10% for CYC) suggested researching a new way to handle the waste, rather than dispose of it. The reuse of other waste to stabilize pollutants, as already suggested in literature [3], was the choice. BA and CYC were mixed with coal fly ash (CFA) and silica fume (SF), together with poultry litter ash (PLA), a type of waste rich in P and poor in HM [4]. After the stabilization, acid leaching was performed on the samples, followed by precipitation trials of P at different pH values.

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Greenhouse gas emissions from digestate composting

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Composting and anaerobic digestion are the most common ways to treat organic residues. Sometimes the organic rest after anaerobic digestion (digestate) is also composted. We found that digestate applied to soil can induce relatively high greenhouse gas (GHG) emissions, mainly of nitrous oxide, but there were no emissions when composted digestate was applied to soil. Then we investigated GHG emission from composting digestate. Cumulative methane emissions over 3 weeks were found to be almost 12 times higher from composting digested food waste than from raw food waste. Cumulative nitrous oxide emissions were also higher when composting solid digestate was compared to composting raw food waste, but the global warming potential was mostly driven by the impact of methane emissions. We believe that an adapted microbial community transferred from the anaerobic digestion to the compost process may be the reason for the enhanced methane emissions. We are now carrying out a study to investigate this, as well as assessing some possible mitigation option.

DOC Addition Increases Phosphate Adsorption in Mediterranean Soils

This study aims to investigate the effect of dissolved organic carbon (DOC) extracted from compost sewage sludge on orthophosphate (IP) sorption to five soils encompassing a wide range of properties.

Sorption experiments were conducted using two different background solutions (10mM NaCl and 5mM $CaCl_2$) with and without the addition of DOC (810 mg kg^{-1}). In the kaolinitic soil, the background solution and the DOC addition did not affect the IP Langmuir adsorption capacities (S_{MAX}). Concomitantly, the amount of adsorbed DOC was lower as more IP was added (competitive) and unaffected by the background solution. In the montmorillonitic soils, the IP-S_{MAX} of the $CaCl_2$ solution was higher than that of the NaCl solution, and DOC addition increased the IP-S_{MAX} of the latter. The amount of adsorbed DOC was higher in NaCl than in $CaCl_2$ and was not affected by the amount of added IP, suggesting noncompetitive behavior between DOC and IP.

Our results suggest that when DOC is added to montmorillonite-dominated soils, DOC-IP complexes can interact with the clay's negative planer surfaces (mostly through Ca^{2+} bridging) and increase the soil's IP-S_{MAX}. High Ca^{2+} (5mM) concentrations promote clay face-to-face interactions and tactoids formation, which in turn reduce DOC sorption, and increase IP sorption to the clay's broken edges.

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Nutrient recycling with dry toilets as sustainable solution for communal waste management and regional economies

Sustainable nutrient management is an important topic on research and political agendas due to the negative environmental impacts of current nutrient linearities and the need to assure future fertilizer availability. System analyses repeatedly identified one significant, and yet often untapped resource for nutrient cycling: sanitary residues. Especially separately collected human excreta from dry toilets is considered a valuable resource for the integrated recovery of phosphorus, nitrogen and other nutrients in a regional circular economy from farm to fork to farm. Improved nutrient management and cycling may reduce nutrient and water consumption, reduce greenhouse gas emissions, and improve crop production.

In Barnim, Germany, the project zirkulierBAR establishes a circular living-lab for the production of hygienically safe and quality-assured recycling fertilizers, namely compost from solid matters and liquid fertilizer from urine. Practitioners develop technical elements to integrate dry toilets and the subsequent valorization of the collected contents in municipal waste management. Researchers study the agricultural, resource, and socio-economical requirements for multiplying and scaling-up the specific approach. The project further evaluates social and political acceptance for producing recycling fertilizer from dry toilet contents and the subsequent application in agriculture. We conduct a material and substance flow analysis to unveil the impact of the zirkulierBAR approach on the local and inter-municipal nutrient flows. (209 words)

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Intentions for waste-based fertilizers acceptance across EU regions: a TPB and EUT experiment

Agricultural systems are pushing towards food production with less natural resource inputs, to be energy efficient, and tackle climate change with lower greenhouse gas (GHG) emissions. Future improvements in agriculture will entail a shift in market dynamics from traditional fossil fuel-based fertilization methods. The waste-based fertilisers sector is expanding; however, some scholars have observed that the adoption is low. Studies on the attitude, roles, and preferences of farmers, are crucial for any farm practice, including fertilization. The overall objective of this work is to present to which degree psychological and economical perceptions influence the adoption of waste-based fertiliser products on a farm level. To do so, a EU-wide survey experiment was conducted to measure fertiliser acceptance adoption using decision models such as the Theory of Planned Behavior (TPB) and Expected Utility Theory (EUT).

Main findings suggest that attitude is not the sole predictor of behavior, but a complement to a set of external elements such as social, economic, and geographical factors. This research framework explores behavioral and economic factors and identifies the relative contribution towards the acceptance of waste-based fertiliser products. Results made us to propose targeted solutions for a faster adoption of waste-based fertilisers in different EU regions considering farmers' perceptions

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PYREG Biochar from biosolids: the climate-positive alternative to conventional phosphorus fertilizer

In a 2019 study by the German Federal Environmental Agency, the result is that conventional fertilizer production in Germany emits about +1.2 kg CO_2 eq / kg P_2O_5. Furthermore, phosphate recovery processes like precipitation (in digested sludge or centrate) or sewage sludge ash also demonstrably cause CO_2 emissions.

In comparison to the global warming potential (GWP) of these processes, PYREG biochar from biosolids has a negative GWP of -4,01 kg CO_2 eq / kg P_2O_5. Consequently, the recovery of phosphate within the PYREG process and the final application of the biochar contributes to fight global warming and reaching net zero.
In addition to that the phosphate recovery rate of PYREG biochar from biosolids is nearly 80 %, which is in the range of other thermal treatments and far better than precipitation processes with <40 % recovery rate.

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EBI Whitepapaper

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Biological phosphorus removal from potato processing industrial wastewater – High phosphorus load

In the Belgian potato processing industry (PPI), the current method of phosphorus (P) removal is a physicochemical reaction using metal salts. Although efficient and simple, this method has a number of disadvantages. The goal of the BioPOM-project is to apply the Enhanced Biological Phosphorus Removal (EBPR) process to PPI-wastewater for efficient and sustainable P-removal. Key advantages of the EBPR-process are reducing the amount of chemicals needed, significantly lowering the salinity of the effluent, and enabling P-recovery from wastewater.

We will report about first lab-scale experiments, addressing the efficiency and stability of biological P-removal. The used PPI-wastewater has an anaerobic digestion pretreatment (bioreactor), removing many of the organic carbon sources required by polyphosphate-accumulating organisms (PAOs). Figure1 summarizes the implemented cycle of both bioreactors. For PAOs to dominate a COD:P-ratio of 10-20mg-COD/mg-P is required. Reactor1, as the reference, was fed with biogas-effluent and a constant COD concentration. Reactor2 was fed with the same biogas-effluent as Reactor1, but used biogas-influent as the COD source (1500-4500mg/L.) The stability of the P-removal will be studied over an extended period of time. Initial findings show an efficient P-removal after bioreactor acclimation using the SBR-Cycle in Figure1. Further experiments will address reactor stability with fluctuating COD:P-ratios.

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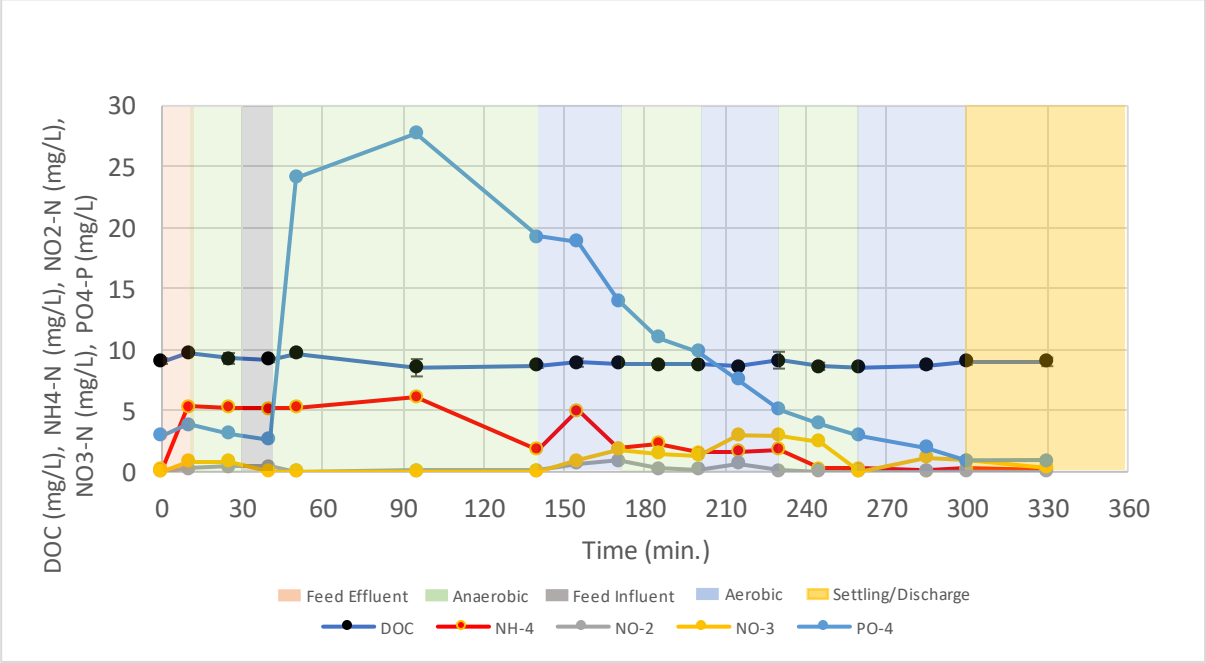
- Diagrams:

Figure 1: Sequencing Batch Reactor (SBR) Cycle



Organo-mineral bio-based fertilisers (and Bioethanol) from mswof through innovative Urban Biorefinery - URBIOFIN

SUMMARY

More than 100 Mit organic fraction of municipal solid waste (OFMSW) are generated every year in the EU cities. When properly separated and collected at the source, according the revised *EU Waste Framework Directive 2018/851,* there is a high potential to convert this bio-waste stream into bio-based products, in the so called **URBAN Biorefineries**.

URBIOFIN Project (TRL 7-8) 2017-2022 has built and operated through the Project, an **Urban Biorefinery** at demo scale, demonstrating the techno-economic viability of transforming 10 t/d of OFMSW into **Bioethanol** and **Organo-mineral fertilisers** as main outputs (but also Biomethane, microalgae based biostimulants and different kind of bioplastic films, bags packaging and biocomposites, -from PHAs obtained from VFAs of AD module-).

Regarding the contribution to the Circular Bio-Economy, URBIOFIN offers the production of at least two final commodities bio-based products with a steep increasing market demand, like Bioethanol and Organo-mineral fertilisers, contributing to nutrients recycling, sustainable agricultural practices and green chemistry.

Regarding problem solving and business projection, URBIOFIN offers municipalities and waste operators an advanced, enclosed and compact design and layout, to be built "ex-novo" or suitable to be integrated in the conventional Plants (AD and Composting) as a previous module, improving quality of digestate, increasing stabilization and dewaterability of final organic residue and giving the option to directly convert it into granular organo-mineral fertilizer compliant with *Regulation on Fertilising Products (EU) 2019/1009*, skipping the Composting phase, saving investment resources, space, processing time from months to days, saving fossil energy needed for compost production and environmental impact of and costs of air emissions treatment.

Regarding environmental performance, URBIOFIN offers a huge potential for CO_2 and GHGs emissions reduction, alone or when combined with AD.

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KEYWORDS

Circular Bio-Economy, Municipalities, Bio-waste, Biorefinery, Bioethanol, Bio-based fertilisers.

MORE INFO and REFERENCES

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Reduced nitrous oxide emissions in a pot trial with novel organic NP(K)-char fertilizers

Pyrolysis-derived P-char fertilizers from manure and biogas fermentation residues that deliver carbon dioxide removal (CDR) with each use are expected to release nutrients slowly to the plants and to have positive environmental effects like nitrate retention and reduction of nitrous oxide (N_2O) emissions. We tested the effects of four novel organic P(K)-char fertilizers – loaded with vinasse as N source – on yield, plant and soil nutrient content, greenhouse gas emission rates and nitrate leaching in a greenhouse pot trial (May – August 2021) with two consecutive vegetable cultures (celery and spinach). Additional treatments were triple superphosphate (TSP) + vinasse and TSP + calcium ammonium nitrate (CAN). The experiment showed that P-char fertilizers, combined with a commonly used organic N fertilizer (vinasse), can provide the same P-fertilization as TSP, with yields similar to or higher than those obtained with mineral N fertilizers. Furthermore, the treatments with char fertilizers showed the lowest nitrate leaching (<10 mg $N\text{-}NO_3^-$ after heavy irrigation) and N_2O emission rates (<800 µg N_2O m^{-2} h^{-1}). P-char fertilizers may thus provide a promising building block for delivering annual CDR doses when applied, with the benefit of reduced environmental costs in the form of less nitrate leaching and lower N_2O emissions.

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Egestabase – Navigating technologies for recovery and reuse of plant nutrients from human excreta and wastewater.

Research and development of circular nutrient technologies has intensified over the past years, making research output in the field increasingly hard to navigate and keep track of. There is a need for a robust and comprehensive mapping and synthesis of existing relevant research and better brokering of scientific knowledge to policy and practice. The project *End-of-wastewater*[1] is a joint initiative of a group of Swedish researchers who have set out to: (1) map peer-reviewed English language research on the recovery and reuse of nutrients found in human excreta and domestic wastewater, and (2) develop an online evidence platform to navigate relevant scientific papers with ease.[2] Our hope is that this online evidence platform – called *Egestabase*[3] – will become a trusted open-access database that compiles and consolidates best available scientific evidence in a systematic and easily accessible manner. This poster provides an overview of *Egestabase* and its current functionality, and a live version will be available next to the poster. The idea is to give potential future users the opportunity to influence the design and functionality of *Egestabase* during its development phase, thereby increasing its relevance and usefulness for researchers and practitioners.

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Cities revisited: Out-of-the-box governance of phosphorus flows in food

As a stowaway of every traded food item, phosphorus flows span the globe from agricultural production lands to consumption in cities - often ending in sinks or landfills. Breaking up this linear transportation of the finite resource to close the loop is attempted preferably by intervening via national or supra-national regulation for the largest possible coverage. An alternative pathway to phosphorus sustainability lies in addressing the actors that have fuelled the current setting with their growth: Cities. From a systemic perspective, they are dynamic hubs that can strategically impact phosphorus flows by exercising various modes of urban governance. This hypothesis is qualitatively supported by an in-depth case study of the city of The Hague (The Netherlands) in synthesis of urban metabolism- and policy analysis. Additionally, currently ongoing research expands the understanding of influential urban parameters and quantitatively explores the modelled urban phosphorus flows of multiple world cities. First results show that cities are neither powerless in nor unaccountable for phosphorus governance. Instead, they can cross system boundaries of analysis, bridge administrative limitations, and tap into a range of underutilized governance measures if they think outside the known box.

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Phenotypic and genotypic screening of potato cultivars for phosphorus efficiency

Potatoes (*Solanum tuberosum* L.) require an optimal amount of phosphorus (P) for their growth, tuber production and starch quality. As the crop has a small and shallow root system, which makes it harder to acquire nutrients from the deeper level of soils, excessive amounts of inorganic P fertiliser are often applied, causing economic and environmental concerns.
Our study aims to explore the natural variation among potato genotypes for higher phosphorus uptake efficiency. We screened a set of 179 cultivated and four wild potato accessions of the Gross Luesewitz Potato Collections (GLKS) and compared the panel to 17 modern starch cultivars, in response to optimal and low P supply in sand hydroculture under greenhouse conditions. In-vitro plantlets were cultivated for four weeks and different growth parameters were measured. An initial pot screening was followed by a two-year field trial with selected genotypes at the University of Rostock. The pot experiments resulted in an average reduction of shoot biomass of 67.1 %, with an increased root: shoot ratio under low P. However, roots showed a reduction of only 39.8 % under stressed conditions, simultaneously exhibiting extensive variation in architecture and development. P uptake varied between 0.71 and 5.76 mg pot-1 in the high P treatment and between 0.18 and 1.33 mg pot-1 at low P. Field trial results detected significant differences in tuber yield between the genotypes in the second-year trial under different organic and inorganic fertiliser treatments.
In conclusion, a high variability was observed among the genotypes regarding both shoot and root development, forming a good basis for breeding towards P efficient potatoes.

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Developing fertilizer compliance test methods for recycled P fertilizer products

The lack of phosphate deposits in Europe has prompted the recycling of different secondary phosphorus (P) rich materials into fertilizers. As a result, many novel bio-based fertilizer (BBF) products are entering the European fertilizer markets, which necessitate the development of suitable quality assurance test methods.

In this study, the P extractability of 41 chemically diverse P fertilizers was tested with the EU 2019/1009-compliant test procedures (water and neutral ammonium citrate) and with five alternative extractions methods: 0.5 mol L^{-1} $NaHCO_3$ and four sink-based extractions, including anion exchange membranes, electro ultrafiltration (EUF) and diffusive gradients in thin films (DGT).

The fertilizers were also tested for their fertilization efficiency in three pot experiments in Austria, Finland and Switzerland using wheat, barley (grown up to maturity) and ryegrass (three subsequent cuts) under controlled conditions in low-P soils. The biomass and P contents of each crop were related to the fertilizer P extraction results to assess the accuracy of these methods for predicting P bioavailability. Besides the water extraction, all extraction methods correlated reasonably well with plant performance parameters. These experimental results and additional considerations, such as lab practicality, will be the basis for a proposition of P compliance test methods for BBFs.

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- https://www.lex4bio.eu/

Sustainable phosphorus management under the future Common Agricultural Policy?

Global environmental targets like the Paris Agreement require a sustainable transition. The agricultural sector plays a dual role in this transition: it can accelerate climate change while also acting as carbon sink. Sustainable phosphorus management sits at the intersection of these two issues. P issues arise where unsustainable phosphorus management leads to e.g. phosphorus accumulation in soils and discharges into water bodies. In turn, sustainable phosphorus management which is characterised by e.g. site-adapted fertilisation can contribute to combat global environmental challenges. Above all, sustainable phosphorus management is embedded in sustainable soil management. This presentation seeks to assess the extent to which the future Common Agricultural Policy (CAP) of the EU contributes to sustainable phosphorus management. To this end, I apply a qualitative governance analysis. I analyse the agricultural subsidy scheme in its effectiveness in complying with global environmental goals – with a focus on phosphorus management. Results show that the future CAP is not in line with these goals and instead is likely to further worsen e.g. soil degradation. It fails to provide incentives for sustainable soil and phosphorus management. Apart from that, implementation flexibility increases for Member States. While this could better tailor subsidies to local conditions, the future CAP lacks robust baselines to avoid a race to the bottom regarding (soil) standards. Still, a promising instrument are 'Eco-schemes' and Member States could use their flexibility to design ambitious Strategic Plans.

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Novel hybrid membrane process coupled with freeze concentration for phosphorus recovery from cheese whey

The ever-increasing demand of phosphorus (P) fertilizer for securing global food production, coupled with finite phosphate rock (PR) reserves, is one of the emerging problems in Europe. Indeed, PR was listed as an EU critical raw material, triggering attention to find alternative source to potentially substitute the use of this limited source. Cheese whey (CW), characterized by high content in organic matter and P, represents a promising feedstock for P recovery. For this reason, an innovative application of membrane system coupled with freeze concentration (FC) was assessed for the CW valorisation. The performance of three different types of flat sheet membranes with different pore sizes (microfiltration: 0.2 µm, ultrafiltration: 30 kDa and 200 kDa, and nanofiltration: 0.6-0.8 kDa and 1 kDa) was evaluated and optimized under different transmembrane pressures and cross flow velocities. Once the optimal conditions were determined for each membrane, the efficiency of FC for the treatment of different matrix was evaluated at specific operating conditions (-5^{o}C and 600 rpm of stirring speed). This coupled technology showed promising results which recovered more than 80% of P, obtaining a P-rich product with high agronomic value, indeed constituting a further step towards the establishment of a broader circular economy framework.

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Phosphorus Recovery Methods from Secondary Sources, Assessment of Overall Benefits and Barriers with Focus on the Nordic Countries

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Phosphorus (P) recovery and recycling play a crucial role in improvement of resource efficiency and sustainable nutrient management whether there is a P-peak within centuries or not. P is a limited resourceand as a nutrient, it is an inseparable part of lifecycle. Furthermore, increasing demand for fertilizers, sign of geopolitical constraints, and high discharge of P to waterbodies are the other reasons to pursue circular economy of P. In a circular economy one of the main goals is generating a new life for wastes and new trading opportunities for secondary raw materials. In the case of P, one of the key actions underthe Circular Economy Package is to facilitate the recognition of organic and waste-based fertilizers and support the role of bio-nutrients in the market. Many processes have been developed for P-recovery from different resources, among these methods, some have been succeeded and commercialized in Europe, Asia and America. However, there is still huge potential for P-recovery from the four main waste-based resources including food chain waste, manure, mining waste, and sewage sludge. In general, P-recoverymethod should have high recovery rate, energy efficiency, synergies, and economic feasibility. While there is no one solution which fits all countries and regions, sustainable conversion of lost P-flow to an added value product is a crucial step in closing the P-loop. This study investigates several recovery methods of P from various secondary resources comprehensively. Moreover, it analyses the Nordic viewpoint of P-cycle by evaluating Nordic reserves, demands, and secondary resources to gain a systematic analysis of how Nordic countries could move toward circular economy of P. For bridging thegap between recovery and recycling in the Nordic country there are several factors to consider including: Legal framework, sufficient quantities and proper qualities of secondary resources, geographical scattering of the resources, technology feasibility, and a holistic strategy. Developing the most suited P-recovery method in the Nordic country benefits each national economy in several ways. Improving independency of mineral P-suppliers, reducing environmental and health hazards and decreasing the Baltic sea environmental concerns and issues are the main logic behind the embracing P circular economyin these countries.

Keywords: Circular Economy, Critical Raw Material, Nutrient Cycle, Phosphorus Recovery, Nordic Countries

Effects of dairy-processing-sludge (DPS) and derived hydrochar on greenhouse gas (GHG) emissions from maize field

The dairy industry is a large source of nutrient-rich aqueous wastes containing phosphorus (P) and nitrogen (N) within the EU. The P in Dairy Processing Sludge (DPS) has a large potential as a P-fertilizer. However, application of untreated DPS to fields contributes to greenhouse gas (GHG) emissions, e.g. nitrous oxide (N_2O) and carbon dioxide (CO_2), and climate change. Hydrochar derived from DPS via hydrothermal carbonization has a high concentration of plant-available P, and of recalcitrant carbon (C) that contributes to C-sequestration. This was examined in a field study at Foulum Research Centre where untreated DPS and two DPS-derived hydrochar were applied to maize (30 kg P/ha) in May 2021. Untreated and plots added mineral fertilizers were included as control. The N-fertilizer equivalent values (N-FEVs) of the biofertilizers were assessed by including four N application rates (32.5, 65, 97.5, 130 kg N/ha). Each treatment was replicated three times. GHG emissions and soil inorganic N were measured over time and maize crop yields measured at harvest in November 2021. The GHG emission rates, crop yields, N&P uptake and N-FEVs are under analysis now and at the conference the authors will present GHG emissions and maize yields under different fertilization and hydrochar levels.

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Phosphorus Recovery from Steelmaking Slag by Selective Leaching and Precipitation

Since phosphorus is widely used in agriculture, medical care, military industry, etc., its preservation is an important issue. In Japan, the annual amount of phosphorus ore imported is comparable to that contained in steelmaking slag generated.[1] Therefore, the steelmaking slag can be considered one of the new phosphorus resources. At the steelmaking temperature, phosphorus concentrates in $2CaO{\cdot}SiO_2$-$3CaO{\cdot}P_2O_5$ (C_2S-C_3P) solid solution phase. While the slag cools, various mineral phases generate during solidification and crystallization. By exploiting the differences in water solubilities between the C_2S-C_3P solid solution and the other mineral phases, the acid leaching process was developed to selectively separate phosphorus.[2)3)] To improve the elemental selectivity of acid leaching, it was important to eliminate the glassy phases and to change the valence of iron trivalent for the inhibition of the matrix dissolution.[4)5)] The dissolution ratio of phosphorus from the artificial steelmaking slag reached about 91%. After the leachate was separated from the residue, an appropriate amount of NaOH aqueous solution was added to precipitate CaO-P_2O_5-H_2O compounds by increasing pH value. At pH=7, it was observed that over 80% of the phosphorus in the leachate was precipitated and the phosphorus concentration in the calcined precipitate became approximately 25 mass%.[5)]

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Development and evaluation of innovative technologies for the phosphate removal and recovery

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Excess phosphorus (P) in water is one of major causes of eutrophication. In the UK, 80% of 98 surveyed rivers were found to exceed the accepted standard of P concentration, e.g. 0.1 mg/L. Effluents from wastewater treatment plant (WWTP) are considered to contribute up to 60–80% of the P in rivers due to discharge of treated effluents containing residual P concentrations. The discharge level of P from WWTPs in many countries is going to be strictly limited to 0.1 mg/L or even less due to the growing concern over eutrophication. Hence, the innovative and efficient technologies are sought to enhance the P removal efficiency from WWTPs.

In this talk, innovative technologies designed to remove and recover phosphate from both P spiked synthetic solution and real WWTP's effluents are presented. First, Ca/Mg-layered double hydroxide (LDH) has been demonstrated to effectively remove P from 1.4–5.6 mg/L to meet future stringent discharge limit at the level of 0.1 mg/L (Figure 1). Moreover, the LDH adsorbents can be reusable for up to 12 times in terms of no effluent P concentrations exceeding to the treatment targets.

Secondly, a liquid–liquid extraction (LLE) process has been developed to recover phosphate. During the LLE, phosphate in wastewater transfers into an organic phase (extractant) and then the P in extractant is transferred into an acid phase. The extractant can be recycled and reused in the process. Figure 2 shows that the recycled extractant could be reused for 5 times in order to maintain the P recovery efficiency above 80%. 2/3 of extractant in each run was the recycled and this represents the cost effectiveness of using the LLE method to recover P from wastewater.

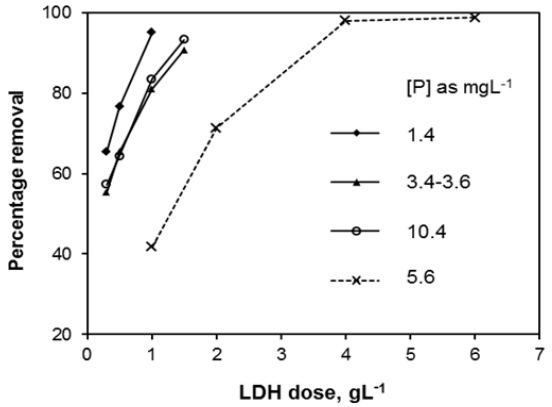

Fig. 1. Phosphate removal from effluents with different starting P concentrations vs. LDH dose (pH_o = 7.1±0.4, mixing time = 2 h). Solid and doted lines indicate the P removal by Ca-Al-NO_3 and Mg-Fe-Cl LDHs, respectively

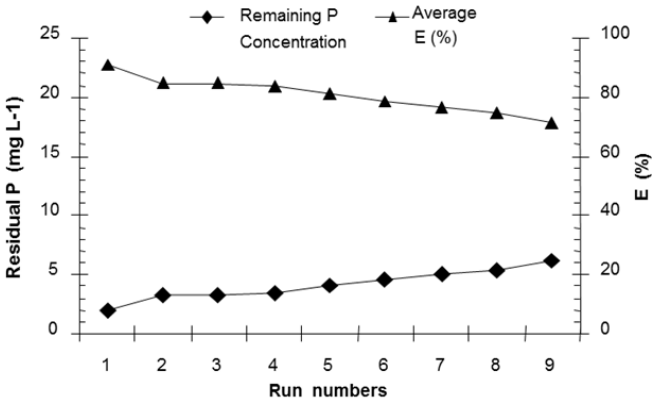

Fig. 2. The effect of extractant recycle run numbers on the remaining P concentration and the extraction efficiency. (E = extraction efficiency; P concentration in sewage sample was 21 mg/L)

Exploration of low energy flotation process to selectively separate purple phototrophic bacterial biomass from anaerobic digestate

Purple phototrophic bacteria (PPB) are facultative anaerobes capable of accumulating phosphorus as polyphosphate in anaerobic conditions [1]. In a wastewater treatment context, PPB biomass has the potential to be a suitable agricultural phosphorus fertilizer. However the effluent and biosolids mixture fed to wastewater treatment centrifuges is usually at 1-2% solids content [2] and contains significant amounts of inorganic impurities, making most fertilizer applications unviable [3, 4]. Selective dewatering and PPB biomass concentration through a hydrophobicity-exploitative dewatering technique could open this processing bottleneck. The flotation separation process uses fine gas bubbles and sometimes chemical enhancement that can selectively float or suppress micron-scaled particles.

Preliminary dewatering flotation experiments were conducted with a model organism (*Saccharomyces cerevisiae*) and a Partridge-Smith micro flotation tube. Preliminary results indicate the potential for total phosphorus concentration to be slightly and selectively increased in the flotation concentrate. Subsequent tests will optimize and verify if selective separation of yeast is possible in the presence of dissolved iron and aluminium, and will explore the separation of purple phototrophic bacteria by flotation.

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STEPS: a New Convergence Research Center for Phosphorus Sustainability

Phosphorus (P) underpins the productivity of food systems as a key nutrient in fertilizers. Yet the sustainability of P is understood as a wicked problem. Thus, a paradigm shift is needed in how we discover and develop materials, technologies, and strategies to control, recover, reuse, and manage phosphorus. This presentation will introduce the **Science and Technologies for Phosphorus Sustainability (STEPS) Center**, a recently announced, U.S. National Science Foundation (NSF)-supported Science and Technology Center (STC). STEPS is a **convergence research center** that addresses the complex challenges in phosphorus sustainability by integrating disciplinary contributions across the physical, life, social, and economic sciences. STEPS draws from atomic and molecular insights (e.g., chemistry, materials research, biochemistry, bioengineering) to develop materials and technologies that are deployed at the human scale (e.g., environmental and agricultural engineering, plant biology, crop and soil sciences) while considering supply-chain logistics, life cycle, and other regional and global issues (e.g., ecology, economics, sociology, policy). STEPS further leverages disciplinary contributions that transcend length scales and serve as integration mechanisms within the Center (e.g., science of team science, data science). Some very early work undertaken by STEPS will be highlighted, including example projects in which the presenter (and Center Director) is directly involved.

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NPHarvest – Calcium based P recovery process as a pre-treatment for N recovery

Figure 1. A chunk of NPHarvest P-product.

NPHarvest is a nitrogen and phosphorus recovery process developed by Aalto University in Finland. Wastewater flows with ample nutrient content are also loaded with suspended solids (SS). We have developed the process for digester effluent streams, also called reject waters, but any waste flow with ammonia and P are within the applicability of NPHarvest.

Our process recovers nitrogen is recovered with hydrophobic membranes. While we designed our process to tolerate moderate SS concentrations, some pre-treatment is still necessary. P is recovered simultaneously while removing unwanted solids with calcium hydroxide. There is also a possibility to use other chemicals if it is necessary (depends on the characteristics of the waste flow).

The quality of the P product depends on the source waste flow. In our tests with reject waters with high SS concentration and low pollutant concentrations, the resulting product (Figure 1) has approximately 1% P content. In addition, the product contains significant amounts of calcium and carbon, which we deem beneficial elements in a fertilizer or soil amendment product. The pollution levels in the product have been well below legislative limits.

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Elaborative video: https://youtu.be/geh2-C4bxBU

SOIL PHOSPHORUS TURNOVER IN SOILS UNDER LONG TERM P MANAGMENT

Soil P turnover rates and availability were measured in grassland under long-term P management using a ^{33}P isotope tracing technique. Soils received 0 (0P), 15 (15P) and 30 (30P) kg P ha^{-1} annually for >50 years resulting in negative, balanced, and positive P budgets, respectively.

The impact of previous fertilization on P turnover was evident from measurements of the available (Morgan's P) and exchangeable P pools (E) and P turnover rates between the pools. The P deficient (0P) site had low Morgan P (2.3 mg L^{-1}) with imbalanced turnover predominantly supplying the exchangeable pool. The 15P soil had Morgan's P of 4.8 mg L^{-1} and balanced P turnover and the 30P site recorded surplus Morgan's P of 12.6 mg L^{-1} with balanced P turnover.

Application of Dairy processing waste (DPW) increased P turnover, resulting in balanced turnover in the 0P soil and build-up in P pools across all soils. However, P turnover and build-up using DPW was slower compared to conventional fertiliser. Under P deficiency the preferred mechanism was a build-up in exchangeable P pool through transfer of DPW from the available P pool. Soils with balanced P turnover rates and positive P budgets responded to DPW by a build-up in available and exchangeable pools.

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Nutrient Content of Manures and Potential for Valorisation: Case Study of Monaghan and Tipperary, Ireland

Agriculture accounts for 33% of Ireland's GHG emissions and is rising due to dairy sector expansion caused by the removal of milk quotas. This in turn will lead to an increase in manure production. In Ireland, an excess of 39 Mt manure is produced each year through dairy, beef, poultry, pig, and sheep farming. Manure management has been identified by project stakeholders as a major problem facing the Irish farming industry. While poultry produce less manure than cows (0.05 tonnes/year/animal compared to 22.7 tonnes/year/animal), poultry manure contains higher concentrations of phosphorus (3.8 kg/tonne compared to 0.8 kg/tonne) and is easier to collect for valorisation options.

Agri Bio Circular (ABC) Economy targets agricultural and forestry sectors wastes to develop bio-based products and energy generation in a cascading system of biomass use to reduce GHG emissions and valorise wastes. Novel value chains will be created in conjunction with farmers, food processors, and foresters in counties Monaghan and Tipperary in Ireland. ABC Economy moves beyond current research by conducting full Life Cycle Assessment (LCA) to highlight the synergies and trade-offs between using biomass for bio-based products and energy generation.

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Pilot- and industrial scale R&D at Emschergenossenschaft and Lippeverband: From Phos4You to AMPHORE

Emschergenossenschaft and Lippeverband (EGLV) are two large water management boards in Germany. Operating almost 60 wwtp of all size classes, the upcoming obligation of P-recovery is of great relevance. In preparation of this task, EGLV is intensively involved in R&D-projects covering both technical and strategical aspects of P-recovery.

Within the INTERREG VB NWE project Phos4You (2016-2021), EGLV constructed and operated a large demonstration plant of the EuPhoRe®-process; moreover, several ash-leaching technologies were assessed via Pilotdemonstration (REMONDIS TetraPhos®, PARFORCE).

EGLV is also currently involved in the BMBF-project AMPHORE (2020-2025). Here, five large water management boards of the Ruhr metropolitan area (capacity of wwtps: 7 Mio. P.E.) cooperate to develop an optimized *regional* sewage sludge- and ash management. Together, they plan the implementation of a semi-industrial P-recovery plant of the PARFORCE technology (ash leaching and production of P-acid) which will be build and operated by EGLV. The commissioning of the P-recovery plant is scheduled for 2023.

The presentation will focus on the results of the EuPhoRe®-pilot plant operation, on the planning of the PARFORCE-plant, as well as on strategical considerations with regard to a holistic, regional sludge- and ash management.

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Decentralised phosphorus recycling from sewage sludge using dust firing and in-situ heavy metal separation

Future-proof sewage sludge disposal strategies must include the required P-recycling and at the same time guarantee maximum disposal safety with the greatest possible economic efficiency. In the project "DreiSATS", a process chain consisting of modified dust firing with in-situ heavy metal separation and fertiliser granulate production is currently being developed and demonstrated for decentralised phosphorus recycling from sewage sludge.

Initial combustion tests in a pilot plant demonstrated the feasibility of dust firing for the thermal treatment of sewage sludge. This technology offers economic thermal utilisation even with much smaller plant sizes than conventional fluidised bed technology. The aim of the research is to combine dust firing with a concept for heavy metal separation by adding additives to the combustion and obtaining high-quality ash with downstream hot gas filtration. Within the scope of laboratory tests, several additives were evaluated regarding suitability and process parameters, such as temperature or quantities added. The heavy metal load could be significantly reduced.

The aim of this presentation is to outline the DreiSATS concept as well as the results on sewage sludge incineration and the correlation between dust particle size, temperature distribution during filtration and the use of additives on heavy metal separation and ash properties.

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DreiSATS: https://www.dreisats.de/willkommen.htm

Activation of P-rich biochars and ashes to increase plant P availability

Summary of content (max 200 words)

Pyrolysis and incineration of phosphorus (P)-rich wastes results in biochar or ash with a high P content, but a high pH and limited plant availability. Activation of the materials with H_2SO_4 could increase plant P availability. Increasing amounts of H_2SO_4 were applied to digestate solids char and ash (DS-C, DS-A), poultry litter ash (PL-A), insect frass char (IF-C), sewage sludge char and ash (SS-C, SS-A) and meat and bone char (MB-C). pH and water extractable phosphorus (WEP) of the activated materials were measured. Accordingly, all materials were acidified to a WEP content of 30%-50% total P. Activated and untreated materials were applied to ^{33}P labelled soil. After growing maize, shoot biomass, total P uptake, P uptake from fertilizer and soil pH was analyzed. Biomass of the activated materials ranked in the following order mineral P>DS-C>SS-A>PL-A>IF-C>DS-A>MB-C>SS-C>Control. Acid activation resulted in an increased plant P uptake compared to the control and compared to the untreated materials. Activation eliminated the liming effect of ashes and biochars. pH was not decreased by activated materials compared to the control. Activation increases P extractability and plant P availability without effects on soil pH and is therefore a promising approach to increase the P fertilizer value of ashes and chars.

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ViviMag: a successful public private research collaboration to recover iron and phosphate from sewage sludge

Abstract

ViviMag is a novel approach to recover iron a phosphate from sewage sludge. The technology potentially opens a new route for phosphate recovery from sewage sludges produced by plants that use chemical phosphate precipitation for phosphate removal. This technology was developed in a close cooperation between industry, academia and public partners. Fundamental research revealed that the paramagnetic vivianite mineral plays a key role in phosphate binding in chemical precipitation processes applied for phosphorus removal in sewage sludge treatment. This finding opened the way to test the recovery of vivianite via conventional magnetic mining technologies and the concept has been successfully demonstrated at pilot scale using commercial magnetic separators at a sewage treatment plant in Breda, The Netherlands. Further long-term validation of the technology will take place on three sites in Germany, Denmark and The Netherlands. Focus will be on understanding differences between sludges, operability and testing applications for the vivianite, in particular for use as iron fertilizer. The presentation will present the ViviMag technology and discuss how the cooperation between the partners stimulated this innovation process. Lessons learned and the next steps in launching the technology will be discussed.

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Vacuum degasification/acidic-neutral absorption for nitrogen recovery from agricultural digestate

Nitrogen losses from fertilisation with biogas residues via leaching or gaseous emission have a major negative impact on our environment. In the scope of the Horizon 2020 project Circular Agronomics, a novel approach[1] for TAN recovery from agricultural digestates is pilot tested.

By inducing thermal energy and addition of sodium hydroxide to the digestate the dissociation equilibrium of ammonium is shifted. Negative pressure assisted by an external air stream or internally recirculated process gas is then utilized to outgas ammonia in a degasification column. To allow adaption to different substrates, the column geometry can be adapted to work with or without packing material. Using an acidic absorption scrubber, ammonia is immobilized and refined into a mineral product.

Designed for an hourly throughput of 50 – 150 L, batch trials were used to commission the plant. Depending on process conditions, up to 90 % of TAN can be removed from liquid digestate in 60 min of processing. Sodium hydroxide consumption has been significantly optimised via prior stripping of CO_2. In the remaining project duration, it is expected to gain insight into the performance of substrates other than agricultural digestate and further optimise the process in terms of heat and chemical consumption.

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Production of a safe and nutrient-rich material from a mixture of human waste via pyrolysis

The research project Rural Urban Nutrient Partnership (RUN) aims on closing the loop between urban residual resources and the need for nutrients in rural areas for agricultural production.

Heart of the RUN process is a container unit to process a mixture of black water and kitchen waste (10:1 v/v) in a semi-continuous process. After extraction of organic acids for bioplastic production the liquid phase is processed via struvite production for P- and N- recovery. Further nutrient recovery is obtained with the help of adsorber materials (zeolite and biochar) for N- and K-recovery. The obtained solid phase was introduced to a laboratory scale pyrolysis process.

It could be shown that the solid phase material obtained can be purified to a safe and still nutrient-rich material. Via pyrolysis of the solid residue material overall efficiency of P-recovery during RUN-process could be significantly improved. PAHs could be detected significantly below critical levels after pyrolysis of the gained material. The examined process of pyrolysis therefore yields a safe material which is appropriate for soil amendment or as carrier material for a carbon-based fertilizer and safe for direct use in agricultural production.

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Mandatory P-recovery from sewage sludge (ash) in Germany – a multiple-goal conflict?

In Germany, P-recovery from sludge or sludge ash will be mandatory for large- and medium-sized wastewater treatment plants from 2029 onwards. Currently many municipalities have to elaborate concepts to meet the P-recovery targets, while combining multiple political goals.

Our study shows exemplary for a large German municipality how these different targets affect each other. P recovery from ash is expected to reach a high recovery rate as claimed in the sewage sludge directive. Furthermore, a fertiliser or product with low contaminant levels is produced to comply with the fertiliser regulation and to detoxify waste streams before their reuse in accordance with the Zero Pollution Initiative of the EU. In addition, the municipality and its wastewater treatment and P recovery system should be climate neutral by 2030. The municipality expects also that fees for wastewater treatment will not increase (in relevant orders), despite the additional environmental services.

To achieve a high recovery rate and produce a fertiliser with low contaminant levels, several wet-chemical sewage sludge ash treatments have been studied. Our analysis indicates that recovery of P the carbon footprint severely compared to current ash disposal, even if the P product and by-products are credited. The carbon footprint for recovered P is expected to be 2 to 3-fold higher than for mined P, however the products show low contamination levels. Meanwhile, it is expected that costs of ash disposal will increase by the factor 3 to 6, resulting in additional annual costs for P-recycling of 1-3 Euro/(person equivalent and year) already considering a centralised treatment plant and revenues for products. Furthermore, the transport of ash, chemicals and (by-)products play a crucial role in terms of location and investment decisions.

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Changes of phosphorus forms in soil as a function of different fertilizing strategies

Phosphorus became one of most discussed elements in plant nutrition. The main reason are the strongly limited nonrenewable sources – rock phosphates. The possible ways to solve this problem can be summarized in five points: a) plant breeding, b) use of waste materials, c) biostimulants, d) local application, e) sociological and economical aspects. Only the combination of two or more of these strategies seems to be most promising way to overcame P deficiency. Only the data from long-term field experiments can provide the valuable information about the success of these strategies in field conditions. The objective of this study is the monitoring of common fertilizing strategies in comparison with sewage sludge application within three crop rotation (potatoes, wheat and barley) with focus on soil phosphorus. Common fertilizing strategies comprises of mineral NPK and farmyard manure application. All treatments are compared with non-fertilized control treatment. Whole experiment is set up to uniform nitrogen rate 330 kg/ha per 3 yearcrop rotation (except control) and runs in different soil-climatic conditions. Readily available, potentially available as well as residual P forms were evaluated. At the same nitrogen level, sewage sludge seems to be more effective source of readily and potentially available phosphorus compared to farmyard manure.

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The Swedish Nutrient Platform - A Swedish Innovation Platform for Nutrient Reuse from Wastewater

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Abstract: In order to move away from fertilizing farmland with nutrients taken from virgin material or produced with substantial inputs of fossil fuels, long-term investments and engagement is crucial. Wastewater and sewage sludge are potential streams for recovery of nutrients and is a cornerstone in a circular nutrient economy. In Sweden, a national innovation platform on nutrient recovery from wastewater, was launched in the summer of 2019. The objective of the platform is to promote stakeholder involvement and cooperation, to support, facilitate and overcome obstacles that prevent a system change towards a clean circular nutrient economy. The actors connected to the platform are municipalities, research institutes, academia, sludge entrepreneurs, technology developers and manufacturers. We are also in the processes of reaching out to the food industry to close the circular loop from farm to fork and back to farm.

Keywords: Innovation platform; nutrient re-use; national cooperation

Swedish wastewater treatment plants annually produce 900 000 tons of sludge, of which a third is used on agricultural land. If all nutrients in sewage sludge would be recovered, 40 % of the imported phosphorus and about 6 % of the nitrogen in mineral fertilizers could be replaced (Myrbeck & Lundin, 2019). As Sweden is in the process of obtaining a new regulation that will potentially limit sludge disposal on farmland and enforce a requirement on phosphorus recovery, nutrient recovery is high on the agenda. Research about the topic has intensified and is driving the development of new technologies (Harder et al. 2019, von Bahr et al. 2019). In this dynamic and fast development many Swedish wastewater treatment plants experience similar challenges:

They have an urgent need to find sustainable solutions for their disposal of sludge. They are courted by different innovation companies but feel unequipped to decide on solutions based on current knowledge and they also find it difficult to follow this quickly sprawling area of research and innovation. The need to coordinate activities nationally and to address the challenges of the Swedish W&S-sector lead to the establishment of the Swedish Nutrient Platform. The Innovation Platform's value proposition is to:

- Channel joint activities in sludge management and nutrient recovery;
- Working together on new business models;
- Process management of collaborative projects and;
- Create an overview of the entire system and make knowledge easily accessible.

The platform greatest value is created through the collaboration of actors covering the entire nutrient value chain from wastewater to food. The relationship with and between stakeholders is maintained through newsletters, webinars, network meetings and an informative website, including news coverage on nutrient recovery. Examples of projects that already have been initiated through the platform are a new test arena for biochar from sludge (ongoing), a comprehensive literature review of the potential of nitrogen recovery from wastewater (ongoing), and guidelines on how to compare the environmental impact of different recovery systems (Ahlgren et al, 2020). With this paper the authors wish to highlight the role of a national innovation platform to enable cross-institutional coordination as well as partnership beyond the W&S-sector to move forward in the transition to a circular nutrient economy.

Hydrothermal carbonization of surplus sludge from effluent treatment in various milk processing factories

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Abstract

Dairy processing plants must deal with the disposal of high volumes of surplus sludge resulting from effluent treatment. Dairy processing sludge (DPS) contains valuable macro and micro-nutrients, and it is applied to land as a fertilizer in many countries [1]. Drawbacks of land spreading include local oversupply because due to high transport costs sludges are spread on lands in the vicinity of the dairy factories. DPS when spread on land retains 80 to 90 % of water [2]. Hydrothermal carbonization (HTC) breaks up the physical/ chemical structure of the sludge; oxygen is partially removed, and the organic fraction is rearranged into carbonaceous solid product which is less hydrophilic [3] thus water can be much easily removed. The purpose of the study is to investigate the potential of HTC as a conversion technology for DPS. Laboratory scale HTC of DPS from three different milk processing plants was carried out at 180, 200 and 220°C for 1 hour. The properties of the resulting hydro-char and liquor (separated by filtration) were examined. The distribution of plant nutrients as well as heavy metals between the two products was measured. The properties of hydro-char were compared against requirements for component category materials according to the new Fertilizing Products Regulation [4].

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Technical comparison of phosphorus recovery technologies from wastewater

Wastewater nutrient recovery has two-way benefits by removing impurities from usable water as well as by concentrating nutrients to be utilized as chemical products. In this study, different phosphorus recovery technologies were studied using municipal wastewater as a feed; precipitation as calcium phosphate, concentration by nanofiltration (NF), reverse osmosis (RO) and evaporation, and adsorption by granulated activated carbon (GAC). Phosphorus was precipitated as relatively pure calcium phosphate when lime was used as a precipitation chemical. This was possible with a good pre-treatment, e.g. flocculation aided belt filtration and subsequent microfiltration for particles removal prior to phosphorous recovery. Removed particles could be utilized as a carbon source in hydrothermal carbonisation for solid hydrochar production. When containing sufficient amount of calcium in the feed, also other bases for phosphorous precipitation could be used. NF was found as good technology as RO and evaporation for phosphorus concentration from wastewater, achieving over 99% rejection. However, in addition to phosphorous these technologies concentrated soluble impurities. GAC treatment removed a bit less phosphorus from municipal wastewater than the other studied technologies, leading to 85% rejection. Additionally, it was considered more removal than recovery technology. The phosphorous recovery technology for larger scale experiments was selected based on the rejection efficiency and advantage for subsequent resource recovery. Since nitrogen recovery as ammonia was found to be a promising alternative, precipitation of phosphorus as phosphate at high pH was also found to be advantageous for the subsequent ammonia recovery, and hence acceptable for production of reused water by RO.

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Nanofertilizer obtained by colloidal self-assembly of amphiphilic molecules for controlled release of phosphorus in soil

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Phosphorus an essential macronutrient for plant growth and the primary source of this nutrient is the soil [1]. However, long-term excessive application of phosphorus-rich fertilizers and animal dung causes phosphorus buildup in soil, which can be mobilized by erosion, surface runoff, and subsurface leaching [2]. Moreover, some phosphate mineral fertilizers include trace levels of cadmium, which is highly toxic to humans [3]. In this study, we have proposed a formulation of a new nanocluster obtained by colloidal self-assembly of amphiphilic colloids acting as a nanoporter for gradual and sustainable release of phosphorus and other essential elements for plant into soil. The raw materials used for the synthesis of the nanonutrients were analyzed by atomic absorption spectrometry to rule out traces of cadmium and other heavy metals. In comparative field trials with different soil, this nanonutrient provided a gradual and sustained release of nutrients compared with the initial burst and fluctuating amounts releasing from conventional fertilizers. Similarly, the application of the nanonutrient on field-grown tomatoes, 30% less than control treatments, showed a significant increase in yield without soil damage, contributing to the recovery of soil structure and agroecological functions. Moreover, the nanocluster provides the energy that the plant needs for its initial development, because among its multiple functions, it activates the thermodynamic transport [4].

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The impact of P on Fe(II) catalyzed ferrihydrite transformation under oscillating redox condition

Iron (Fe) cycling exerts a substantial control on the bioavailability of phosphorus (P), which depends on the crystallinity and reactivity of Fe (oxyhydr)oxides. Conversely, P can also alter the structure and surface property of Fe oxides. In variably water-saturated, redox-fluctuating environments such as capillary fringe in the aquifer, the retention or release of P is often linked to the fate of Ferrihydrite (Fh), a poorly crystalline Fe mineral. Under anoxic conditions, aqueous Fe(II) rapidly catalyzes Fh transformation to more crystalline forms such as lepidocrocite and goethite, altering their surface characteristics and retention capacity. Yet, these processes in the presence of P during redox cycles remain poorly understood. We conducted laboratory experiments to compare the effects of coprecipitated and adsorbed P with pure Fh on Fe(II) catalyzed mineral transformation under oscillating redox conditions. While pure Fh underwent significant structure changes, P-bearing Fe oxides remained amorphous and poorly structured. The current study provides insight into the environmental implication of iron mineral dynamics in the presence of P under fluctuation redox conditions and the associated consequences of regulating P fluxes from soils to surface waters.

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Contributing to sustainable rural development and transition to a circular bioeconomy with a special focus on nutrient sustainability

Summary

The main mission of the BETA Technological Centre is to be a relevant actor for the technological development, the improvement of the competitiveness and the quality of life of rural societies for a sustainable future. BETA TC works to find solutions for environmental problems that involve the integration of the treatment of gaseous effluents, wastewater and municipal and industrial organic solid waste, with a special focus on the agri-food sector and the bioeconomy. Additionally, BETA is complementing the part of technologies with other knowledge such as sustainability assessment, ecosystems conservation and governance.

A safe and cost-efficient nutrient management is a highly strategic element for the EU agricultural sector. Member States have an urgent need to optimise the use of resources and facilitate the transition towards a circular bio-based agriculture. That is why nutrient management is in the key central activities developed by BETA TC. A clear example is the FERTIMANURE project, which is coordinated by BETA, and is willing to work on new sustainable manure management strategies, enhancing the creation of new business models that can benefit the rural societies and build new links and value chains among the farmers and the fertilizer industry.

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New urban wastewater treatment based on natural coagulants to avoid phosphorus pollution

Phosphorus levels have been measured in lakes and rivers and this level has increased in recent years. In order to resolve this issue, GOMSL is making lot of activities including Life NEWEST ENV/ES/000156.

The LIFE NEWEST project aims to respond to this problem by designing and implementing a new technology based on natural-based coagulants for use in tertiary wastewater treatment process. This technology is designed to replace the inorganic coagulants which have several disadvantages:

- Inorganic coagulants are really corrosive including risk to workers in the WWTP.
- The Manage waste is really difficult and expensive including several risks to the environment.

Life NEWEST includes the next activities:

- Industrial scale validation of the natural based organic polymer coagulant efficiency in 2 urban WWTP and 2 industrial WWTP. Nowadays, the results about this activity are being positive and we can use the new coagulant to remove phosphorus in WWTP.
- The agronomic quality of the produced compost is being evaluated, the ecotoxicological effect of this compost application is being studied and the new coagulant effect at the biogas production of the anaerobic sludge digestion is being quantified. Nowadays, the results are showing an important increase about the biogas production.

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Reduction kinetics of iron-rich by-products from drinking water treatment

Iron (hydr)oxide containing by-products obtained from drinking water treatment are applied for long-term binding of phosphate in lake sediments or soils. In these environments, the by-products can be exposed to reducing conditions. Their susceptibility to chemical or microbial reduction is, therefore, an essential factor in controlling their applicability for phosphate immobilization. However, the iron-rich by-products vary regarding their mineralogy and composition depending on the chemistry of groundwater source and the treatment process. Here, we investigate how the heterogeneity of iron (hydr)oxide mineralogy affects the kinetics of reductive dissolution.

For this, the reduction of 12 iron-rich by-products from Dutch drinking water treatment plants by ascorbic acid was measured at pH 3 and 60 °C. The rates of reductive dissolution (J) can be described by the generic rate law proposed by Postma et al. (1993): $J/m_0=k_{app}(m/m_0)^{\gamma_{app}}$ where k_{app} is the initial rate constant and $(m/m_0)^{\gamma_{app}}$ reflects the change in reactivity with progressing consumption of the initially added amount of iron (hydr)oxide (m_0). It turned out that the different by-products can be grouped with respect to the parameters k_{app} and γ_{app}. The resulting classification, in turn, can be related to the composition and mineralogy of the by-products.

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P-TRAP project: https://h2020-p-trap.eu/

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Phosphorus leaching following a long-term cattle manure application

Research on environmental P loss from agriculture is primarily focused on erosion, runoff, and tile drainage as opposed to leaching. However, there can be a substantial P leaching in dissolved and particulate forms in long-term manure applied fields where P-adsorption efficiency is saturated. The objective of this study was to evaluate the effects of manure application on P leaching in the long-term furrow irrigated continuous maize experimental field in Scottsbluff, Nebraska, USA. The main factor treatment included cattle manure at 27 Mg/ha/yr and the control (no manure) since 1942. The ortho-phosphate (Olsen-P) was detected at a concentration 25 µg g^{-1} at 120 – 150 cm below the soil profile following 70 years of manure application compared to 7 µg g^{-1} in the non-manured plot. This result suggests manure-induced active dissolution and mobilization of P down the soil profile. However, the complete transformation/speciation cycle of P in manure amended soil is far from being deciphered. There are studies suggesting that manure derived high molecular weight dissolved organic matter might reduce the P-adsorption efficiency of Al, Fe, and Ca and make it more bioavailable and prone to leaching. However, manure influenced chemical-biological processes involved in absorption and mobilization of P need further studies.

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Extraction Effects on Polyphosphate Ion Diffusion as Detected with Gel Electrophoresis and ^{31}P-DOSY-NMR

Polyphosphate is a ubiquitous biopolymer that is found in archaea, bacteria, algae, fungi, protists, plants, insects and mammals. Extraction methods are necessary prior to the identification and measurement of intracellular polyP chain length. Commercially available sodium polyphosphate glasses were either dissolved or dissolved and extracted by two commonly used polyphosphate extraction techniques - perchloric acid or buffered phenol-chloroform. The products were separated by PAGE, stained with toluidine blue O or methyl green, and the migration results quantitatively compared. Both extraction processes reduced the relative peak migration distances suggesting reduced polyphosphate migration and dispersion. ^{31}P DOSY NMR confirmed that polyphosphate extraction by perchloric acid or phenol-chloroform processes reduced polyphosphate diffusion coefficients. Reduced polyphosphate diffusivity after extraction makes possible an overestimation of polyphosphate chain length assignment when compared to unextracted polyphosphate ladders with PAGE. Accurate characterization of P molecules, including polyphosphate, is a critical component for the understanding of P-recycling and the application new technologies.

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A novel process for an efficient phosphorus utilization from cereal by-products in feed industry

Cereals are a valuable source of carbohydrates, proteins and minerals – among them mainly phosphorus which is mostly accumulated within the outer grain layers in the form of phytate. However, when feeding cereal bran phosphorus cannot be utilized by monogastric animals due to a lack of phytate-cleaving enzymes in the digestive tract. Thus, phosphorus accumulates in manure and then in the soil which leads to enhanced run-off and severe environmental issues. Therefore, we now investigate different mechanical and chemical methods to make the phosphorus in cereal-based feedstuff available for animal absorption.

The investigated chemical process comprises three steps: phytate solubilisation in diluted hydrochloric acid, phytate cleavage within a microwave digestion system and phosphate recovery by precipitation. First results from chemical hydrolysis of the acidic rye bran extract showed a clear temperature dependence. By a 10 minutes-treatment at 180 °C over 90% phytate cleavage was achieved. Subsequent precipitation by addition of magnesium and ammonium salt at pH 8-9 reached up to 99% phosphate removal from the liquid phase.

By this potential process far more than 100 Mt phosphorus could be made available in Europe e.g. for fertilizing purposes – thus significantly contributing to a more sustainable phosphorus management.

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Turning wastewater treatment plants into biorefineries: global value chain from bioresources to valuable products

Summary of talk content:

Environmental sustainability is a major goal for 21st century and high demand is being put for upgrading wastewater treatment plants (WWTP) into Biorefineries to address the recovery of nutrients such as phosphorus and nitrogen to be reintegrated in the value chain as fertilizers. A case study at Murcia Este WWTP [1], P-recovery is achieved by P elutriation at full-scale followed by a pilot crystallization unit producing 5 kg/d of struvite (85% P recovery). N-Recovery is achieved in a pilot plant based on ion exchange with zeolites and membrane contactors which allows to produce (7 kg/d) fertilizers in form of ammonium salts (nitrate, phosphate and sulphate depending on the acid selected). The development of a treatment train for nitrogen and phosphorus recovery in existing urban WWTP is expected to allow a P-recovery of 40% (> 50% as struvite) and a N-recovery of 15% (regarding the influent concentrations in both cases). Furthermore, this presentation will include insights about a new H2020 project (WalNUT) in which Cetaqua will design new smart biofertilizers (Smart BBFs) combining recovered products (struvite and ammonium salts) with plant growth stimulants (PGBs) in order to improve crop performance.

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OPTIONAL:

[1] - LIFE + ENRICH (LIFE16 ENV/ES/000375), European funded project - http://www.life-enrich.eu/

[2] – H2020 WalNUT https://cordis.europa.eu/project/id/101000752/es

Pilot scale Recovery of Calcium Phosphate from UASB effluent after elimination of Dissolved Inorganic Carbon

A pilot scale experiment ran for one year on the effluent of an upstream anaerobic sludge blanket reactor (UASB) of a potato processor. The effluent was first nitrified to consume most of the dissolved inorganic carbon (DIC), a prerequisite for magnesium-free calcium phosphate precipitation with minimal coprecipitation of calcium carbonate. Two routes to recover phosphate were studied. Initially, after ultra-filtration and under aeration to expel DIC the addition of calcium chloride resulted in the precipitation of calcium phosphate. 30 kg of orange-brown precipitate was subjected to the wet process for phosphoric acid production. Both the acid and the isolated calcium sulphate were colored, but fulfilled all other chemical criteria. The precipitate can be decolorized and decarbonated by calcination at respectively 600 °C and 900 °C. Later on, after further pre-treatment of the effluent by anion selectrodialysis, the addition of calcium chloride resulted in a pure white precipitate that only contained calcium phosphate and some calcium carbonate. The Ca/P ratio of the precipitate could be reduced by aeration of the pre-treated UASB-effluent to further expel DIC before selectrodialysis. The recovered calcium phosphate had a Ca/P ratio of 1.84, a P_20_5 content of 38 % and was free of other ions.

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Synthesis of struvite with compost slurry: analysis of the fertilizer potential for the circular economy

Summary of content: Organic solid residues from human activities are basically composed of food waste (animal or vegetable), in addition to garden waste, pruning, among others, rich in nutrients (phosphorus - P, potassium - K and nitrogen - N). An environmentally correct solution is the composting of organic waste. Tests were conducted in a compost bin, which gave rise to a slurry with nutrients of the order of PO43- = 760 mg/L and NH3 = 192 mg/L, at pH 7, which corresponds to optimal conditions for struvite precipitation. The synthesis of struvite will be evaluated under the optimal conditions proposed by Meira et al, 2020, for phosphorus concentrations of 300 mg/L under the same room temperature (RT) condition and a magnesium to phosphorus to nitrogen (Mg: P: N) molar ratio of 1: 2:1, under a moderately alkaline pH (10). Struvite is an excellent quality slow-release fertilizer that can be used directly in horticulture, agriculture, and even fish farming. Nutrient recycling from the synthesis of struvite from compost slurry will enable the utilization of secondary P among other nutrients in a sustainable manner in agriculture on Amazonian soils.

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Balancing multiple priorities for a circular phosphorus economy: spatial tools to help select processing locations.

To meet sustainable food and energy goals, societies need to radically transform production and consumption systems. At the same time, the infrastructure(s) required to support effective nutrient and energy extraction from biomass take a long time to build and thereafter can be inflexible. Planning infrastructure such as biogas plants must thus balance requirements and constraints under current conditions and account for the fact that the extent and type of agriculture of the future will be different. Spatially-explicit planning tools which compare how robust biogas plant locations are across scenarios can help stakeholders make resilient investments. We created two novel Swedish agricultural land use maps based on stakeholder co-designed visions (notably reductions in meat consumption and thus manure production). These were converted to 25km^2 grids of organic waste supply and crop demand (nitrogen and phosphorus). These grids were overlayed with a 1km^2 resolution dataset of current location constraints (e.g., road access). We used optimization modeling to select the location of new biogas plants which would minimize the transport distances and costs associated with redistributing biobased fertilizers without exceeding crop nutrient demands. We show results from the Swedish island of Gotland – a municipality keen to increase biogas production and nutrient self-sufficiency.

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Optional additional information:

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Potential of recycled vivianite as P and Fe fertilizer – from a mechanistic point of view

The ferrous iron-phosphate mineral vivianite ($Fe(II)_3(PO_4)_2*8H_2O$) forms readily in natural and artificial environments under anoxic conditions with high dissolved Fe(II) and phosphate (PO_4) concentrations. Thus, vivianite can act as a PO_4 sink by controlling the dissolved PO_4 concentrations in lakes and wastewater treatments plants. Moreover, vivianite has also been proposed as a potential PO_4 source as a slow-releasing Fe-P fertilizer to support crop growth. Linking both properties (sink and source), vivianite might help to mitigate two major problems in the current P-cycle: (i) P scarcity in crop production, and (ii) eutrophication of surface waters. To evaluate potential applications, mechanistic and quantitative understanding of environmental fate (dissolution, oxidation, re-precipitation) of vivianite is needed.

Through our experimental work, we aimed to elucidate the vivianite dissolution mechanism and to quantify the dissolution rates. Further, we investigated the influence of environmental conditions such as pH, temperature, O_2 partial pressure and organic ligands and studied the formation of secondary phases. Finally, the risk of contaminant incorporation during vivianite precipitation, followed by contaminant mobilization after application as fertilizer, was examined. Based on our results we propose a mechanism for vivianite dissolution, aiding to assess the suitability of vivianite as Fe and P fertilizer.

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Nutrient pollution in Stockholm's water catchments: Systemically assessing its social, ecological, and technological determinants

The poster will be a preliminary presentation of a transdisciplinary case study of several urban water bodies in Stockholm that suffer from excess nutrient pollution. The project will focus on urban catchments that contain allotment gardens due to stakeholder interest in understanding their impact on water quality in Stockholm. Furthermore, this research will act as a contribution to work on the potential role of urban gardens and agriculture as green infrastructure, and in improving the circularity of urban nutrient flows.

The first goal of the project is to identify and quantify the sources of phosphorus and nitrogen pollution to each water body. Working at catchment scale will allow the identification of any pollution 'hotspots,' like urban allotments, that may be significant within a specific urban catchment, but may be missed in a city-scale analysis. The second goal is to determine the ecological, technological and social factors that directly and indirectly drive the flow of nutrients into water bodies in the catchments, in order to identify opportunities to synergistically improve water quality and other ecosystem services. Finally, it will assess the role of transdisciplinary methods for increasing the relevance of research to stakeholders and for improving systems understandings supported by modelling.

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Assessment and comparative analysis of willingness-to-pay for bio-based fertilisers in the European Union

To assess the willingness-to-pay for bio-based fertilisers an EU-wide survey is conducted. The survey covers seventeen EU countries with the target respondents of field crop farmers, horticulturists and agricultural advisors and is expected to be finalised by early Spring 2022. The survey is a result of the collaboration between two MSCA ITN consortia (FertiCycle and ReFlow).

To quantify the willingness-to-pay, Westendorp's Price Sensitivity Meter technique was selected. The technique measures four psychologically perceived price levels - too cheap, cheap, expensive, too expensive. Thus, allowing to distinguish the lowest market acceptable price and the highest market acceptable price, thus effectively generating an acceptable price range. In addition, optimal price point is generated, which suggests the price that will meet the least resistance from the consumers.

This analysis uncovers the existing market opportunities, possibilities for expansion across EU countries, but also serves as a benchmark for farmer's readiness for the transition to a wider use of bio-based fertilisers. The presentation will outline the differences and similarities in willingness-to-pay for bio-based fertilisers across the EU as well as provide the suggestions for development of marketing strategies, policy recommendations and guidelines.

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Effect of Fe addition on P retention in peaty freshwater sediment

Increased P concentrations in surface waters are a global challenge for water quality and ecosystem functioning. As external P input has been decreasing due to sterner regulations, internal loading caused by legacy P stored in the sediments can become the main factor controlling surface water P concentrations. We investigated the long-term effects of adding $FeCl_3$ or Fe containing byproducts from drinking water production ("Fe-sludge") on the P and Fe dynamics in sediments of a peaty lake and a peaty agricultural ditch system, respectively. Sediment P and Fe speciation were determined using sequential extraction methods and P and Fe fluxes across the sediment water interface were measured by incubation of undisturbed sediment cores. The results suggest that the added Fe changes the P burial regime of the sediment by enhancing the binding capacity of the sediments. Furthermore, the redox-sensitivity of Fe might lead to increasing P concentrations in the pore waters when P containing Fe phases become reduced. This potentially leads to the enhanced formation of authigenic P minerals. However, our data also suggest that binding of Fe to organic matter hampers the Fe redox cycling in these organic-rich sediments. This, in turn, might exert influence on the sediment P dynamics and the benthic P fluxes.

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Modelling phosphorus dynamics in European agricultural soils and assessing phosphorus policy goals

Only part of the phosphorus (P) applied to agricultural systems is taken up by plants. A significant share ends up in aquatic systems. To come up with effective solutions for this environmental problem, we need to be able to depict the P cycle in agricultural systems. However, we currently lack a spatially explicit P model.

Field observations of long-term agricultural trials are used to calibrate and validate the P cycle into a daily time series biogeochemical model used to simulate P fluxes between the atmosphere, vegetation, and soil. This model enables the spatial depiction of P's magnitude and temporal dynamics in agricultural soils, P input (mineral, organic), P export (via plant harvest, erosion, leaching), and the P balance. A large-scale Europe wide integration will exhibit the current state of the P cycle as well as advance prediction capabilities of planned policy scenarios. For instance, the estimation of decreasing P fertilization is enabled as it is one of the farm to fork strategy goals of the European Commission (reducing fertilizer use by at least 20%). This model will help connect soil science and land management policy and be of assistance in developing management strategies for policymakers.

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Phosphate retention by Fe(III)- and Ca-phases formed upon oxygenation of anoxic groundwaters

The cycling of phosphorus in environmental systems is tightly coupled to the redox-cycling of iron (Fe). The oxidation of dissolved Fe(II) upon oxygenation of anoxic groundwaters leads to precipitation of poorly crystalline Fe(III)-solids that strongly bind phosphate (P). Fresh Fe(III)-precipitates may transform into more crystalline phases over time, which may lead to the release of initially co-precipitated P. The formation and transformation of Fe(III)-precipitates in natural waters and P retention capability are affected by solutes (Ca, Mg, silicate (Si), P, dissolved organic matter (DOM)) that interfere with Fe(III) polymerization and P binding. Furthermore, in Ca-containing waters, the formation of Ca-carbonates or -phosphates can limit P release into solution over extended periods.

For an improved assessment of the fate of P in aquatic and terrestrial environments, there is a need for an enhanced mechanistic understanding of coupled Fe (and Ca) phase formation and transformation processes triggered by groundwater oxygenation and their effects on solid-phase P retention. In this project, we study the interdependent effects of Ca, Mg, silicate, P, and DOM on these coupled processes in laboratory experiments under conditions representative for natural waters. Using spectroscopic and microscopic techniques, we aim to gain new insights into the molecular- and nanometer-scale processes that control the fate of P in environmental systems.

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Hydrothermal Carbonization (HTC) of Dairy Waste: Effect of Temperature and Initial Acidity on the composition and quality of solid and liquid products

Summary of content

Hydrothermal carbonization (HTC) of dairy waste was performed on a laboratory scale at different operating conditions to assess the effect of initial parameters on the quality and composition of the products, with special focus on the qualification of hydrochars as potential solid organo-mineral fertilizers.

Maximum hydrochar yield (60.67%) was at T=180°C and pH=2.25, whereas maximum P-recovery (80.38%) from hydrochar was observed at T=220°C and pH=4.6. All hydrochars qualified as solid organo-mineral fertilizers in terms of P-content and all heavy metals except for Chromium (Cr), which exceeded the allowed EU limit (2 mg/kg). The best conditions for heavy metal content in hydrochars were observed at T=200°C and pH=4.6.

Finally, liquid product analysis showed that HTC enhanced the concentration of inorganic nitrogen into the liquor, thus reducing their potential polluting effect in the hydrochars. Also, the reduction in P-concentration in the liquors upon the increase in temperature and initial acidity was compatible with P-concentration in hydrochars.

To sum up, HTC of dairy waste at moderate temperatures and elevated initial acidity allowed for the production of P-rich hydrochars with potential application as solid organo-mineral fertilizers. However, the need to mitigate Cr concentration persists to complement the environmental safety of hydrochar application.

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Phosphorus recovery as struvite from hydrothermal carbonization liquor of chemically produced dairy sludge[1]

Summary:

Phosphorus (P) recovery from dairy wastewater involves its accumulation into phosphorus-rich sludge using a chemical or biological process. The high iron content in chemical sludge decreases its usability in agricultural activities. The hydrothermal processes are used to treat the sludge to obtain hydrochar for various applications, including its use as an energy source and as a carbon-dense material. However, this process leaves a bigger volume of nutrient-rich liquor, which P purification was the subject of this work. By direct precipitation, the product iron content was excessive for phosphate fertilizers. Thus, P extraction followed by struvite precipitation was studied. The use of oxalic acid extracted 86.7% of P from the hydrothermal carbonization liquor, and 86.6% of iron removal. The process conditions of pH, and salt dosage for struvite precipitation from P extract were achieved with P recovery of 99.96%, and P concentration below 2 $mg.L^{-1}$ in the effluent. By assays, high iron content in the product induced phytotoxicity, whilst the struvite from P extract demonstrated an advantage for plant macro and micronutrient availability. The used method of P extraction followed by struvite precipitation is useful for both P and iron recovery into two separate products with agricultural and chemical applications, respectively.

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Phosphorus recovery from sewage treatment plant in Brazil through sorption and coagulation-flocculation

A considerable advance in new technological alternatives for phosphorus (P) recovery via effluents and sewage sludge has been reached around the world, unfortunately in Brazil, data is still lacking and currently very little is done about nutrient recovery process, with treated water still rich in nutrients and sewage sludge being disposed in landfills. We urgently need viable alternatives for developing countries. Based on that, we studied two distinct mechanisms, adsorption, and coagulation-flocculation, in the improvement of wastewater treatment in the city of Piracicaba/SP - Brazil, regarding the parameters of total P and total nitrogen (Total N). In coagulation-flocculation, we compared the use of inorganic coagulant aluminium sulphate [$Al_2(SO_4)_3$] and commercial organic coagulants based on cationic tannins (black wattle extracts). In the adsorption process, adsorbents obtained from modification of sugarcane bagasse with $MgCl_2$ and zeolite with $CaCl_2$ (BMgC and ZCaC, respectively) were produced, characterized, and tested. From the results, coagulation-flocculation were able to reduce around 25 - 85% of the total P, accelerated the sedimentation and reduced parameters of control (COD and N – Kjeldahl). With the adsorbents was possible to simultaneously reduce total P and NH_4^+- N by more than 65 - 85% and 11 - 44%, respectively.

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Sustainable Phosphorus Removal with the Hias Process

Summary of content

The moving bed biofilm reactor (MBBR) was invented in Norway in the late 80's and is today a widespread mature technology for removal of nitrogen and organic matter from wastewater (Ødegaard et al, 1994). Phosphorus removal in MBBR reactors is up till now done with use of precipitation chemicals. This practice is a significant barrier for sustainable recovery of phosphorus.

The Norwegian utility Hias IKS has developed the Hias Process, which is a continuously mode MBBR reactor (Saltnes et al, 2017). The Hias Process removes organic matter, phosphorus via EBPR, and both nitrogen and phosphorus via simultaneous nitrification and denitrification P-removal (SND-P). The Hias Process has been demonstrated since 2016 (10 000 PE) and in large scale (192 000 PE) since 2020 with excellent results for phosphorus removal (PO4-P < 0,20 mg/l). Due to the compactness of MBBR technology, the solution is volume-to-area efficient compared to current state of the art for BNR. Minimal use of precipitation chemicals and external carbon sources results in favourable OPEX, and at the same time pave the way for sustainable phosphorus recovery.

The presentation will cover the design and function of the Hias Process and present long-term results in large scale. A complete process train for full biological removal of phosphorus and nitrogen will be proposed, including a Ostara Nutrient Recovery system.

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Effect of Phosphogypsum on faba bean and its nutrients and heavy metals uptake

Abstracts: Phosphogypsum (PG) is a by-product of the phosphoric fertilizers industry which generates around 280 Mt annually. However, only 15% of the PG produced are recycled. PG is used in agriculture as fertilizer for crops and as amendment for reclaiming degraded soils. A study was undertaken in pot trials, at Mohamed 6 Polytechnic University in BenGuerir Morocco, in collaboration with OCP, the Moroccan phosphate industry, to evaluate the effect of Phosphogypsum on nutrients (N, P, K, Ca and S) and heavy metals (As, Pb, Cd, Ni, Fe, Cu, Zn, Mn, Al and Cr) uptake by faba bean shoots and grains. PG at rates 0, 15, 30 and 45 t/ha was mixed with the upper 9 cm layer of the soil. PG application significantly increased K and Ca uptake by faba bean shoots. The highest dose of PG improved Ca content in shoots by 41% compared to the control. Grains content of all analyzed nutrients were significantly improved by PG application and were highest with 30 and 45 t PG/ha. Grains P uptake was increased by 39% and 36% with 30 and 45 t/ha of PG, respectively. Grains and shoots heavy metal contents were similar across treatments and bellow the international standards.

Keywords: Phosphogypsum, nutrients uptake, heavy metals, faba bean.

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New technology to recover phosphorus from wastewater within the Circular Economy: a Scottish case study

Phosphorus (P) recovery from wastewater will become increasingly vital in the future in terms of the protection of valuable freshwater resources (i.e., from eutrophication) and due to rapidly dwindling terrestrial rock phosphate stocks [1]. The Environmental Research Institute (ERI) has been developing the FILTRAFLO™-P reactor (with Veolia Water Technologies) to recover P from final effluent through a filtration/adsorption process (Phos4You Project - INTERREG VB North-West Europe). This small unit employs enhanced gravitational filtration through adsorption media (here, a novel KOH deacetylated crab carapace-based chitosan-calcite adsorbent (CCM)) with continuous self-backwashing [2]. A six-week pilot trial of this technology was carried out at the Scottish Water Horizons Development Centre at Bo'ness. High P recovery potential was achieved even at low P concentrations, bringing the residual effluent P level below 1 mg/L (EU limit for sensitive water bodies). Surface microprecipitation and inner-sphere complexation were postulated as key P removal mechanism. The results showed that the FILTRAFLO™-P unit with CCM could serve as a water polishing unit (with low P concentration effluents) and/or as a P harvesting unit (where P concentrations were high). The quality analysis of CCM indicated ~3% P_2O_5, trace levels (well below legislative limits) of heavy metals (i.e., Cu, Co) and organic pollutants (e.g., PCBs) and no detectable levels of target bacterial pathogens. A pot trial (at Ghent University) showed that the ryegrass plants treated with the CCM adsorbent achieved higher plant dry matter and P concentration compared to the unfertilised control.

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Nutrient removal/recovery from water using functionalised biochars

This work looked to explore biochar's potential to mitigate against nutrient pollution by testing biochar for its capacity to remediate water through the capture of excess nutrients [1]. Here, we propose that brash from forest-to-bog restoration sites through conversion to biochar, may be transformed into an added-value water treatment product. The specific objectives were to determine the best production methods for biochar through a Response Surface Methodology. The raw biochar was then functionalised with Ce/La/Zr metal hydr(oxides). All the biochars were characterised with SEM-EDX, BET, FTIR, XRD and XPS techniques. The removal efficiency/adsorption capacity of nutrients (PO_4^{3-}, NO_3^- and NH_4^+) were optimised through a series of batch studies to explore the kinetic/thermodynamic behaviour and equilibrium phase of the biochar/nutrient system in an aquatic environment. The results suggest that the raw biochar only weakly adsorbs nutrients, which is especially true for the anionic forms of PO_4^{3-} and NO_3^- due to electrostatic repulsion elicited by the negatively charged biochar surface. Chemical functionalisation significantly increased adsorption capacity for all nutrients (especially for PO_4^{3-}, with a more than 1000-fold improvement). Instrumental characterisations showed that the adsorption mechanisms were dominated by metal-phosphate precipitation reactions, and inner- and outer-sphere complexation onto metal ligands. As a next step, a series of dynamic column studies will be conducted to determine the most relevant engineering parameters for scale-up.

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Recovering nutrients from aquaculture industry by-products for the production of bio-based fertilizers

The aquaculture industry generates large quantities of animal by-products that need to be managed appropriately to minimize their potential health risk (EC1069/2009). The fish sludge, composed of fish feces and animal feed, requires a special attention since the fast growth of land-based aquaculture during the last years and the ever-increasing application of recirculating aquaculture systems have significantly increased the volume of sludge generated. The composition of the fish sludge, with a high content of nutrients and minerals, evinces its potential as a fertilizer product. Nevertheless, its direct use as a natural fertilizer is limited by governmental regulations, being necessary to examine suitable processes based on a holistic approach to produce agronomic value products. To overcome this challenge, in the framework of SEA2LAND project, BETA Technological Center is evaluating an innovative valorization system integrating technologies such as membrane systems, freeze concentration, biodrying, thermal treatment coupled to phosphorous-ash recovery and acid scrubber, to obtain products with agronomic value to be applied directly as bio-based fertilizers in field crops and others to be used as precursors for the formulation of tailor-made fertilizers. The fertilizing products obtained are: i) a nutrient-rich concentrate, ii) ammonium salts, iii) a phosphorous-rich organic amendment and, iv) phosphoric acid.

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H2020-CE-RUR-08-2020. SEA2LAND: Producing advanced bio-based fertilizers from fisheries wastes. ID Grant Agreement: 101000402. SEA2LAND project website: https://sea2landproject.eu/

Sewage sludge compost and wastewater nutrient sources in forage production of *Urochloa brizantha*

Resources derived from wastewater treatment plants can be efficiently reused in agriculture as good nutrient source for crop production. To manage these residues one alternative is composting for the stabilization of C/N ratio, nutrients and harmful elements. Furthermore, there are other processes for recovering P from wastewaters and sewage sludge, like struvite precipitation and/or incineration generate ashes. Therefore, our objective was to evaluate the initial and residual effect of sewage sludge compost and other sources derived from wastewater and sewage sludge treatment as potential phosphate fertilizers for *Urochloa brizantha* forage production. Experiment was carried out in a greenhouse, where the development of *Urochloa brizantha* was evaluated during six consecutive cycles. Products tested were: sewage sludge compost (SSC), SSC pelletized, SSC + monoammonium phosphate (MAP) pelletized, SSC + AshDec® pelletized, AshDec®, struvite, MAP and a control. Each treatment received 100 mg/kg of P. Recycled sources presented accumulated forage production superior to MAP, in addition, they left more P in the soil, mainly in the moderately and non-labile fractions, which will have residual effect for the coming cycles. All the recycled sources (SSC, AshDec and struvite and organomineral mixes) released P more gradually to plants, being more synchronized with the crop demand than MAP.

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Cover crops and phosphate sources influencing cash crops yield and soil P dynamics

We aimed to evaluate maize and soybean grain yield and soil P dynamics under phosphate fertilizer sources and winter cover crops, in the period from 2009 to 2020. Cover crops used were common vetch (*Vicia sativa*), white lupin (*Lupinus albus*), fodder radish (*Raphanus sativus*), ryegrass (*Lolium multiflorum*), black oat (*Avena strigose*) and fallow, cultivated every season from 2009 to 2020, preceding by maize or soybean as cash crops in the summer. From 2009 to 2015, phosphorus sources (SSP - 18% soluble P_2O_5, rock phosphate - 9% soluble, and a control) were applied at cash crop sowing. From 2016 and so on it was evaluated the residual effect of the previous fertilization. Shoot biomass of cover crops, P extraction, soybean and corn yield, P export estimate and soil P dynamics were evaluated. Some cover crops favored soybean and corn grain yield, tied to a higher biomass production and P absorption, recycling more P via plant tissue. The efficiency of use of rock phosphate is lower than SSP, but has a greater residual effect and grain yield stability under fertilizer suppression. High soil P content was still detected after five years of fertilizer suppression under rock phosphate initial fertilization.

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Acid-induced phosphorus release from hydrothermally carbonized sewage sludge

Phosphorus (P) recovery from P-rich residues such as sewage sludge (SS) is crucial to sustain food and industrial demands globally. This study investigated the speciation and recovery of P from SS after hydrothermal carbonization (HTC). Treatment with organic acid solutions at different pH conditions was investigated to determine how the composition of SS and hydrochars affect the P and major metals release. HTC experiments at 180, 215 and 250 °C showed that P remained immobilized (>75% of total P) in the hydrochars and that almost all of that P was present as inorganic P. Extraction efficiencies of P and major metals decreased with increasing pH, with maximum extraction efficiency reached in the pH range of 0-1 for oxalate and 0 for citrate and HCl, demonstrating that HCl is only effective for P and metal dissolution at extreme low pH. Oxalate treatment was found to have higher P release and metal leaching compared to citrate. Moreover, P and major metals extraction seems to have no clear difference between hydrochars generated at different HTC temperatures (180, 215 and 250 °C) for 2 h extraction time. Kinetic studies with oxalate solution at pH=1.4 showed that P recovery at lower HTC temperature is the most time-efficient.

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The Leachphos-REALphos process

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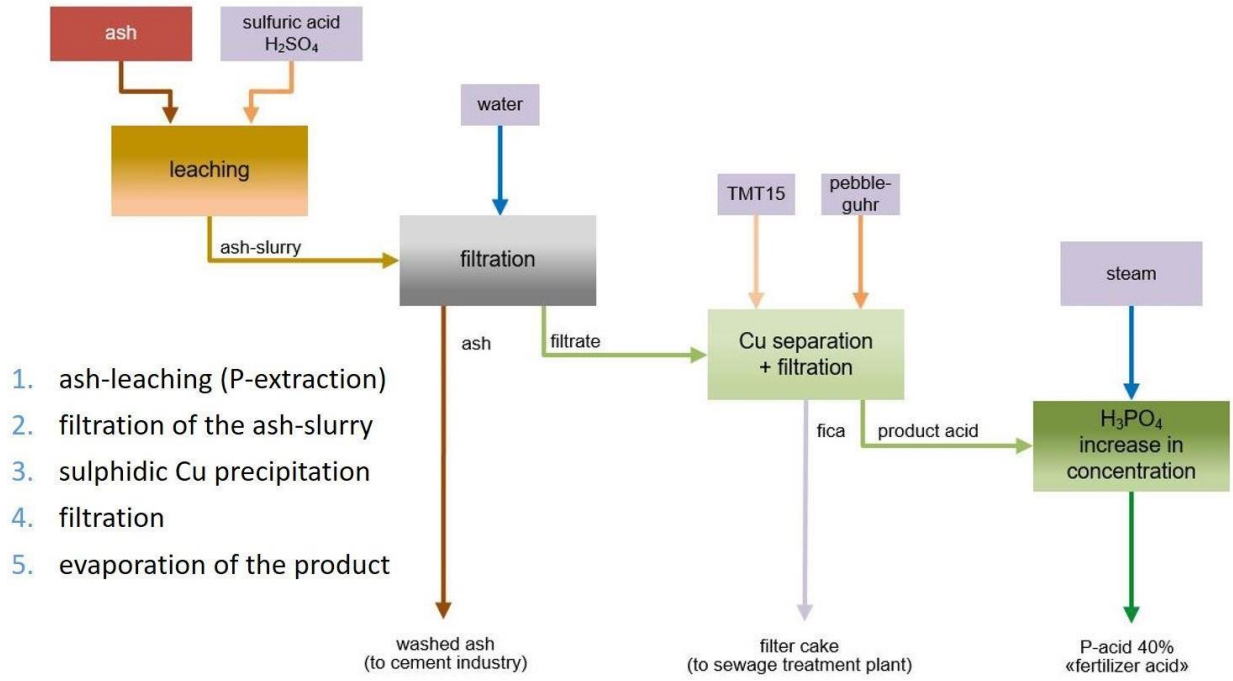
Ashes from sewage sludge incineration are rich in phosphorus content, about 9%.
The Leachphos-REALphos process proposes the possible processing of SSA (sewage sludge ash), whereby more than 80% of phosphorus can be extracted to make an adequate phosphate fertilizer.

Leachphos-REALphos is a wet chemical process. The phosphorus is leached with the help of weakly concentrated sulfuric acid. The phosphate salts contained in the sewage sludge ash go into solution. The heavy metals are only slightly removed from the ashes in this first step. In the next step, the phosphorus-containing liquid is separated from the insoluble ash particles by means of filtration. The copper is then separated off by means of sulfide precipitation. Finally the product (phosphoric fertilizer acid) is concentrated to 70% by evaporation.

SSA was supplied by from rotary kiln incinerator or from fluidized bed incineration. The incinerator is in the possession of WWTP. The WWTP operate a biological wastewater treatment with a chemical phosphorus removal using iron salts. The resulting sewage sludge is dewatered in centrifuges to 25% dry solids and finally incinerated.

The sludge incineration in CH-Oftringen (erzo) needs to comply with the new Swiss regulation for recovery of Phosphorus from sewage sludge. From 2026, the regulation on theprevention and disposal of waste will come into force, requiring the recovery of phosphorus from sewage sludge. A target of 50% recovery for each plant and for each process in 2026 was announced by BAFU. The final target would be 75% recovery in 2036.



Research on Fe-P interactions at Wetsus for P recovery

Over the last years, the iron phosphorus interactions have been studied in depth within the Phosphate team of Wetsus to find new routes for phosphorus recovery from waste streams. The team is composed of a

consortium of industrial partners and water authorities supported by TUDelft to ensure innovative and societally relevant research.

The research at Wetsus follows two main axis: phosphorus removal by adsorption and by precipitation. Our participation to the Georges Barkley prize, aiming to remediate to the eutrophication issue in the Everglades region boosted our research on iron-adsorbents. Fundamental work with iron nanoparticles supported by advanced analytical techniques like Mössbauer spectroscopy uncovered the potential of doping to improve adsorption.

Another research track focuses on the recovery of phosphorus from sewage sludge. Vivianite ($Fe_3(PO_4)_2.8H_2O$) was found to be an important phosphorus sink in reduced environments like digested sewage sludge and that 70-90% of the phosphorus in digested sludge could be present as vivianite. It was later shown at pilot-scale that vivianite, thanks to its paramagnetic properties, could efficiently be extracted from digested sludge, offering a new phosphorus recovery route.

Current research investigates the relevance of vivianite and adsorption in phosphorus recovery from animal manure and lake sediments.

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Key publications:

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POTENTIAL OF WASTE-DERIVED PHOSPHATE FERTILIZERS FOR SUGARCANE PRODUCTION IN A TROPICAL SOIL

The use of highly water-soluble phosphorus fertilizers can lead to phosphate fixation in the soil reducing fertilization efficiency (Bindraban et al., 2020). Recycled from waste, low water-solubility sources can potentially increase sugarcane's phosphorus uptake efficiency compared to conventional the fertilizer triple superphosphate (Römer and Steingrobe, 2018). Our objective was to test the waste-recycled fertilizers struvite, hazenite and AshDec® in a sugarcane pot trial using a typical tropical soil (sandy clay loam Ferralsol) for two cycles of 90 days each and three P doses (30, 60 and 90 mg kg^{-1}). We hypothesize that these sources can reduce phosphorus fixation in the soil, increasing its availability and sugarcane's absorption when compared to triple superphosphate and a control (nil-P). At both cycles, sugarcane biometry (number of sprouts, plant height and stem diameter), dry mass yield, shoot phosphorus and soil phosphorus pools were investigated. At 90 days, struvite and hazenite performed significantly better for dry mass yield (70.7 and 68.3 g pot^{-1}, respectively) than AshDec® and triple superphosphate (59.8 and 57.4 g pot^{-1}, respectively) and for shoot phosphorus, with 98.1, 91.6, 75.6 and 66.3 mg pot^{-1}, respectively. At 180 days, struvite outperformed all treatments for dry mass yield (95.3 g pot^{-1}) and was higher than AshDec® (75.5 mg pot^{-1}) for shoot phosphorus. For phosphorus uptake efficiency, struvite and hazenite were respectively 38 and 21% more efficient, while AshDec® was 6% less efficient than triple superphosphate. Furthermore, soil data disclosed higher levels of labile phosphorus for struvite, hazenite and AshDec® in the end of the first cycle (90 days) compared to triple superphosphate, the only source under which the non-labile phosphorus pool showed an increase pattern by the end of the experiment (180 days).

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Efficient nutrient recovery from urine: turning the entire waste stream into a product on-site

The Autarky urine treatment is a technology that addresses two major global challenges:

10) The recovery of nutrients to satisfy the rapidly growing demand for fertilizers in the food production industry
11) The access to safe and dignified sanitation for all

At Eawag, we have developed a process that treats urine and recovers valuable major nutrients (NPK) and micronutrients. A combination of alkaline stabilization and concentration converts urine into a dry, pathogen-free product that is easy and safe to handle. By evaporating the water in the urine, the initial volume is decreased by over 96%, thus allowing efficient transportation of the dry fertilizer. The dry fertilizer is an excellent supplement for local agriculture and horticulture, providing, a nine times higher phosphorous plant uptake than rock phosphate in alkaline soils. The urine treatment technology operates completely off the drinking water and wastewater grids. An energy demand of 1.2 kWh per day allowed an operation with photovoltaic cells, and thus autonomy from the electrical grid.

Successful field-tests took place at Eawag in Dübendorf, in a tiny house in Au, in the alpine mountain hut Leglerhütte (all in Switzerland) and in a large family household in a peri-urban zone of Durban (South Africa).

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Recovery of Nitrogen and Phosphorous from Livestock Slurry through Membrane Technologies

SUMMARY

The livestock sector in Europe based on diversified and local farm structures is the backbone of the EU rural areas. However, livestock sector involves some unsolved environmental issues such as slurry production which is used in direct land disposal agriculture delivering nutrients, but also heavy metals or pathogens leaching to groundwater (Van der Linden *et al*., 2020).

Compounds of economic interest such as ammonium or phosphates can be found in the manure. Its recovery as fertilizers can assure a more sustainable production of both animal and vegetable food resources, in the framework of circular economy (Mhatre *et al.*, 2021).

In this work, membrane technologies [membrane contactors (MC), microfiltration (MF) and reverse osmosis (RO)] for ammonium (Brennan *et al*., 2021) and phosphates (Camilleri-Rumbau *et al*., 2021) recovery were assessed in an on-site pilot plant located in Muntanyola (Spain). The obtained results showed the feasibility of recovering nitrogen from slurry as ammonium sulphate by using MC. However, phosphates tend to form complexes with metals present in slurry and it is retained during MF which difficult its on-site selective recovery. Besides, the use of RO allowed to obtain a reclaimed water that can be used as biomass growing media but also accomplishes with the parameters set in RD1620/2007 for water reuse.

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Impact and opportunities for the urban water cycle of the 'fully circular in 2050' target of the Netherlands - Circular Water 2050

SUMMARY

A vision and roadmap for the water sector was developed, with a view to the national 'A Circular Economy in the Netherlands by 2050' program. This involved the raw material efficiency in the urban water cycle, including the extraction and reuse of raw materials, such as nutrients. The incoming and outgoing substance flows of the current water chain in the Netherlands have been mapped. The material flows are presented in the form of Sankey diagrams. An overview of possible conceptual and technological innovations that can be relevant for the water cycle in 2050, including an inspirational illustration, has been produced. Also a tool with 16 characteristics to monitor and evaluate circularity has been developed. Finally a circular system integration is needed. We investigated, described, discussed, defined and established what is meant in the water cycle with fully circular in 2050 and how this can look like in practice. Via back casting the steps and open questions to reach circularity in 2050 have been defined. Cross-sectoral collaboration is really needed for a sustainable circular economy. Integration of water, waste and climate adaptation with other aspects in a city will make cities a more attractive place to live and save money too.

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KEYWORDS

Circular Economy, Future implications, Impact, Implications for Cities, Resilience, Resource Recovery, Water Cycle, Water demand.

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- Meaning of circularity for the water sector: https://www.kwrwater.nl/en/actueel/meaning-of-circularity-for-the-water-sector/

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P-recycling via hydrothermal carbonization and the use of complexing agents and acids

German law restricts the agricultural use of sewage sludge and requires a dedicated P-recovery for sludge exceeding P-concentrations of 2 % in its dry matter by 2029. Therefore, mono-incineration sites for sewage sludge are subsidized due to various options for P-recovery from ash. Yet, existing co-incineration plants cannot use sewage sludge from large-scale WWTPs from then on due to the amendment of the law. Hydrothermal carbonization (HTC) is an alternative for P-recovery as it mobilizes P, more specifically phosphate, before incineration. The resulting hydrochar can be incinerated in co-incineration plants as it contains less than the threshold of 2 % of P in its dry matter. This ongoing work presents research performed in the BMBF-funded project abonoCARE. The HTC-treatment with the use of additives like sulphuric acid, citric acid, or complexing agents addresses different mechanisms of P-mobilization. Strong acids are promising due to protonation and complexing agents immobilize the binding partners of phosphate resulting in soluble anions. Citric acid combines both mechanisms and is environmentally friendly yielding promising results.

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Nutrient balance and handprint of the Finnish forest industry

Circular economy and nutrient recycling are recognized vital in the EU. The European Green Deal sets the blueprint for turning the EU carbon neutral by 2050, while the Circular Economy Action Plan is a major pillar of it. This study assesses the nutrient balance of nitrogen, phosphorus, potassium, and calcium and presents examples and best practices of nutrients recycling in the Finnish forest industry. Nationwide balance and four pulp and/or paper mill case studies are presented. By-products in question include bark, sawdust, and sludges, mostly utilized in energy production at the mills. Produced ash is rich in phosphorus, potassium and calcium, and its increased fertilizer use would increase nutrient recycling. In energy recovery, nitrogen is lost in the atmosphere. Increasing bark use in land applications would increase nitrogen recycling. However, bark is an important renewable energy source for the mills. Overall sustainability is always the matter of multi objective optimization of different aspects and case specific. New innovations and practices as well as regulatory environment promoting nutrients recycling play key roles in increasing nutrients recycling in the industry as further discussed in the study.

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Removal of dissolved organic phosphorus from synthetic agro-industrial wastewater using ferric chloride

The available phosphorus removal/recovery technologies can achieve low concentrations of orthophosphate phosphorus (P-OP). Furthermore, P-OP can be recovered for reuse as fertiliser. However, in some agro-industrial wastewater, the dissolved organic phosphorus (DOP) is a relevant fraction that remains after conventional phosphorus removal processes and is not recovered [1]. Therefore, improvements and new technologies to recover DOP are necessary to advance the circular phosphorus economy [1,2]. Ferric chloride is frequently used to control P-OP effluent concentrations [3]. When $FeCl_3.6H_2O$ is added, hydrous ferric oxides (HFO) are formed [4]. The dominant P-OP removal mechanism is the $H_2PO_4^-$ adsorption on HFO [3,4]. However, there are no reports about the mechanisms of DOP removal into HFO. Operational conditions can affect DOP adsorption/removal mechanisms.

In this work, batch experiments were conducted using $FeCl_3.6H_2O$ and synthetic wastewater (2 mg-P-OP/L as KH_2PO_4 + 18 mg-DOP/L as myo-inositol-1,2,3,4,5,6-hexakisphosphate) to quantify the effects of alkalinity (Alk=50-100 mg-$CaCO_3$/L), Fe/total phosphorus molar relationship (r=0.6-1.5) and pH (pH=4.0-6.0) on DOP removal efficiency (RE_DOP). With Alk=75 mg-$CaCO_3$/L, r=1.05 and pH=5.31, DOP was not detected. For low r, the RE_DOP was adversely affected by increasing alkalinity and decreasing pH. The results suggested that competition for the active sites depends on the decreasing preference: H^+>HCO_3^- >DOP>$H_2PO_4^-$.

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Comparative consequential LCA: microbial fertilizers grown on potato wastewater, common organic fertilizers, and mineral fertilizers

The production of chemical fertilizers (CFs) is linked to severe environmental impacts. Hence, the EU Farm-to-Fork strategy aims at reducing fertilizer use and increasing organic farming. However, certain organic fertilizers (OFs) have a higher environmental impact than CFs. In this study, the environmental impact of common OFs, CFs and a group of novel microbial fertilizers (MFs) – aerobic heterotrophic bacteria (AHB), a consortium of microalgae and AHB (MaB), and purple non-sulfur bacteria (PNSB) – were compared using life cycle assessment. The impacts of MFs on human health are comparable to those of fishmeal and green manure, but exceed those of CFs and horn meal, while being 42-72 % lower than for soybean meal. Regarding ecosystem quality, the impacts of MFs and CFs are comparatively low – for AHB and PNSB even negative –, while green manure's and soybean meal's impacts are over 90 % higher. AHB and PNSB have the highest impacts on resource depletion, while MaB scores similarly to other CFs and OFs. The choice of fuels for energy production has a big impact on the results. If waste heat is reused instead of consuming fuels (e.g. in industrial symbiosis systems), currently underexploited MFs would become high quality, low impact organic fertilizers.

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Recycled iron phosphates are not effective phosphorus fertilizers in the short term on lowland rice

Iron (Fe) minerals are commonly used to trap phosphorus (P) from waste streams yielding either P-loaded Fe(III) oxides or Fe(II) minerals such as vivianite. The P fertilizer value of these materials were tested based on the assumption that under flooded conditions, only Fe(III)-based products will be effective due to reductive dissolution of Fe(III) minerals. A pot experiment was set-up to test the P fertilizer efficiencies to rice of three Fe(III) and three Fe(II) materials, each in three P-deficient soils (acid, neutral and calcareous) with or without flooding the soil, all in reference to corresponding unfertilized or triple super phosphate (TSP) amended treatments.

The application of recycled FeP products did not significantly increase the P uptake of rice shoots compared to unfertilized treatments and in contrast to TSP application. An exception was Fe(III)P-gravel, a product freshly loaded with P, which yielded significant increase in P uptake at equal total P dose as TSP and more in flooded than in unflooded soils. It is speculated that the short duration of soil flooding (13 days) was not sufficiently long to stimulate Fe reductive conditions whereas prolonged flooding in the field results in redox values enough for Fe(III) reduction. This suggests a potential release of P from these products on the longer term for which long-term experiments may reveal that potential.

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The funding measure RePhoR - Regional Phosphorus Recycling

The Regional Phosphorus Recycling (RePhoR) measure, funded by the German Federal Ministry of Education and Research (BMBF), aims to contribute to the implementation of the new Sewage Sludge Ordinance through innovative economic solutions for regional P recycling. The resulting increased use of secondary phosphorus from the recycling economy should significantly reduce the loss of phosphorus and Germany's dependence on phosphorus imports. To this end, various technologies for P recovery from wastewater, sewage sludge or sewage sludge incineration ash are being implemented on an industrial scale, thus providing scientifically sound knowledge and practical experience under real conditions. Innovative regional utilization concepts for the locally produced sewage sludge and holistic concepts are being developed and implemented that close the gap between P-recovery and P-recycling and thus return the recovered phosphorus to the nutrient cycle via agriculture or as a raw material to industry. They are intended to serve as a model for other regions with similar conditions. The funding measure consists of 7 collaborative projects, which work with different processes and products and investigate the respective economic viability and technical feasibility until 2025. In addition, the results are compiled and synthetized by the scientifically accompanying transfer project TransPhoR.

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Safe Use of Dairy Processing Sludge and STRUBIAS Food System Fertilising Products in Agriculture

The dairy processing industry generates large quantities of different dairy processing sludge (DPS), which is an agricultural fertilizer. Three types of DPS exist: (1) activated sludge aluminium-precipitated (Al-DPS) (2) activated sludge iron-precipitated (Fe-DPS), and (3) lime-stabilised sludge calcium-precipitated (Ca-DPS). Further processing of raw waste into second-generation struvite, biochar and ash fertilizer (collectively known as STRUBIAS) shows promise. This study collected and analysed nutrient and metal content of all major DPS and STRUBIAS products, conducted pot trials to examine fertilizer equivalence value (FEV) of some products, and created an application calculator in MS Excel™ to provide guidance on maximum legal application rates for ryegrass and spring wheat. Sample analysis showed that raw DPS and STRUBIAS have high phosphorus contents. Nitrogen (N) in DPS was high, whereas N concentrations decreased in thermo-chemical STRUBIAS products (chars and ash) due to the high temperatures used in their formation. The heavy metal content of DPS and STRUBIAS was significantly lower than the EU-imposed limits. Using the calculator, application rates of DPS and STRUBIAS products for ryegrass and spring wheat were determined. The estimated heavy metal ingestion to soil annually by the application of the DPS and STRUBIAS products was lower than the EU guideline.

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European sewage sludge ash monitoring

Sewage sludge contains significant amounts of phosphorus and is widely used in agriculture. However, it also represents a pollutant sink, in which many pollutants accumulate whose risk is not yet known. In the European Union, the handling of sewage sludge is controversial. The EU Sewage Sludge Directive (86/278) is currently being revised, and the results of the Commission's evaluation are expected in summer 2022. There are countries that are increasingly relying on agricultural utilization, while other members clearly prefer thermal disposal, particularly in Central Europe. In Switzerland, Germany and Austria, there are already legal efforts to recover phosphorus from sewage sludge. This project aims to obtain a complete record of all European sewage sludge mono-incineration plants and to systematically investigate their sewage sludge ashes. Currently, ashes from Germany, France, Austria, Italy, Poland, Switzerland, the Netherlands, and Denmark are available. In addition to the total phosphorus content, the portion soluble in citric acid and in neutral ammonium citrate is being investigated, as well as various matrix and trace elements. In this way, a European overview of existing sewage sludge ashes shall be compiled as a potential for future phosphorus recovery as well as an estimate of the pollutants contained.

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Nutrient recovery from pig slurry – Production and agronomic quality assessment of added value bio-based fertilsers

Abstract:

FERTIMANURE project aims to develop, integrate, evaluate and validate innovative strategies for nutrient management, for recovering mineral nutrients and other agronomically valuable elements from animal manure. Hence, 5 different biorefinery configurations, around Europe, were proposed to valorise animal manure into reliable and safe bio-based fertilizers (BBFs).

The Spanish biorefinery was implemented in a pig farm in Catalonia where several innovative and conventional technologies were combined to selectively recover nutrients from pig slurry. The nutrients recovered are aimed to be used (i) directly as a bio-based fertiliser or (ii) as a raw material to produce high added value tailor-made fertilisers to cover specific needs of crop-soil pairs. The BBFs obtained in the Spanish on-farm pilot includes: (1) dry organic amendment rich in macronutrients; (2) phosphoric acid from the ashes generated from the energetic dry solid fraction valorisation of slurry; (3) liquid concentrate rich in NPK and organic matter; (4) plant biostimulants rich in free amino acids; (5) ammonium sulphate.

The aim of this study is to evaluate the technological performance and composition of the BBFs obtained in the FERTIMANURE Spanish on-farm pilot. The agronomic trials performed assessed the bioavailability of nitrogen and phosphorus, and soil carbon sequestration potential of the obtained products. The obtained results showed a good overall performance of the FERTIMANURE BBFs equivalent to current fertilising products, showing that these bio-based products could reduce the use of mineral fertilisers in the future.

Keywords: nutrient recovery; bio-based fertilisers; agronomic quality; manure management; pig slurry

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Closing the loop of Phoshorus cycle in the Visegrad Group (V4) countries

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Abstract:

Phosphorus (P) is indicated as a critical resource for Europe, but also as a kay and strategic resource for the countries of the Visegrad Group (V4), which include Poland, the Czech Republic, Slovakia, and Hungary. Due to the V4 region has no primary phosphorus deposits, it needs to cover the demand for the P by import from countries of varying stability, both economic and political as Russia, China, Morocco, Algeria and others. It is risky, if the borders for deliveries of goods are closed (due to epidemiological and political reasons), it may be impossible to meet the needs of P. On the other hand, the individual countries in the V4 region have large secondary P resources in P-rich waste (incl. sewage, sewage sludge, food waste), which are lost because there are no commercialised technologies for phosphorus recovery in this region. To promote closing the loop of P cycle and increase knowledge and awareness of importance of P raw materials for food production in the V4 region, the project "How to stay alive in V4? Phosphorus Friends Club builds V4's resilience" is conducted in 2021-2023 by consortium of partners from the V4 region - Mineral and Energy Economy Research Institute of the Polish Academy of Sciences (Poland, Project Coordinator), Bay Zoltán Nonprofit Ltd. for Applied Research (Hungary), Technical University of Kosice (Slovakia), Brno University of Technology (Czech Republic) and Warsaw University of Life Sciences (Poland). Project includes inventory on P-rich waste in the V4 countries and economic analysis of possibilities of P recovery from waste. It also includes various awareness-raising events, as workshops and summary conference. The expected results of the project will be the Roadmap for P management in the V4 countries to secure enough P for food production.

Keywords: *phosphorus (P), Visegrad Group (V4), roadmap, circular economy*

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Hydrochar – a cheap efficient P-biofertilizer with low climate footprint

Hydrothermal Carbonization (HTC) of sludge and animal slurry produce a hydrochar that is hydrophobic and can act as a low cost dewatered technique. Due to low production temperature phosphorous (P) in the hydrochar can be easily plant available and can be used as a bio-fertilizer. HTC is, therefore, an economical sustainable and environmental friendly recycling of P. The great advantage is that this technology contribute to reduce greenhouse gas emission (GHG) from sludge and slurry. Here we provide a system analysis of emission from hydrochar as related to emission of traditional management of dairy sludge that in EU is a large source of P in wastewater. The system analysis calculates GHG emissions from HTC production, storage and hydrochar application and has shown that the climate footprint of sludge management could be minimised by producing a biochar P-fertilizer. Methane (CH_4) emission from the sludge is eliminated and nitrous oxide (N_2O) emission is reduced. Less carbon is transferred to agricultural fields where sludge is processed into hydrochar, but due to higher recalcitrance of the carbon, the carbon is retained much longer in the soil and the hydrochar P fertilizer represents a more stable carbon contributing much to C-sequestration.

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Recent improvements in Prayon technologies for Phosphorous recovery from secondary P containing materials

Prayon is the market leader in phosphate processes through its Prayon Technologies division and high-quality phosphate production, with four plants in Europe and the United States.

The portfolio of technologies offered by Prayon covers almost all phosphate markets and aims to answer the challenges of the modern phosphate industry such as depletion of high-grade phosphate rock, environmental concerns linked to the production and use of phosphate, as well as the challenging phosphate market.

In this context, phosphate recovery from waste products – secondary sources- is necessary. Therefore, Prayon is very active in these aspects of the industry by developing and proposing several technologies, as well as using secondary phosphates in its facilities.

One of the technologies proposed by Prayon is the production of phosphoric acid from sewage sludge ash. This process initiated, by Ecophos, has been further developed and validated since the acquisition of Ecophos's technology portfolio by Prayon in 2019. The phosphoric acid quality obtained meets Prayon's standards for technical applications such as phosphate salts and soluble fertilizers.

The presentation will focus on this technology through key results obtained during pilot tests performed in 2021 at Prayon's pilot and semi-industrial plant at Technophos in Bulgaria.

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Sustainable agriculture as a vehicle of corporate reputation: sustainability within the value chain of food and agricultural production as a core element of business strategy

Sustainability within the vast sector of food and agricultural production has become an essential element of the sector's value chain. Demands for enhanced environmental protection and management within the sector have grown exponentially with the global challenge of the climate crisis and the international community's increasing awareness of the harmful aspects of quantitative-based production. At the same time the need to balance environmental sustainability with the world's ever-growing food security requirements have posed an often intractable set of challenges.

The United Nations SDGs address food and agricultural production as a prime objective. Sustainable agriculture is more than merely one target of the SDGs: it permeates the entire sustainability agenda. SDG#2 calls for united action to "End hunger, achieve food security and improved nutrition and promote sustainable agriculture". But this objective pervades much more: sustainable agriculture enables SDG#3: "Ensure healthy lives and well-being"; it allows the achievement of SDG#6: "Ensure availability and sustainable management of water.."; it will help ensure SDG#15 "Protect, restore sustainable use of terrestrial ecosystems…"; it relates to SDGs#1 "End poverty" and #8 "Promote…sustainable economic growth…and decent work…"

The international corporate community has had to respond massively to the challenge of sustainability within food and agricultural production. The fertilizer industry, including phosphates, is no exception. New platforms have been established and myriad new partnerships created. Sustainability is now incorporated within all the major companies' agenda and public policy pronouncements. However the degree of genuine integration varies from mere Public Relations activities, where lip-service is paid to the principles for the sake of consumers and regulators, to a more transformational integration into the core business strategy. The poster will examine the dilemma within the broader context of corporate ESG management.

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Mapping the availability of nutrient-rich side-streams – mission impossible?

The need to close material and nutrient cycles with subsequently reduced environmental impacts is the main driver for developing nutrient recycling. To achieve this, knowledge on the availability and spatial distribution of nutrient-rich side-streams (NRSS) is essential.

The generation of the most relevant and abundant NRSS in the EU were based on the Eurostat database on national or NUTS2 levels. Nitrogen and phosphorus contents were based on averages from literature due to no data on national variation. The NRSS included were livestock manure, municipal biowaste and sewage sludge, and industrial side-streams (animal by-products, grape and olive pomace). Agricultural plant biomasses potentially available or currently used for nutrient recycling (e.g. straw, maize, grass) were left out due to no Eurostat data.

In total, the NRSS were estimated to contain 1 890 kilotonnes of P and 11 025 kilotonnes of N. Their spatial distribution highlights hotspots in which recycling measures are especially needed. Still, the availability and quality of NRSS data in the Eurostat database is not sufficient for proper mapping. The data is either lacking, outdated or not in sufficient detail. Data collection should thus be developed on the EU level to truly serve as a tool in promoting circular economy.

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Supplementary information:

Eurostat database https://ec.europa.eu/eurostat/web/main/data/database

LEX4BIO-project website https://www.lex4bio.eu/

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Investing in Phosphorus Fertilizer Recovery from Dairy Processing Wastewater

While fertilizers are an essential contributor for food security, a large proportion of the introduced phosphorus dissipates into water bodies leading to problematic environmental outcomes. Moreover, mineral phosphorus supply is finite and scarcity and regional concentration are a cause for supply risk in the entire value chain. A major source of phosphorus loss is production waste from food production like dairy processing. The recovery of losses addresses concerns of pollution and food security at the same time.

This work combines a quantitative literature review and expert interviews to investigate the financial characteristics of dairy processing wastewater (DPWW) fertilizer recovery with the aim of identifying adoption barriers. An explanation for the low adoption of fertilizer recovery could be the uncertainty involved in the investment, as returns depend on different stochastic factors (e. g. DPWW quantities vary with milk production; fertilizer prices depend on food prices). We analyse and quantify the uncertainty relating to the investment of DPWW phosphorus recovery. The results benefit dairy processors and policy makers with the aim of improving the sustainability of the phosphorus cycle.

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Thermochemical equilibrium calculations of char formation during co-pyrolysis of municipal sewage sludge with straw

Phosphorpus (P) is among the necessary macronutrients for plant growth and plant health. In recent years, there has been growing attention toward the recycling of P from secondary resources since its mined ores are under depletion and it is non-renewable. Municipal sewage sludge (MSS), as a phosphorus-rich waste from wastewater treatments plants, has a considerable potential to become a main renewable phosphorus resource. However, the application of MSS is limited duo to heavy, pathogens, and toxic compounds. Pyrolysis of MSS with biomass is a promising solution to obtain char from MSS and destroys the organic pollutants and partly volatilizes the heavy metals. In the present study, thermodynamics equilibrium calculations (TEC) were applied to investigate the characteristics of chars during co-pyrolysis of different mixture of MSS and straw at different temperatures. Results showed that adding straw as a Potassium-rich agricultural residue enhance the quality of chars in a way where it is more available for plants in comparison with chars after pyrolysis reactions of pure MSS.

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Biological and chemical drivers over P availability from different P forms: an incubation experiment.

The potential shortage of mineral phosphorus (P) sources and the shift towards a circular economy motivates the introduction of bio-based P fertilizers in agriculture. These new forms of fertilizers contain significant proportions of poorly-soluble P forms. In this experiment, we incubated soils in the presence of a range of poorly-soluble P forms commonly found in bio-based P fertilisers (hydroxyapatite (P-Ca), iron phosphate (P-Fe), phytic acid (P-Org), a combination of P-Ca and P-Org (P-Mix) and triple superphosphate (TSP) in two successive 63 days incubations; one with cellulose (C) and KNO_3 (N) amendments to stimulate microbial P solubilization, and the other without additional amendments. We monitored changes in available P over time weekly during the first month, then bi-monthly. Concurrently, soil microbial biomass, enzymatic activities, microbial diversity, N and C mineralization and soil pH were measured. For the TSP treatment, P availability decreased over time for both incubations. For the other P forms, P availability decreased in the absence of C and N amendments, indicating adsorption on soil particles, but increased over time after C and N were added, indicating P solubilization. These different patterns can be explained by soil chemical factors, such as pH and redox conditions, rather than microbial processes.

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P-TRAP - Diffuse phosphorus input to surface waters

In 2019 the EU Marie Sklodowska-Curie Training Network *P-TRAP* has been launched. *P-TRAP* establishes a framework of partners from multiple science and engineering disciplines. The project is targeting the diffuse flux of phosphate (P) into surface waters, i.e. the problems of understanding and controlling environmental P fluxes. *P-TRAP* aims to develop new methods and approaches to trap P in drained agricultural areas and in the sediments of eutrophic lakes. Trapping of P involves the application of iron(Fe)-containing by-products from drinking water treatment. *P-TRAP* aspires the ideas of a circular economy and aims at recovering the retained P in agricultural systems. Novel microbial technologies will be developed to convert P-loaded Fe-minerals into marketable fertilizers whose suitability will be evaluated. The *P-TRAP* technologies have in common that they rely on the naturally strong connection between P and Fe and the innovative *P-TRAP* strategies will be underpinned by process-orientated investigations on the behaviour of P during the transformation of Fe minerals. The latter are key in trapping and recycling of P in agricultural systems and lakes. The poster will present the structure and the planned research of the project, including an overview of achievements of the first years.

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The content of available phosphorus in soils of the Czech Republic

Summary
Phosphorus is an important element whose agronomic and physiological function in the soil is irreplaceable. At present, according to the date from Central Institute for Supervising and Testing in Agriculture, there are differences in the supply of phosphorus in the various regions of the Czech Republic. The acceptability of phosphorus is greatly influenced by soil chemistry, especially by the change of soil reaction, which is also a limiting factor of its usability. The extraction procedure Mehlich 3 is the official analytical method currently used for the determination of the content of available phosphorus. Based on the results obtained by Mehlich 3, current maps of the influence of the exchange soil reaction on the phosphorus content in arable lands in 2015-2020 were compiled. Due to the different content of fine particles in sandy and clayey soils, a different sorption capacity of the phosphorus is observed. Furthermore, the content of available phosphorus depends on the soil type. The uptake and utilization of phosphorus is also affected by current climatic conditions, for example in the drier and colder periods the uptake of phosphorus is limited.

The use of organic and mineral fertilizers, crop rotation, the use of post-harvest residues and careful soil management is the only possible remedy for the unsatisfactory condition of the soil in some areas of the Czech Republic.

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Phosphorus and relationships with other nutrient in various soil tillage in the Czech Republic

The structure and properties of the soil are affected by soil tillage. The content of nutrients from applied fertilizers increases in soils with minimum tillage or no-tillage in the upper soil horizon, lower nutrient contents are therefore determined in deeper parts of the soil profile. There is necessary to study the nutrient concentrations in the soil profile under conventional and conservation tillage practices, including the surface layer, and to decide about the appropriate doses of fertilizers and their incorporation with respect to specific soil conditions, used technology and grown crop. Two analytical methods (Mehlich 3 and KVK-UF) were chosen for determination of nutrients content in soils.

The highest phosphorus contents were found in the top layer in the case of minimum tillage and especially under no-tillage in comparison with deeper soil layers. The content of phosphorus determined by both methods decreased with increasing depth of the soil profile. In fact, the soil pH is higher than 7 and Ca content also indicates carbonate soils in which the direct P availability for crops can decrease. The calcium content determined by the KVK-UF method was compared to the Ca content determined by the Mehlich 3 and increased in the deeper layers of the soil.

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Phosphorus and food security in India: opportunities and barriers to recycling phosphorus from human sewage

The aim of this project is to ascertain the potential of human sewage as a nutrient source for fertiliser in India and to determine the social, economic and agronomic opportunities and barriers to its use. Our focus is on phosphorus (P), due to the challenges arising from its increasing scarcity as a non-renewable resource, and the damaging impact that excess P has on marine and freshwater environments. A circular economy model redirecting P from human sewage into agricultural soils could address both these issues.

India has considerable potential for P recycling due to its important agricultural sector, low existing use of sewage in agriculture and large areas of highly populated cultivated land.

The first stage of this research asks: how much P could be recovered from human sewage and how does this compare with crop requirements in India? To answer this, substance flow analysis (SFA) of P is being undertaken for India at the national scale, and in two small case study areas (one rural and one peri-urban). Future work will involve qualitative research into stakeholder attitudes regarding the use of human sewage as a fertiliser, and social, economic and cultural barriers to the adoption of this approach.

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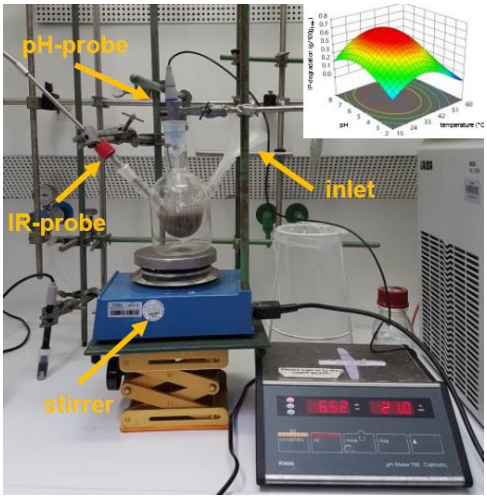
FT-IR Based Inline Analysis of Phytic Acid During Enzymatic P-Adjustment in Monogastric Animal Feeding

Phytic acid ($InsP_6$) is the main source and storage form of phosphorus (P) in seeds and grain. However, monogastric species can almost not digest $InsP_6$ present in plant-based feeds due to limited activity of endogenous intestinal $InsP_6$-hydrolyzing enzymes. To increase $InsP_6$ digestibility, phytases are often supplemented to animal feed rations. Nevertheless, about 50% of $InsP_6$ is continuously excreted and, therefore, used inefficiently by the animals.

Conditioning of feed material prior feeding fosters P reduced feed meanwhile P bound to $InsP_6$ recovered can be used as food, feed or fertilizer ingredient. Thus, enabling a step towards an autarkic P-cycle. For process control FT-IR (Fourier-Transform-Infrared-Spectroscopy) analysis is used in the liquid phase, as it allows fast response to changing process conditions.



Experimental setup for P-adjustment in rye bran and the development of FT-IR based inline analysis.

A chemometric model for the indirect determination of $InsP_6$ in the biological material during the conditioning was developed. However, the aqueous system poses a challenge for FT-IR analytics and the absorption bands of $InsP_6$ and the hydrolytic product (H_3PO_4) are identical.

The chemometric data were compared to offline analytical ones (HPLC) and showed a RMSE (Root-Mean-Square-Error) of 2.2 $mg_{InsP6} \cdot 100\ g_{bran}^{-1}$. Thus, the real-time analysis developed shows high accuracy. In the next step, the inline analysis will be used for process control for an enzymatic feed material conditioning process that is currently on research scale.

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Selective Phosphate Removal and Recovery from Water Using Sorption

One of the solutions for the dual problems, P-based eutrophication and mineral P scarcity, is to remove P from water and wastewater using sorption and recover it for beneficial reuse. Given the low phosphate concentration and abundance of other competing anions in water and wastewater, sorbents with high phosphate selectivity are desired. However, a systematic understanding of selective phosphate sorption is lacking. Our work summarizes the most fundamental aspects of selective phosphate removal processes (Figure 1). Based on the differences in acid–base properties, geometric shapes, and metal complexing abilities, selective sorption of phosphate over other competing anions can be achieved through hydrogen bonding, shape complementarity, and inner-sphere complexation. Among these mechanisms, inner-sphere complexation between phosphate and metal-based materials is the most studied and effective one. Correspondingly, we developed iron-, zirconium-, lanthanum-, and cerium-based materials and investigated their performance for selective removal of phosphate through batch/pilot-scale experiments, advanced materials characterization and theoretical calculations. These findings are not only helpful to people working on adsorptive phosphate removal from water and wastewater, but also shed light on other research fields such as phosphate detection in aqueous solutions, phosphate recognition in analytical chemistry, and the removal of other ionic pollutants from water.

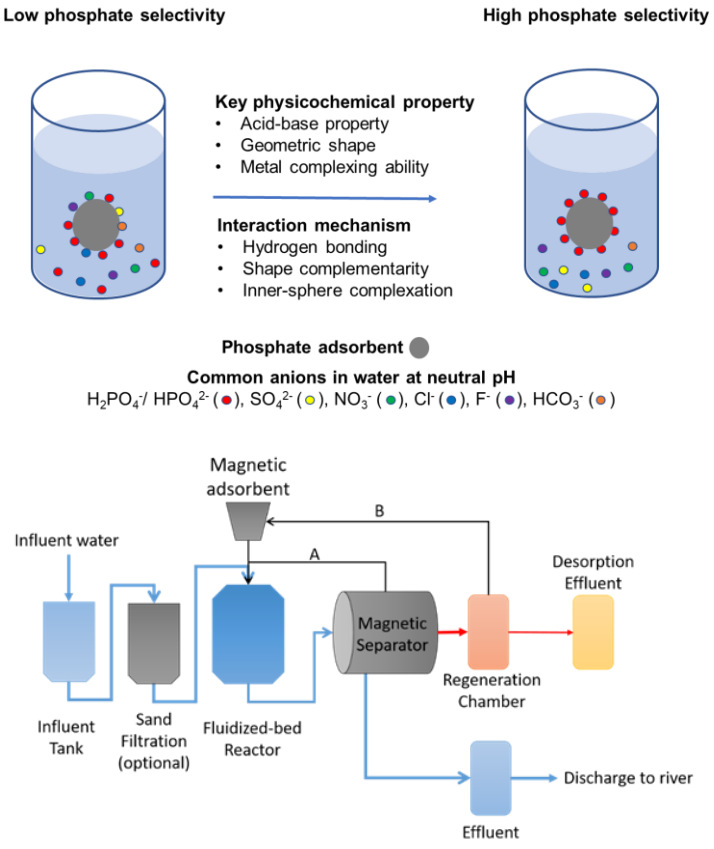

Figure 1 (up) Mechanisms to achieve selective phosphate sorption from water and wastewater; (down) Schematic diagram of pilot-scale magnetic system for phosphate removal from river water

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Phosphorus losses from different soil types caused by bio-based fertilisers

The new Fertilising Product Regulation (FPR), EU 2019/1009, enhances the utilization of nutrient-rich side-streams in agriculture as CE-labelled fertilisers across the EU. To increase the acceptance of these bio-based fertilisers (BBF) among farmers and citizens, agronomic efficiency and safety should be examined both from human and environmental point of view. Because agronomic efficiency and environmental losses of P are dependent on climatic conditions and soil properties, it is critical to select the site-specific BBFs for optimizing their efficient and safe use in the EU.

Phosphorus losses from three different types of soils, originating from Finland (pH 5.7), Germany (pH 7.4) and Spain (pH 8.1), were evaluated by conducting a rainfall simulation (5 mm h^{-1}) after an incubation period with different types of BBFs, belonging to different product function categories (PFC) and component material categories (CMC) according to FPR. The resulting percolated water was analysed for total and soluble P and dissolved organic carbon. As a reference P source, common mineral P fertilizer, triple superphosphate was used.

Properties of both soils and BBFs were evaluated for determining environmentally safe BBFs for minimising P losses after being applied to different soil types.

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Phosphorus recovery from hydrothermally treated sewage sludge. Closing the P cycle.

TreaTech is bringing to market the catalytic hydrothermal gasification (cHTG), an innovative technology for the treatment of liquid waste with focus on sewage sludge (SS). The technology, developed in collaboration with the Ecole Polytechnique Fédérale de Lausanne and the Paul Scherrer Institute, harnesses the properties of supercritical water (>22.1 MPa, 400°C) to transform SS into renewable gas, clean water and minerals that can be upgraded to fertilizers.

Phosphorus, a finite resource that is essential for agriculture and food production, mostly comes from primary sources and is lost after entering the economy. Conveniently, the extracted solids from cHTG contain >90% of the phosphorus initially present in SS. Lab-scale results show that >95% of phosphorus in the cHTG solids can be transformed into phosphoric acid and/or high purity struvite. Our project with the University of Applied Sciences and Arts Northwestern Switzerland, focuses on the technical-economic optimization and scale-up of the phosphorus-valorization process implementing innovative purification methods.

cHTG combined with phosphorus-valorization closes the phosphorus cycle. Besides, compared to conventional SS incineration followed by phosphorus recovery from the ashes, our process has higher energy efficiency. Via cHTG, 10,000 tons of phosphorus could be recovered per year by treating 200,000 tons SS (dry basis).

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Additional information:

Company's website

Press publications

Turning wastewater sludge into energy and minerals EPFL media, Switzerland

Quand les boues d'épuration livrent des trésors RTS, Switzerland

Getting maximum energy out of biomass, PSI, Switzerland

Interview with Frédéric Juillard (TreaTech Sàrl), SCCER Biosweet, Switzerland

Etude de cas présentée dans le magazine ARPEA, Switzerland

Transformation of Soluble Phosphate within Manure to a Less Soluble Calcium Phosphate Solid

Manure has a long history as an effective fertilizer, as it is rich in nutrients. However, due to the nutrient imbalance between the plants' needs and intensive agricultural activities, excess soluble P from manure can flow into natural waters and cause eutrophication. This project aims to solve this problem by decreasing the soluble phosphate in manure, therefore, reducing the P run-off risk. The cementitious phase in recycled concrete contains hydraulic lime, which is a source of calcium and alkalinity. Soluble P in a manure-water-waste cement mixture likely forms amorphous calcium phosphate (ACP) under alkaline conditions. ACP has lower phosphate solubility compared to manure and can be considered as a slow-release phosphate fertilizer. Crushed cement powder (-600 um) separated from recycled concrete was mixed in different ratios with diluted manure solutions. Preliminary results showed a significant reduction of soluble phosphate concentration with treatment. The greenhouse pot test with manure treated with recycled cement showed reduction in both phosphate fertilizer efficiency (plant P uptake ratio) and phosphate solubility. Furthermore, recycled cement addition did not visibly affect the plant or soil negatively. Waste cement treatment of manure has a high potential to reduce the P run-off risk while providing sufficient crop nutrients.

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