

Sustainable Phosphorus Recycling from Secondary Resources in Europe: Challenges and Opportunities

Aleksandra Bibow^{1*}, Monika Karsznia¹, Piotr Skowron¹, Damian Wach¹, Agata Witorożec-Piechnik¹, Cheryl Marie Cordeiro², Erik Sindhøj²

¹IUNG Institute of Soil Science and Plant Cultivation – State Research Institute, Czartoryskich 8, 24-100 Puławy, Poland, abibow@iung.pulawy

²RISE Research Institutes of Sweden, Box 14092, 40020 Göteborg, Sweden, cheryl.marie.cordeiro@ri.se

Short Abstract

Despite growing interest in nutrient recycling in agriculture and increasing EU policy support in this area, the sector continues to face numerous technological, legal, economic and social challenges that hinder the mass market implementation of alternative fertiliser products (AF). The FERTITEC project, EU Horizon grant CSA 101181513, has identified and analysed the main gaps, challenges and barriers limiting the development of AF technology and market, including issues related to phosphorus recycling.

This study used secondary data analysis based on desk research to assess the current state of development of nutrient recovery and recycling technologies from secondary raw materials, identify key barriers, and indicate possible directions for further development. The analysis draws on an extensive review of scientific literature using public databases and on results generated to date by the project consortium.

Phosphorus (P) is an essential and non-substitutable nutrient for global food production, yet its management faces increasing environmental, economic and geopolitical pressures. Secondary resources such as manure, wastewater, sewage sludge, food waste and industrial by-products offer significant potential for phosphorus recycling, particularly as access to high-quality phosphate rock becomes increasingly constrained. However, the efficiency of P recovery from these heterogeneous waste streams remains limited. Many raw materials contain poorly soluble P forms, and advanced recovery technologies such as acidification, thermal hydrolysis, struvite precipitation, or vivianite formation are often energy-intensive, costly and not widely implemented beyond pilot scale. Additional barriers include variable product quality, contamination risks, lack of standardised methods for P speciation, and logistical challenges associated with transporting bulky or dilute recycled fertilisers.

Economic and regulatory constraints further hinder adoption, as recycled P products frequently struggle to compete with conventional mineral fertilisers. At the same time, recent disruptions to global fertiliser supply chains have highlighted the vulnerability associated with dependence on primary P imports.

Strengthening phosphorus circularity through improved recycling, better stakeholder cooperation, and supportive policy measures is therefore essential for building resilient, sustainable nutrient systems. Advancing transdisciplinary research and integrating diverse stakeholder perspectives will be key to accelerating the transition toward a closed-loop phosphorus economy.

Topic: 1) Technologies **Keywords:** nutrient recycling; phosphorus recycling; recovery technologies; alternative fertilisers; circular economy

Integrated Stripping–Scrubbing Pretreatment and Duckweed Cultivation for Increased Nutrient Recovery from the Liquid Fraction of Pig Manure

L. Audenaert^{1,3*}, M. Fernandes De Souza¹, N. De Zutter², D. P. L. Rousseau³, E. Meers¹

¹ Laboratory for Bioresource Recovery, Ghent University, Coupure Links 653, Ghent, Belgium

² Laboratory of Applied Mycology and Phenomics, Ghent University, Valentin Vaerwyckweg, 1, Ghent, Belgium

³ Laboratory for Industrial Water and Ecotechnology, Ghent University, Graaf Karel de Goedelaan 46, Kortrijk, Belgium

[*Lukas.Audenaert@Ugent.be](mailto:Lukas.Audenaert@Ugent.be)

Short Abstract

The treatment of pig manure, and other agricultural waste, for nutrient recycling has gained increasing attention within circular agriculture. Conventional manure treatment systems, such as nitrification/denitrification and membrane separation entail significant drawbacks and limitations. Biological nitrogen removal processes can lead to increased emissions of nitrous oxide (N₂O) which has detrimental effects on climate change, while membrane separation systems are prone to clogging. Therefore, duckweed offers a promising alternative enabling both nutrient removal and recovery while simultaneously generating biomass that can be further valorised. Moreover, the water effluent can be reused for non-potable applications. Duckweed is a fast-growing macrophyte that thrives on highly polluted wastewater; additionally, it accumulates high amounts of nutrients and can be applied as a supplement for (pig)feed. In this study, a stripping/scrubbing process was investigated as a pretreatment to mitigate the N₂O emissions during the biological nitrogen removal process. Two *Lemna minor* clones were investigated for their nutrient recovery capacity when cultivated on different dilutions of stripped liquid fraction of pig manure. Alongside, the nutrient recovery capacity of both clones was assessed and plant health and growth was monitored using multispectral imaging, a non-destructive technique that allows real-time visualization of various physiological plant traits, based on specific absorption, reflection, and emission patterns. The lowest dilution (1:6) of stripped liquid pig manure caused total chlorosis and duckweed death but the duckweed could manage the higher investigated dilution (1:9) with a corresponding photosynthetic activity of 0,7 and enhanced nutrient removal. In a parallel treatment, the clones were grown on 100% biological effluent with good health and growth, which served as conventional control. The results of this research contribute to the development of sustainable manure management strategies and support the transition to a circular bioeconomy.

Topic: 1) Technologies.

Keywords: Duckweed; Stripping/Scrubbing; Nutrient Recovery; Pig manure

Acknowledgements: This work is funded by the NutriBudget project within the framework of the European Union HORIZON-CL6-2021-ZEROPOLLUTION-01 No.101060455.

Valorization strategies for manure-based digestate

Shruti Katti, Çağrı Akyol, Erik Meers

Laboratory for Bioresource Recovery (Re-Source), Department of Green Chemistry and Technology,
Ghent University, Coupure Links 653, 9000 Ghent, Belgium

cagri.akyol@ugent.be; shruti.katti@ugent.be; erik.meers@ugent.be

Short Abstract

In regions with intensive livestock production, anaerobic digestion (AD) of manure generates large volumes of digestate whose management increasingly represents an economic and regulatory challenge. High transport costs, nutrient surpluses, and legislative constraints on land application often result in a net negative value per unit of recovered nutrients.

The study reviews current challenges associated with digestate management and examines a broad spectrum of valorisation strategies. These include direct agronomic use, nutrient recovery processes for nitrogen and phosphorus (e.g. ammonia stripping and struvite precipitation), soil improvers, hydroponic media, and growing substrates for microalgae. In addition, thermochemical and biochemical routes such as pyrolysis, gasification, hydrothermal carbonisation, bioethanol and volatile fatty acid production, as well as the generation of bio-stimulants, enzymes, and bio-based materials, are evaluated for their technical potential and regulatory relevance. A comprehensive analysis was further conducted on these manure-based digestate valorization strategies to assess their strengths, weaknesses, opportunities, and threats (SWOT).

The integration of AD into flexible biorefinery schemes emerges as a key approach to overcome current limitations. Fractionation of digestate into solid and liquid streams enables optimised nutrient recovery, energy production, and the generation of value-added products, while reducing environmental impacts such as nutrient losses and greenhouse gas emissions. Overall, the results highlight the need for continued technological development, standardisation, and policy support to enable scalable and economically viable digestate valorisation pathways. Although the technical feasibility of digestate valorisation has been demonstrated, its commercial viability hinges on improving feedstock consistency, advancing robust and scalable processing technologies, and strengthening product quality assurance. Nutrient recovery pathways, which are less sensitive to feedstock variability, offer a promising avenue for producing standardized, high-value digestate-derived products.

Topics: Technologies and Agronomy

Keywords: biochemical; digestate; growing medium; soil improver; thermochemical

From Greenhouse Waste to Resource: Nutrients Recovery from Mixed Tomato Plant Residues

A.Castagna^{1,2*}, S. Katti², Ç. Akyol², E. Meers²

¹ Thermochemical Conversion of Biomass Research Group, Department of Green Chemistry and Technology, Ghent University, Coupure Links 653, 9000 Ghent, Belgium

² Laboratory for Bioresource Recovery (Re-Source), Department of Green Chemistry and Technology, Ghent University, Coupure Links 653, 9000 Ghent, Belgium

[*Alessandra.Castagna@Ugent.be](mailto:Alessandra.Castagna@Ugent.be)

Short Abstract

Greenhouse cultivation in Flanders generates approximately 27-30 kton per year of crop residues mixed with plastic support materials. This mixed waste stream results from standard greenhouse production practices, where plant biomass is removed after harvesting together with polypropylene (PP) clips and ropes used to support plant growth. Due to the high level of plastic contamination, these residues are currently managed mainly through incineration or landfilling, leading to greenhouse gas emissions and loss of potentially valuable resources. Among these residues, tomato plant waste represents one of the largest fractions and is particularly rich in nutrients that are currently lost during disposal. This study investigates a potential valorisation pathway for mixed tomato plant waste (MTPW) through the extraction of nutrients and valuable compounds from the biomass. Tomato plant residues containing approximately 35 wt% polypropylene components were collected from local greenhouses after harvesting. The samples were subsequently dried and milled to a particle size of 2 mm. Acetic acid was selected as the extraction solvent due to its effectiveness in recovering mineral constituents from organic matrices. Additionally, previous studies have shown that acetic acid can efficiently extract alkaloids such as tomatine, which is a valuable bioactive compound with numerous pharmacological applications. The extraction is carried out using maceration for 2 hours, with liquid-to-solid (L:S) ratios of 7.5, 10, 12.5, 15 and 20, and solvent concentrations of 0.1, 0.25, 0.5 and 1 M. Nutrient concentrations in the supernatant are measured using inductively coupled plasma optical emission spectroscopy (ICP-OES), while the amount of tomatine is either quantified by ultra-performance liquid chromatography (UPLC) or estimated based on existing models. The expected recoveries range between 80 –100% for phosphorus (P), and 60 – 70 % for tomatine.

Topic: Technologies

Keywords:

Mixed agricultural waste; Solid liquid extraction; Nutrient recovery; Phosphorus; Tomatine

Acknowledgements: We gratefully acknowledge the financial support of the Flemish Government and Flanders Innovation & Entrepreneurship (VLAIO) through the Moonshot project SUSPLASM (HBC.2024.0632).

On-site P recovery from waste water – the iPHOS process

Joachim Clemens*, **Christine Oeppert***, **Gereon Ploenes***, **Yihao Li***

*SF-SoepenberG GmbH, D-53229 Bonn, Germany, j.clemens@soepenberG.com

*c.oeppert@soepenberG.com

*g.ploenes@soepenberG.com

*y.li@soepenberG.com

Short Abstract

The iPHOS process remobilizes reductively phosphorous from activated excess sludge (AES). Later on it is precipitated in the form of struvite. The technology was developed for treatment plants that use iron for phosphorous-elimination. We constructed a mobile plant that started its operation on the first wastewater treatment plant in summer 2025. We present our laboratory results and first experiences of the operation of the mobile plant.

So far we have tested P-remobilisation from AES from 24 different plants. P is remobilized to a small portion only (<30 %), when aluminium is used for P-elimination. For Al/Fe-mixed products the P-remobilisation was satisfying. Best P-remobilisation was found when P was eliminated by iron or in wastewater treatment plants that used biological P removal and iron. P recycling of more than 60% from wastewater is possible.

During the first weeks of operation, we were able to confirm the laboratory results. It is possible to remobilize P and remove it from the sludge. With the amount of P removed, the sewage sludge will have a P content of less than 2%. Currently we optimize the process to reduce chemical use. In addition, we adapt the mobile plant for P-remobilisation that was eliminated in form of aluminium-phosphates. The precipitated struvite is very fine and can be used for fertilizer production.

Topic: Technologies

Keywords: Phosphorous recycling; wastewater; struvite

Hydrometallurgical recovery of potassium and phosphorus nutrients from ashes derived from bioindustries

Ehsan Moslehi*^{a, b}, Elin Larsson^a, Gulaim A. Seisenbaeva^b, Cristian Tunsu^a

^a *EasyMining Services Sweden AB Ultunaallén 2A, 756 51 Uppsala, Sweden*

^b *Department of Molecular Sciences, Swedish University of Agricultural Sciences, Box 7015, 75007 Uppsala Sweden*

Short Abstract

The increasing demand for potassium and phosphorus fertilizers has raised concerns about the sustainability of securing these materials through traditional mining practices. Mining accelerates resource depletion, habitat destruction, and environmental degradation. Finding alternative nutrient sources can offset these. Recovery of potassium and phosphorus fertilizers from wastes and secondary sources offers a more sustainable approach, supporting circular economy. Promising sources of nutrients are bioindustry ashes, which are byproducts of biomass combustion in energy and industrial processes. The results presented here show that these ashes contain significant amounts of nutrients (e.g., over 20 wt.% potassium) which can be effectively recovered for use in agriculture. We have evaluated seventeen different samples to identify the most promising ones based on their chemical properties (composition, leaching behaviour, speciation etc.). Among the materials tested are bottom, boiler and fly ashes after poultry litter incineration, streams from the Kraft process, and fish litter and ensilage. Hydrometallurgical processing of nutrient-rich ashes offers considerable advantages over direct land application, particularly by enabling the removal of heavy metals and recovering concentrated compounds with specific uses, such as fertilizers tailored for particular crops or soil types. Transforming them into pure commercial products is essential for complying with regulations, reducing landfill waste, and fostering circularity by providing a sustainable secondary nutrient source.

Topic: Technologies

Keywords: Nutrient recovery; Potassium; Ash; Poultry litter; Fertilizer

Mapping technologies for circular fertilizer production: insights from 30 nutrient recovery cases in the EU and AU

Elina Tampio*¹, **Johanna Laakso**¹, **Mina Kiani**¹, **Cheryl Marie Cordeiro**², **Erik Sindhøj**²

¹Natural Resources Institute Finland (Luke), Latokartanonkaari 9, FI-00790 Helsinki, Finland;
firstname.lastname@luke.fi

²RISE Research Institutes of Sweden, Box 14092, SE-40020 Göteborg, Sweden,
firstname.lastname@rise.se

Short Abstract

The move from mineral and fossil-dependent systems toward a circular economy calls for redesigned approaches. Developing alternative fertilizer products is a critical part of this shift, as it enables more sustainable farming practices and helps bring nitrogen and phosphorus cycles back within ecological limits. Yet, much of the existing knowledge on nutrient recovery technologies is scattered across different projects and platforms, which has slowed progress toward circular solutions.

The EU-funded FERTITEC project responds to this gap by compiling current nutrient recovery technologies, identifying operational cases, and examining their performance and ability to scale. In total, the project gathered information on 188 technologies and practices related to circular fertilizer production from national and EU-level initiatives. From this larger set, 30 cases from regions across the EU and the African Union were chosen according to criteria such as geographical balance, representativeness of secondary raw materials and relevant technologies, scale of operation, availability of environmental and technical data. The selection process was supported by an expert panel.

For each of the 30 cases, an extensive literature review was carried out. The review examined aspects such as the types and availability of raw materials, the potential for nutrient recovery and transport, emissions of greenhouse gases and ammonia during production and use, risks of eutrophication and acidification through nutrient losses, and potential impacts on soil health and biodiversity.

The chosen cases reflect a wide array of nutrient recovery routes that utilize secondary materials from agricultural, municipal, and industrial sources. One third of the cases involve agricultural feedstocks like manure or plant residues, another third focus on municipal wastewater treatment, and the remainder cover urban and industrial waste streams. The technological approaches in these cases are equally diverse, ranging from anaerobic digestion and digestate processing to nutrient precipitation techniques, and further to thermal treatments. Other methods include insect bioconversion, composting, fermentation, and various physical processing steps.

These cases form a comprehensive foundation for the next stage of the project, which will deepen the assessment of technological, environmental, and societal performance and support the development decision-making of future circular fertilizer solutions.

Topic: 1) Technologies

Keywords: nutrient recycling; recovery technologies; fertilizing products; circular economy

Enhancing Wheat Yield via Sustainable Phosphorus Management Using Calcium Silicate Hydrate-Based Fertilizer

Svedaite Evelina^{1*}, Baltakys Kestutis¹, Dambrauskas Tadas¹, Povilaitis Virmantas²

¹Department of Silicate Technology, Faculty of Chemical Technology, Kaunas University of Technology, Radvilenu 19, LT-50254 Kaunas, Lithuania

²Department of Plant Nutrition and Agroecology, Institute of Agriculture, Lithuanian Research Centre for Agriculture and Forestry, Institute al.1, Akademija, Kedainiai distr. Lithuania

* evelina.svedaite@ktu.lt

Phosphorus (P) is a major limiting nutrient in agriculture and is increasingly recognized as a new global sustainability challenge due to finite P resources [1]. Phosphorus recovery from contaminated water for reuse as fertilizer offers a way to address two of the most significant issues nowadays: phosphorus pollution, which causes eutrophication, and phosphorus shortages [2]. To evaluate the practical application of this approach, this study examines the agronomic performance of CSH-derived phosphorus fertilizers in spring wheat.

The calcium silicate hydrate-based fertilizer was made from calcined opoka using hydrothermal synthesis at 200 °C for 16 hours. The synthetic adsorbent was then used to remove phosphorus from wastewater with varying initial phosphorus levels, achieving 99% removal efficiency. The P-enriched product, obtained after adsorption, containing 37% P₂O₅ and 11% K₂O, was used as a fertilizer. Field trials showed that CSH-based fertilizers either maintained or increased grain yield compared to traditional fertilization. At the full nutrient rate, the N+K+Ca/Si 1.5 sample produced 4.65 t/ha higher than conventional N+P+K fertilization (4.35 t/ha). When the fertilizer rate was reduced by 20% in line with the European Green Deal, the N+K+Ca/Si 0.45 sample achieved the highest yield at 4.86 t/ha.

Grain quality was assessed using Infratec analysis, which measured protein, gluten, sedimentation, and thousand-grain weight. The N+K+Ca/Si 0.45 sample produced the highest grain quality, with protein at 14.7%, gluten at 29.2%, sedimentation at 55 mL, thousand-grain weight at 44.2 g, and test weight at 78.5 kg/hL, outperforming the conventional N+P+K fertilization (protein at 13.8%, gluten at 27.5%, sedimentation at 50 mL, thousand-grain weight at 42.1 g, and test weight at 77.3 kg/hL). Using the reduced fertilized rate, the N+K+Ca/Si 1.5 sample maintained grain quality comparable to complete fertilization (protein at 14.2%, gluten at 28.5%, sedimentation at 53 mL, thousand-grain weight at 43.5 g, and test weight at 77.8 kg/hL). These results suggest that CSH-derived phosphorus fertilizers can sustain or enhance grain quality while reducing dependence on traditional fertilizers.

Keywords: Calcium silicate hydrate; Phosphorus; Fertilizer; Spring wheat

Topic: Agronomy

[1] T. Sharmin Hoque et al., Phosphorus in Soils and Plants, Vol. 7, (2024), p. 100225.

[2] A. Jama-Rodzeńska, et al., J Environ Manage, Vol. 287, (2021), p. 112235.

[3] S. O. Akinnawo et al.. Environmental Challenges, Vol.12 (2023), p. 100733.

Comparative analysis of the environmental, climate and overarching economic impact of bio-based fertiliser production, using a custom-made methodology

H. L. Foged^{1*}, I. Sylwan², P. de Morais Lima², O. Valetska³

¹Organe Institute (ORGANE), Skødstrup, Denmark. henning@organe.dk

²Environmental Engineering Group, Research Institutes of Sweden (RISE), Uppsala, Sweden.

³Soil and Environment Department, The Swedish University of Agricultural Sciences (SLU), Uppsala, Sweden.

Short Abstract

Objectives: Bio-based fertilisers (BBFs) are increasingly recognised as a key pathway for advancing nutrient recycling, reducing reliance on mineral fertilisers, and supporting resilient food production. As part of the CiNURGi project, the aim of this study was to assess how current BBF value chains perform in practice by identifying best-practice and innovative solutions and evaluating their environmental, climate, and economic outcomes within a market and policy context.

Methodology: A market screening of BBF production identified 24 value chains spanning waste collection, processing and delivery of BBF to the field. Of these, 11 value chains met the scope criteria and had sufficient data availability for impact assessments. A custom-made method for the envisaged impact assessment was developed, using Single Operation Unit Process scope, inspired by Fazio et al. (2020), to isolate BBFs production from broader facility operations and ensure that only processes with a primary nutrient recycling function were evaluated.

Key findings: The Nutrient Recycling Impact (NRI) averaged 47% with values ranging from -9% to 100%. The Direct Emission Impact (DEI) averaged 0.5 t CO₂-eq per functional unit (fu) defined as 1,000 kg N + P in influent organic wastes, with variations ranging from -13.2 to +28.4 t CO₂-eq. The Guiding Social Cost (GSC) averaged € -1,257 per fu, with variations from € -3,048 to € 280. From a business perspective, BBF production was generally uncompetitive with mineral fertilisers: the average production cost was € 2.62 per kg N + P (range € 0.68 to € 4.94), compared with a long-term market price of € 1.08 per kg N + P for mineral fertiliser.

Conclusions: A substantial cost gap exists between BBFs and mineral fertilisers. This gap could be reduced through improved policy frameworks and mechanisms that channel the value of ecosystems services provided by BBF production back to the responsible businesses. Furthermore, farmers' willingness to pay the same for nutrients in BBF as mineral fertiliser may increase with continued improvements in BBF quality, enhancing their perceived agronomic value and valuation.

Topic: Policy / Path to market.

Keywords: bio-based fertiliser, nutrient recycling, Baltic Sea eutrophication, circular economy, nutrient management

From organic waste to biostimulants: pilot-scale solid-state fermentation using *Trichoderma harzianum*

J. Font-Pomarol^{1,2,*}, E. Molina-Peñate², A. Artola², Ó. Prado¹, A. Sánchez²

¹Aeris Tecnologías Ambientales S.L, Carrer Santa Rosa, 38, local, 08290 Cerdanyola del Vallès, Barcelona, Spain

²GICOM Research Group, Universitat Autònoma de Barcelona, Edifici Q, 08193 Bellaterra, Barcelona, Spain

* jana.font@uab.cat

Short Abstract

The increasing generation of organic wastes highlights the need for sustainable valorisation strategies aligned with circular nutrient management. This study investigates solid-state fermentation (SSF) as a valorisation route for the production of biostimulant products from the organic fraction of municipal solid waste (OFMSW), using *Trichoderma harzianum* as the functional microorganism. Particular emphasis is placed on process scale-up and on the implementation of a sequential batch fermentation strategy to reduce inoculum requirements at pilot scale.

SSF experiments were carried out in 22 L packed-bed bioreactors containing 4.5 kg of substrate, composed of OFMSW mixed with wood chips (30% wet weight) as a bulking agent to ensure adequate porosity and avoid compaction. The substrate mixture was sterilised prior to inoculation. The bioreactors were inoculated with an initial concentration of 10^5 spores g^{-1} dry matter and operated under aerobic conditions for six days, using a controlled humidified airflow. Biological activity during fermentation was monitored through oxygen consumption measurements, expressed as the specific oxygen uptake rate (sOUR). All the SSF processes were conducted for 6 days. Following the first batch, a sequential batch approach was applied, using fermented solids as an alternative inoculum source for subsequent batches through aqueous spore extraction.

Preliminary observations confirm the technical feasibility of SSF at pilot scale and the maintenance of microbial activity throughout the fermentation period. Ongoing experiments are assessing the performance and stability of sequential batches, as well as their potential to significantly reduce the need for fresh inoculum without compromising process efficiency.

Overall, this work demonstrates the potential of SSF as a scalable and resource-efficient approach for transforming OFMSW into value-added bio-based products, contributing to sustainable nutrient recycling and the development of circular bioeconomy solutions for agriculture.

Topic: 1) Technologies; 3) Sustainability

Keywords: Solid-state fermentation; organic waste valorisation; biostimulants; *Trichoderma harzianum*; circular bioeconomy.

Valorization of Biogas Byproducts for Microalgae Protein Production

Georgina del Puerto^{1,2*}, Marcella Fernandes de Souza², Josué González Camejo¹, Sergio Ponsá¹, Erik Meers²

¹BETA Technological Center. Universitat de Vic-Universitat Central de Catalunya Ctra. de Roda, 70. 08500 Vic-Barcelona, Spain.

²Laboratory for Bioresource Recovery (RESOURCE), Department of Green Chemistry and Technology, Ghent University, Coupure Links 653, 9000 Ghent, Belgium

*Corresponding author email address: georgina.delpuertotana@ugent.be

Short Abstract

In conventional biogas plants, carbon dioxide (CO₂) is largely emitted into the atmosphere, while the resulting digestate faces disposal constraints due to high nutrient loads. Consequently, the recovery and reutilization of these byproducts are essential to achieve the sustainability of biomethane production. Within the SEMPRES-BIO project (www.sempre-bio.com), these byproducts are revalorized to cultivate microalgal biomass; CO₂ serves as an inorganic carbon source for autotrophic growth, while digestate provides essential nitrogen (N), phosphorus (P), and micronutrients. Microalgae-digestate systems have high potential to convert N from digestate into high-value algae protein for animal feed; however, some technical and regulatory constraints must be addressed.

In this study, a comprehensive screening of three microalgae species (*Chlorella vulgaris*, *Parachlorella kessleri*, and *Tetrademus obliquus*) was conducted using permeates obtained from digestates of different origins (cow manure, pig manure, and cheese whey). Ten-day batch experiments were performed to evaluate growth rates, biomass productivity, and nutrient uptake. Biomass quality was assessed via Total Kjeldahl Nitrogen for protein content and HPLC for amino acid profiling.

Results indicated that digestate utilization does not compromise nutritional quality. Regarding pretreatment, while filtration reduced turbidity and enhanced light penetration for autotrophic growth, centrifugation combined with coagulation maintained higher COD levels, which likely stimulated mixotrophic growth. Notably, *Parachlorella kessleri* cultivated in pig-manure digestate was identified as the most suitable combination for pilot-scale upscaling, achieving 41 % w/w of protein content. Regarding the protein profile, Glutamine and Arginine were the most abundant amino acids (21 and 16 g/100 g protein, respectively); essential amino acids represented 30 ± 1 %, with Lysine, Leucine, and Methionine (5, 6, and 2 g/100 g protein, respectively) being of nutritional interest. The biomass surpassed soybeans' nutritional value, highlighting its potential as a feed ingredient. Practically, ammonium was not fully consumed; therefore, during upscaling, this must be monitored to avoid ammonia toxicity. Finally, although lab-scale tests provided a necessary explorative screening, further research into long-term and fed-batch operations and outdoor conditions is essential for successful scale-up.

Keywords: *Parachlorella kessleri*; digestate; alternative protein; amino acid

Rebalancing nitrogen and phosphorus flows in agri-food systems: a regional substance flow analysis on Murcia (Spain)

Karen Paulina Felix Valencia*, Hongzhen Luo*, Evi Michels*, Erik Meers*

Laboratory for Bioresource Recovery (RE-Source Lab), Department of Green Chemistry and Technology, Ghent University, Coupure Links 653, 9000 Ghent, Belgium.

Corresponding author: karenpaulina.felixvalencia@ugent.be

Short Abstract

The agri-food system is a major driver of Nitrogen (N) and Phosphorus (P) emissions to soil, water and air, while simultaneously relying on increasingly expensive and energy-intensive fertiliser inputs. Inefficient management of N and P therefore represents both an environmental pressure and a loss of valuable resources, particularly in regions with intensive agricultural production. Addressing this challenge requires a system-level understanding and quantification of N and P flows, to identify losses, surpluses, and structural imbalances, thereby informing strategies for nutrient flow rebalancing across multiple sectors.

This study conducted a regional nutrient budget for the region of Murcia (Spain), using a substance flow analysis (SFA) framework. Located in the East coast of Spain, Murcia is a paradigmatic case of a European region affected by N/P pollution, being the main EU exporter of fruits and vegetables, with 40% of Spanish aquaculture revenues. Therefore, the focus of this study was on mapping and quantifying the N and P flows across two main sectors, S1: Agriculture (Crop production and livestock husbandry), S2: Aquaculture and marine fishing) while counting the impact of other sectors including S3: Waste and wastewater management, S4: Energy and transport, and S5: Food and feed industrial Sectors. A bottom-up approach is used to include data from regional statistics archives, sectoral reports, stakeholder surveys and scientific publications. A Python based tool was developed to manage data input, carry out the data reconciliation and consistency checks, and visualise the results. This SFA framework enables the construction of a mass balanced representation of the regionals N and P metabolism, supporting the identification of dominant inputs, hotspots, losses across industries, and opportunities for recycling. Data processing and analysis is on-going, and results are expected to be available for presentation at the conference.

Topic: Sustainability.

Keywords: Substance Flow analysis; Nutrient circularity; Agri-food systems; Sustainability; Circular Economy.

Acknowledgement:

This work has been done as a part of the NPower project funded by the European Union's Horizon Framework Programme for Innovation Actions under Grant Agreement no. 101181873.

Sustainability assessment of fertilising products from circular sanitation approaches

Karetta Vikki¹, Anu Reinikainen¹, Abdulhamid Aliahmad², Ágnes Óvári³, Erika Cristina Francisco², Elina Tampo^{1*}

¹Natural Resources Institute Finland (Luke), Latokartanonkaari 9, FI-00790 Helsinki, Finland; firstname.lastname@luke.fi

²Swedish University of Agricultural Sciences (SLU), Lennart Hjelms Väg 9, SE-756 51, Uppsala, Sweden; abdulhamid.aliahmad@slu.se; erika.francisco@slu.se

³ELTE CERS Institute for Regional Studies, (ELTE CERS IRS), Tóth Kálmán u. 4., 1097 Budapest, Hungary; agnes.ovari@krtk.hu

Short Abstract

New sustainable solutions are needed to utilise human waste resources and return their nutrients to food production. Transitioning from conventional centralised wastewater treatment towards more efficient, decentralised nutrient recovery systems can provide more concentrated, high-quality fertilising products. The P2GreeN project supports this shift by transforming linear nutrient flows into circular systems. The project develops and demonstrates technologies for collecting and processing human excreta into safe, high-quality recycled fertilisers for agricultural use.

In P2GreeN, four technologies and circular value chains are demonstrated, including two urine treatment technologies, hygienisation and container-based composting of dry toilet contents, and nutrient and water recovery from municipal wastewater. To evaluate the impacts of these new products, we apply environmental life cycle assessment (e-LCA), social life cycle assessment (s-LCA), and farm level cost-benefit analysis (CBA) across the value chains in three pilot regions: (i) Gotland, Sweden; (ii) North German Plain, Germany; and (iii) La Axarquía, Spain.

The e-LCA assesses the following impact categories: climate impact (including carbon sequestration), eutrophication, acidification, resource use, and ecotoxicity. The s-LCA quantifies risks for social impacts following the environmental LCA framework. The CBA evaluates the costs and benefits to farmers of adopting the new fertilisers, incorporating monetised environmental impacts. All results are compared with a reference scenario based on mineral fertilisers or conventional soil amendment, while LCA assessments also include avoided burdens from wastewater treatment.

Preliminary analyses show that the urine-based fertilisers and compost products assessed generally outperform their conventional counterparts in overall environmental performance. However, their social performance remains to be more precisely investigated. Moreover, the new products do not necessarily increase farmers' costs and may also create additional benefits. Therefore, fertilising products derived from circular sanitation systems offer a promising alternative to mineral fertilisers, improving the recirculation of nutrient from human waste resources.

Topic: 3) Sustainability

Keywords: life cycle assessment; cost benefit analysis; nutrient recovery; human sanitary waste; recycled fertilisers

Field-scale evaluation of recycled nitrogen fertilizers on grassland productivity and soil–root interactions

Mayka Schmitt Rahner¹, Katrin Kuka^{1*}

¹Institute for Crop and Soil Science, Julius Kühn-Institut (JKI), Braunschweig, Germany

*Corresponding author: katrin.kuka@julius-kuehn.de

Short Abstract

The use of recycled nutrient fertilizers (RNFs) derived from organic waste is becoming an increasingly popular topic of discussion as a means of closing nutrient cycles and reducing reliance on mineral fertilizers. However, the amount of field-based evidence concerning their agronomic performance and the effects on soil–root interactions remain limited. This study presents results from a grassland field trial, which evaluated different nitrogen fertilizer strategies with a focus on RNFs.

The field experiment was conducted in 2025, with *Lolium perenne*, and involved a comparison of an unfertilized control (N0), mineral calcium ammonium nitrate (CAN), and two organic RNFs: sheep wool pellets (SW) and hair meal pellets (HM). The trial assessed above-ground biomass production before and after harvest as well as soil and root structural characteristics. In addition to classical field measurements, intact soil–root samples were collected prior to fertilization and analyzed using X-ray micro-computed tomography (μ CT). This non-destructive approach enabled a three-dimensional visualization of pore networks and root architecture within undisturbed soil cores.

Preliminary results indicate noticeable differences between mineral and recycled fertilizers in terms of biomass response and root distribution patterns. Organic RNFs exhibited a more gradual nitrogen supply, which was reflected in root proliferation and interactions with soil pore structures. The μ CT analyses provided complementary insights into soil physical properties relevant for nutrient uptake.

Overall, this study demonstrates that RNFs can contribute to the effective management of grasslands, while offering additional benefits for soil–root system functioning. The integration of μ CT imaging into agronomic field studies represents a promising tool for improving the mechanistic understanding of nutrient use efficiency in sustainable fertilization strategies.

Topic: Agronomy; Sustainability

Keywords: recycled nutrient fertilizers; grassland; nitrogen management; soil–root interactions; X-ray micro-CT

Nutrient recovery from local and regional circular sanitation systems: best practices, pathways to implementation and policy recommendations

Erica Locatelli* ICLEI Europe (Freiburg, Germany) erica.locatelli@iclei.org,
Marianne Wagner* ICLEI Europe (Freiburg, Germany) marianne.wagner@iclei.org

Short Abstract

The poster follows three objectives:

1. Offer an overview of best practices for nutrient recovery in sanitation, including upstream solutions for source-separation of human excreta, and downstream solutions for nutrient recovery from wastewater.
2. Highlight the role of local and regional authorities in the transition towards circular sanitation through nutrient recovery and recycling.
3. Provide recommendations to EU decision makers on how to promote and accelerate circular sanitation solutions for nutrient recovery across EU cities and regions.

The poster applies the following research methodology:

- Literature review on circular sanitation opportunities, benefits and challenges.
- Extensive review of 50+ best practice case studies across Europe.
- Qualitative interviews with 3 pilot projects, 3 follower regions, and 5 EU case studies.

The key findings of the poster are five pathways for the implementation of nutrient recovery from local and regional circular sanitation systems. Each of these levers is illustrated by best practices from Europe.

- **Strategise:** Include targets for nutrient recovery in sectoral and cross-cutting strategies and action plans (e.g. water, agri-food, energy, resilience, climate, urban development).
- **Educate:** Include circular sanitation and nutrient recycling in education and awareness raising programmes, knowledge sharing platforms, public spaces and events, and community campaigns.
- **Mobilise:** Engage stakeholders across the nutrient value chain, including public administration across sectors and levels, farmers, businesses, research and academia, and local NGOs.
- **Implement:** adopt circular sanitation and nutrient recovery solutions in temporary and off-grid infrastructure, public buildings, wastewater management infrastructure and urban planning.
- **Support:** provide financial and non-financial support such as public procurement of recycled nutrients, funding of research and innovation, subsidies and grants for the agriculture and construction sectors, taxes and tariffing schemes for the reduction of water pollution, lending material and land for local project implementation.

The conclusions of the poster will include policy recommendations at EU level based on identified challenges and best practices, focusing on policies such as the Water Resilience Strategy and ResourceEU. Resources for decision makers and practitioners, such as Eawag's [Circular Sanitation Toolbox](#), will also be included.

Topic: Path to market and policy on recycled nutrients

Keywords: Circular sanitation; nutrient recovery; recycled fertilisers; policy; implementation

Infographics:

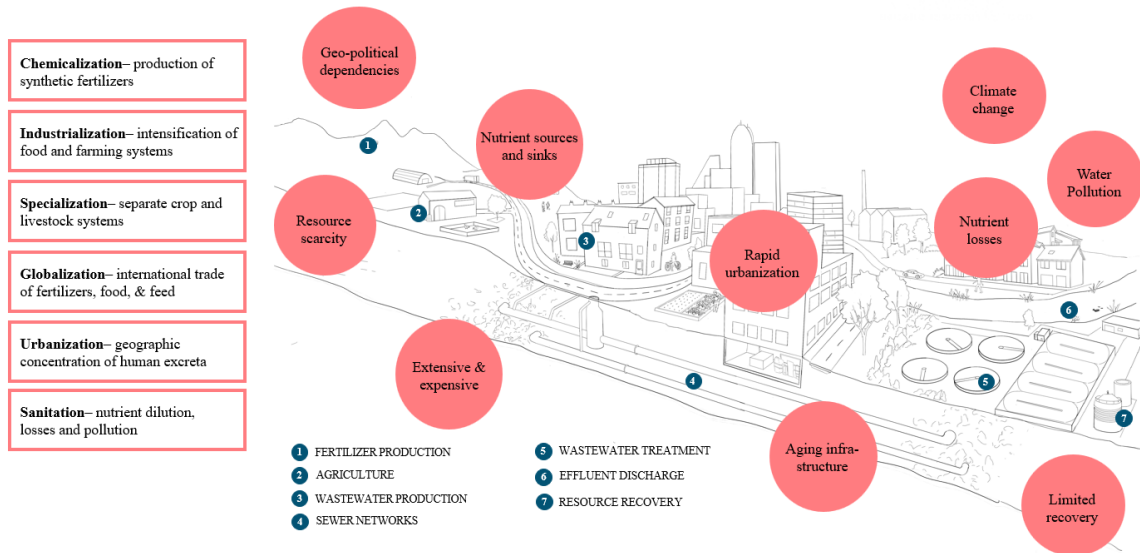


Figure 1: Linear sanitation and its challenges. Source: Wielemaker (2025)

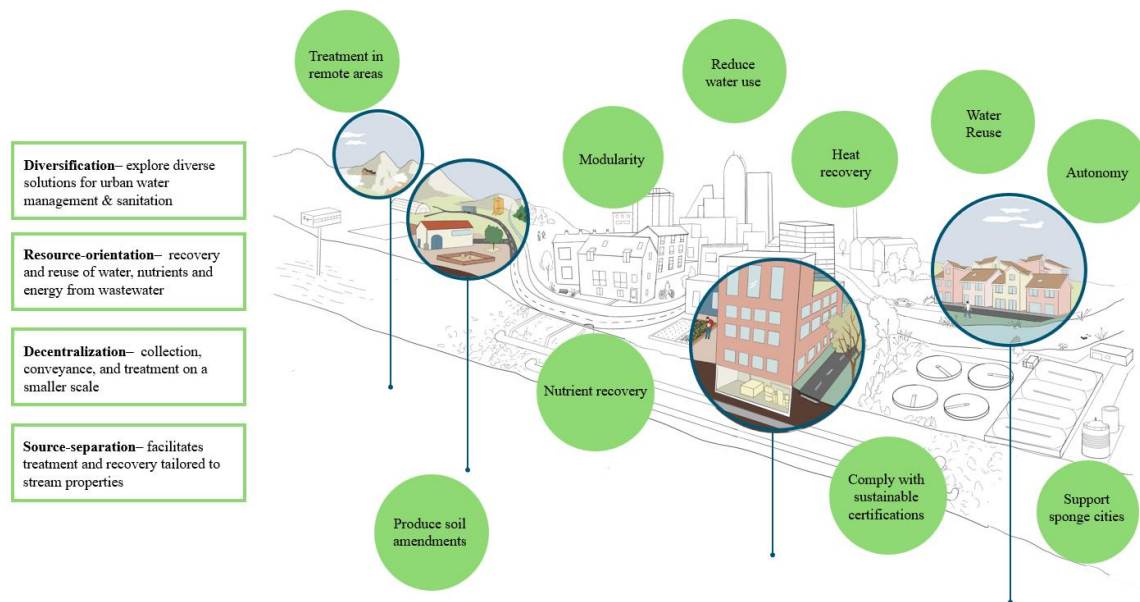


Figure 2: Circular sanitation and its benefits. Source: Wielemaker (2025)

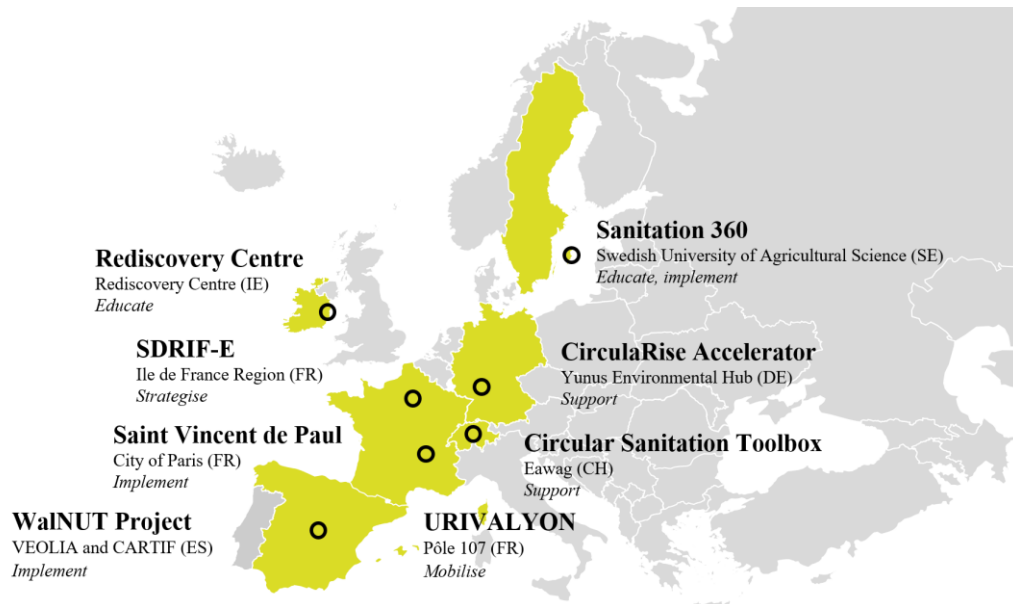


Figure 3: Selection of best practices for the five implementation pathways

High-frequency monitoring of nitrate dynamics in a treatment wetland treating eutrophic surface water

Lukas Willems^{1,*}, Ivona Sigurnjak¹, Evi Michels¹, Diederik Rousseau¹, Erik Meers¹

¹ Department of Green Chemistry and Technology, Faculty of Bioscience Engineering, Ghent University, Ghent, Belgium

* lukas.willems@ugent.be

Short Abstract

Elevated nutrient concentrations in surface water induce negative effects on the behavior of ecosystems and complicate the purification of drinking water. Nature-based treatment solutions such as constructed wetlands (CWs) have been proven to efficiently remove these substances and create the possibility for beneficial water applications (irrigation, infiltration, recreational purposes), resulting in a robust water system in times of scarcity. In the Luikbeek stream (Staden, Belgium), nitrate concentrations often greatly exceed the environmental standards defined by the EU, especially during winter months. Located in an agriculturally intensive area, runoff from applied fertilizers induces pressure on surface water. To tackle this, a free water surface (FWS) CW was implemented on a 0.5 ha plot of land. The area is divided into a large “natural” open system CW, and a smaller rectangular enclosed system (i.e. no infiltration from/to groundwater) of 200 m². The small ‘control’ wetland will be used to construct mass balances and removal efficiencies, which will be used to characterize the complete system. With the use of 4 nitrate sensors and 4 multiparameter sensors (pH, EC, DO, ...), high-frequency data will be collected starting from the coming spring.

The project aims to evaluate the efficacy of CWs in removing nitrate from diffuse polluted surface water, the observations will contribute to the replicability of similar case studies in Flanders.

Acknowledgements: This research is carried out in collaboration with the province of West Flanders and the Flanders Environment Agency, and is funded by the Flemish government and the GreenHood project within the framework of the European Union’s Horizon Europe Programme No. 101181712.

Topic: Technologies

Keywords: Constructed wetlands, water treatment, nutrient pollution

From nutrient recycling potential to circularity targets and progress monitoring

Sari Luostarinen*¹, Eetu Virtanen², Elina Tampio¹, Johanna Laakso¹

*Natural Resource Institute Finland, Helsinki, Finland, sari.luostarinen@luke.fi

** Baltic Marine Environment Protection Commission (Helsinki Commission - HELCOM), Helsinki, Finland, eetu.virtanen@helcom.fi

Short Abstract

The Baltic Sea Regional Nutrient Recycling Strategy, drawn in transnational cooperation under Baltic Marine Environment Protection Commission HELCOM, sets a goal for the region to become a model area for nutrient recycling. One of the joint Baltic Sea Action Plan actions is thus to enhance the use of recycled nutrients in agriculture. An evaluation of substituting mineral fertilizers by recycled nutrients is set as a criterion to achieve the action.

To support progress towards this goal, CiNURGi project made a comprehensive overview of the potentially availability and spatial distribution of recyclable nutrients across the Baltic Sea region. Nitrogen and phosphorus were quantified and mapped for livestock manure, municipal biowaste and sewage sludge, and food industry side streams. The data required was collected with two methods: one relying on open data from Eurostat and literature and the other based on nationally available statistics and other data sources. A comparison between nutrient availability and utilized agricultural land area identifies regions with potential nutrient surpluses or deficits. These data, together with the compiled state of the art on nutrient recycling, can help target measures more effectively.

Monitoring the replacement of conventional mineral fertilizers with recycled nutrients remains highly complex. High resolution and spatially detailed data, essential for assessing nutrient use efficiency, are limited both for conventional commercial fertilizers and for biomass-based nutrients and their use in agriculture. Agricultural variability and year-to-year fluctuations further complicate the picture.

The results highlight that the first essential step is consistent data collection to provide up-to-date information on both recycling potential and its current utilization. CiNURGi recommends establishing regular national and Baltic Sea regional monitoring of nutrient recycling, including periodic assessments of both potential and actual practices. This would enable monitoring progress over time and identifying and targeting additional measures.

To make this possible, CiNURGi recommends assigning responsible national organizations with sufficient expertise and resources to lead data collection and coordination. Improving national data systems, while making use of existing nutrient-related reporting such as emissions inventories, is also essential for consistency and comparability.

These steps would support the development of both national and transnational policies with trackable targets for nutrient circularity and mechanisms for monitoring their implementation across the Baltic Sea region, leading to more effective and evidence-based nutrient management.

Topic: 4) Policy / Path to market

Keywords: nutrient recycling policy; monitoring and evaluation; circular bioeconomy

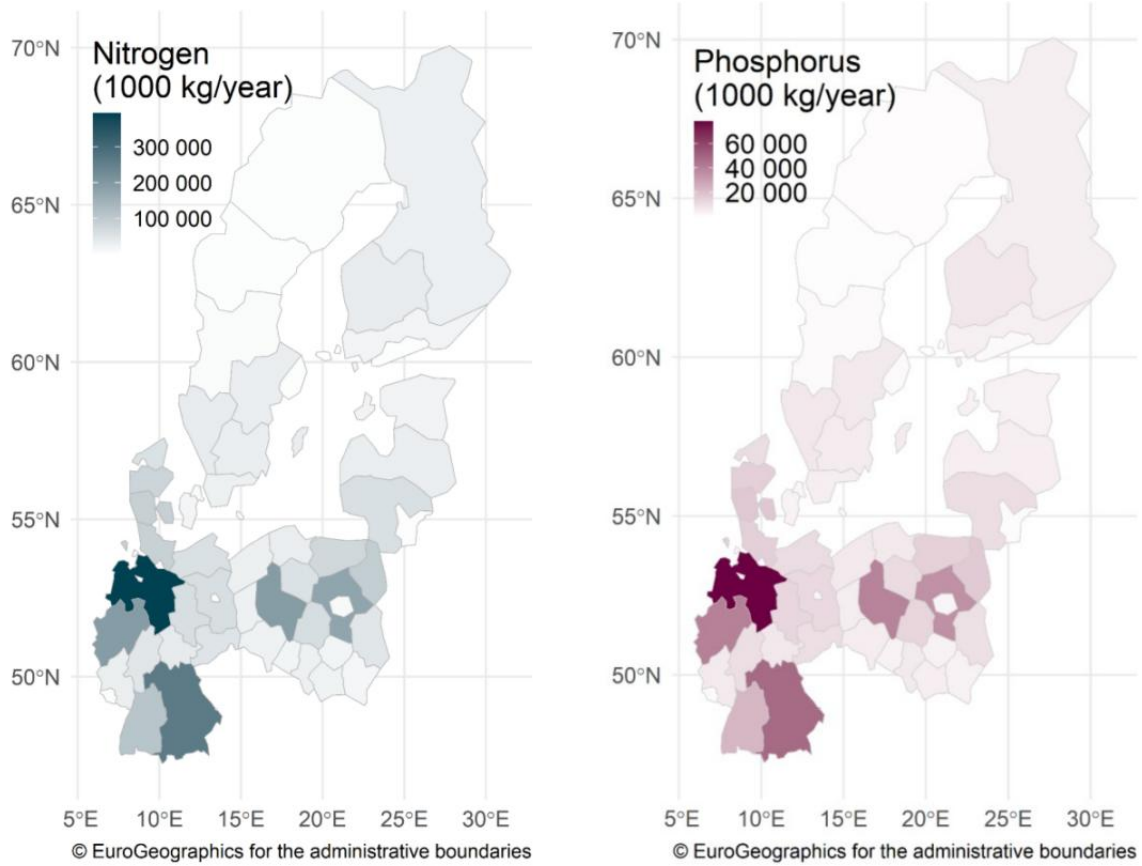


Figure 1. Nitrogen (left) and phosphorus (right) recycling potential in the Baltic Sea region altogether for livestock manure, municipal biowaste and sewage sludge.

A pilot-scale evaluation of duckweed cultivation for pig manure treatment and feed production

Marie Lambert^{1,2,*}, Reindert Devlamynck¹, Marcella Fernandes de Souza², Pieter Vermeir³, Katleen Raes⁴, Mia Eeckhout⁵ and Erik Meers²

¹ Provincial Research and Advice Centre for Agriculture and Horticulture (Inagro vzw), Ieperseweg 87, 8800, Roeselare-Beitem, Belgium; reindert.devlamynck@inagro.be (R.D.)

² Department of Green Chemistry and Technology, Lab for bioresource recovery, Faculty of Bioscience

Engineering, Ghent University, Coupure Links 653, 9000, Ghent, Belgium; marcella.fernandesdesouza@ugent.be (M.F.S.); erik.meers@ugent.be (E.M.)

³ Department of Green Chemistry and Technology, Laboratory for Chemical Analysis (LCA), Faculty of Bioscience Engineering, Ghent University, Valentin Vaerwyckweg 1, 9000 Ghent, Belgium; pieter.vermeir@ugent.be (P.V.)

⁴ Research Unit VEG-i-TEC, Department of Food Technology, Safety and Health, Ghent University, Campus

Kortrijk, St-Martens Latemlaan 2B, B-8500 Kortrijk, Belgium; katleen.raes@ugent.be (K.R.)

⁵ Research Unit of Cereal and Feed Technology, Department of Food Technology, Safety and Health, Faculty of Bioscience Engineering, Ghent University, 9000 Ghent, Belgium; mia.eeckhout@ugent.be (M.E.)

* Correspondence: marie.lambert@inagro.be, mmlamber.lambert@UGent.be

Short Abstract

Livestock-intensive regions in Europe face dual challenges: nutrient surpluses and a high dependency on import of high-protein feedstocks. This study proposes duckweed (Lemnaceae) as a potential solution by recovering nutrients from manure-derived waste streams while producing duckweed. This study evaluated the performance of duckweed treatment systems at a pig manure processing facility in Belgium. Three out-door systems were monitored over a full growing season under temperate climate conditions. Duckweed cultivated on constructed wetland effluent showed die-off and low protein content, while systems supplied with diluted liquid fraction and nitrification-denitrification effluent achieved consistent growth, yielding 8 tonnes dry biomass/ha/year and 2.8 tonnes protein/ha/year. Average removal rates were 1.2 g N/m²/day and 0.13 g P/m²/day. Growth ceased after approximately 100–120 days, likely due to rising pH and electrical conductivity, suggesting ammonia toxicity and salt stress. Harvested duckweed had a high protein content and a total amino acid profile suitable for broilers, though potentially limiting in histidine and methionine for pigs or cattle. Additionally, promising energy and protein values for ruminants were measured. Although high ash and fibre contents may limit use in monogastric animals, duckweed remains suitable as part of a balanced feed. Its broad mineral profile further supports its use as a circular, locally sourced feed supplement.

Topic: Technologies, Agronomy, Sustainability

Keywords: Duckweed; nutrient removal; novel protein; pilot study; *Lemna*

Material Flow Analysis of Nitrogen, Phosphorus, and Potassium in Ireland: Advancing Circular Nutrient Management

Milka Susan Kollannur Biju^{1,2*}, Ivona Sigurnjak², S M Ashekuzzaman¹, Ciaran O'Donnell³, Erik Meers², Niamh Power¹

¹Department of Civil, Structural and Environmental Engineering, Sustainability Infrastructure Research & Innovation Group, Munster Technological University, Bishopstown, Cork, Ireland.

² Laboratory for Bioresource Recovery, Department of Green Chemistry and Technology, Ghent University, Coupure Links 653, 9000 Ghent, Belgium

³Department of Construction, Sustainability Infrastructure Research & Innovation Group, Munster Technological University, Bishopstown, Cork, Ireland.

* Corresponding Author Email Address: MilkaSusan.KollannurBiju@UGent.be

Short Abstract

Efficient nutrient recycling is needed to achieve a circular economy and meet the sustainability goals. Therefore, the concept of recycling-derived fertilisers (RDFs) has emerged, which are fertilisers produced from sources like animal manure, urban green waste, agri-food industry byproducts, and food waste. The utilisation of RDFs in agriculture contributes to increased nutrient recycling rates and reduced reliance on synthetic fertilisers. This study investigates nutrient flows from key organic sources like animal manure, digestate, compost, sewage sludge, and food waste, to enhance nutrient recovery, reduce losses, and support RDFs use in Ireland. By employing a Material Flow Analysis (MFA) framework for Nomenclature of Territorial Units for Statistics (NUTS) 2 regions of Ireland, this research systematically quantifies Nitrogen (N), Phosphorus (P) and Potassium (K) flows (including both recycling-derived fertiliser sources and synthetic mineral fertiliser) across the system to evaluate nutrient transformation, retention, and dissipation within a circular nutrient system.

The MFA comprises several integrated steps. First to identify key nutrient sources to grassland, arable land and horticulture land in the study area, followed by quantification of N, P and K using input and output data pertaining to the concerned lands. A bottom-up approach is used for maximum data granularity on nutrient contents and flows. Second, uncertainty analysis and data reconciliation are performed using STAN software to ensure consistency and reliability of nutrient flow estimates. Third, nutrient hotspots are identified by mapping areas of significant nutrient accumulation or loss. Finally, system indicators, including nutrient use efficiency, nutrient recovery efficiency, retention ratio, and loss intensity, are derived to assess the nutrient flows in a circular economy context.

Preliminary results demonstrate that these pathways hold considerable potential to recover and recycle nutrients from different recycling-derived feedstocks, reducing reliance on non-renewable mineral fertilisers and mitigating nutrient surpluses. This study highlights the value of MFA as a robust decision-support and diagnostic tool for evaluating nutrient flows in systems. By integrating quantitative flow data, uncertainty assessment, and performance indicators, this study will provide actionable insights for optimising RDF production and use. Data processing and analysis is on-going, and results are expected to be available for presentation at the conference.

Topic: Sustainability

Keywords: Material Flow Analysis; Circular Economy; Agriculture, Nutrient Flow; Nutrient Management

Assessment tool for evaluating economic instruments and financial schemes aimed at reducing nutrient pollution

Krisztina Miskó^{1*}, Csaba Bálint², Enikő Zita Vígh¹, Judit Hámori³, Norbert Annus¹

¹ Environmental Research Department, Institute of Agricultural Economics, Budapest, Hungary, misko.krisztina@aki.gov.hu

² Social Research Department, Institute of Agricultural Economics, Budapest, Hungary, balint.csaba@aki.gov.hu

³ Financial Research Department, Institute of Agricultural Economics, Budapest, Hungary, hamori.judit@aki.gov.hu

Short Abstract

Economic instruments, such as taxes, subsidies, tradable permits, and nutrient offset schemes, are important elements of nutrient governance, along with regulatory and information-based measures. Advancing new governance models and evaluating economic and financial instruments in the European agriculture implies the shift from traditional command-and-control approaches toward flexible policy mixes that better reflect regional ecological conditions and sectoral realities.

Based on the results of the NENUPHAR project studies evidence shows that well-designed economic instruments can significantly reduce nutrient surpluses; for example, based on past experiences, in Sweden, Austria, Finland, and Denmark fertilizer taxes led to notable decreases in N and P use. However, fertilizer demand remains price-inelastic, and without compensatory mechanisms, such policies may raise production costs or threaten small farm viability. It is therefore important to emphasize the need for redistributive measures, targeted incentives, and alignment with Common Agricultural Policy rules to ensure fairness and political acceptability.

The main barriers to the uptake of innovative green technologies and circular business models are fragmented legislation, limited financial access for small farms and agri-food Small and Medium-sized Enterprises, the more complex business structures, and higher risk in circular models in terms of financing. Significant financing gaps persist for green and circular investments, despite the EU regulatory frameworks such as the Taxonomy Regulation, and the development of green financial instruments (e.g. green bonds and green loans). The successful adoption of nutrient-recycling technologies depends on early-stage public support, scalable business models, and transparent environmental performance metrics.

To support informed decision-making, building on existing multi-criteria frameworks offered by relevant scholars, a qualitative assessment tool was developed to evaluate the expected impacts of selected economic instruments across different dimensions of sustainability, including nutrient-use efficiency, circularity, biodiversity, and import dependency. The tool stresses the importance of stakeholder involvement and context-specific policy mixes.

Based on this analysis, the study aims to contribute to a sustainable, resilient and economically viable nutrient governance across Europe.

Topic: 3) Sustainability

Keywords: economic instruments; environmental financing; public and private financing; assessment tool; governance

Acknowledgement: This research has received funding from the European Union's Horizon Europe research and innovation programme, under grant agreement No. 101082169, within the project NENUPHAR: "New governance models to enhance nutrient pollution handling and nutrients recycling". Funded by the European Union. Views and opinions expressed are, however, those of the author(s) only and do not necessarily reflect those of the European Union. Neither the European Union nor the granting authority can be held responsible for them.

Synergetic Resource Recovery, CO₂ use, and Demand Side Response via Microwave Plasma Valorisation of Contaminated Biomass

Lukasz Niedzwiecki¹, Rino Morent¹, Anton Nikiforov^{1,2,*}, Çağrı Akyol³, Jakub Pilar^{3,4,5}, Alessandra Castagna^{3,6}, Jafar Fathi^{4,5}, Guido Van Oost⁷, Djamel Eddine Belounis^{1,2,8}, Alan Mašláni⁵, Erik Meers³

¹ Research Unit Plasma Technology (RUPT), Department of Applied Physics, Ghent University, Sint-Pietersnieuwstraat 41, Ghent 9000, Belgium

² Research group PLASMANT, Center of Excellence PLASMA, Department of Chemistry, University of Antwerp, Groenenborgerlaan 171, 2020 Antwerp, Belgium

³ Laboratory for Bioresource Recovery (Re-Source), Department of Green Chemistry and Technology, Ghent University, Coupure Links 653, 9000 Ghent, Belgium

⁴ Department of Inorganic Chemistry, Faculty of Chemical Technology, University of Chemistry and Technology, Technická 5, 166 28, Praha 6, Czech Republic

⁵ Institute of Plasma Physics of the Czech Academy of Sciences, U Slovanky 2525/1a, 182 00, Prague 8, Czech Republic

⁶ Thermochemical Conversion of Biomass Research Group, Department of Green Chemistry and Technology, Ghent University, Coupure Links 653, 9000 Ghent, Belgium

⁷ Department of Applied Physics, Ghent University, Sint-Pietersnieuwstraat 41, Ghent 9000, Belgium

⁸ Electrification Institute, University of Antwerp, Olieweg 97, 2020 Antwerp, Belgium

* Corresponding author: anton.nikiforov@ugent.be, anton.nikiforov@uantwerpen.be

Short Abstract

Biomass represents a well-established renewable energy source with significant potential for both energy and material recovery. However, many agro-industrial and waste biomass streams remain difficult to valorise via conventional waste disposal pathways due to high levels of impurities, heterogeneous composition, or contamination with synthetic polymers. Such challenging feedstocks necessitate the development of more robust and flexible conversion technologies. This work investigates microwave plasma gasification as a versatile platform for the valorisation of low-quality waste biomass streams. The high-temperature plasma environment enables the rapid and efficient conversion of complex organic matter into high-quality syngas, primarily composed of hydrogen and carbon monoxide, which can serve as a chemical synthesis feedstock or clean energy carrier. Beyond gasification, the project explores several complementary resource recovery pathways integrated within the plasma process. This includes the potential use of captured CO₂ as a constituent of the plasma-forming gas mixture, contributing to a net-zero carbon footprint. Furthermore, the concept enables strategic nutrient recovery at multiple stages, assessing the integration of pyrolysis/hydrothermal pretreatment for carbon concentration in the feedstock as well as the sublimation of volatile nutrients within the thermal plasma, followed by controlled condensation. Synergetic extraction of valuable compounds from the raw biomass is also taken into consideration. The key advantage of this microwave plasma system is its exceptional operational flexibility. Rapid start-up and response times of such installations allow providing Demand Side Response services, supporting grid stability by modulating power consumption in response to load fluctuations.

We gratefully acknowledge the financial support of the Flemish Government and Flanders Innovation & Entrepreneurship (VLAIO) through the Moonshot project SUSPLASM (HBC.2024.0632).

Topic: Technologies **Keywords:** plasma, gasification, thermochemical pretreatment

Twenty-Year Nutrient and Cost Effects of Compost Integration in Farm Fertiliser Strategies

Olivier Labrie*¹

¹ European Compost Network e.V., Bochum, Germany, labrie@compostnetwork.info

Short Abstract

Compost application is often overlooked as a means to reduce dependence on mineral fertilisers, as its agronomic value is frequently assessed using short-term or input-based metrics that fail to capture cumulative nutrient and soil effects. This leads to systematic underestimation of compost-derived organically-bound nitrogen contributions and the gradual release of phosphorus (P₂O₅) from soil-bound and organic pools over longer time horizons.

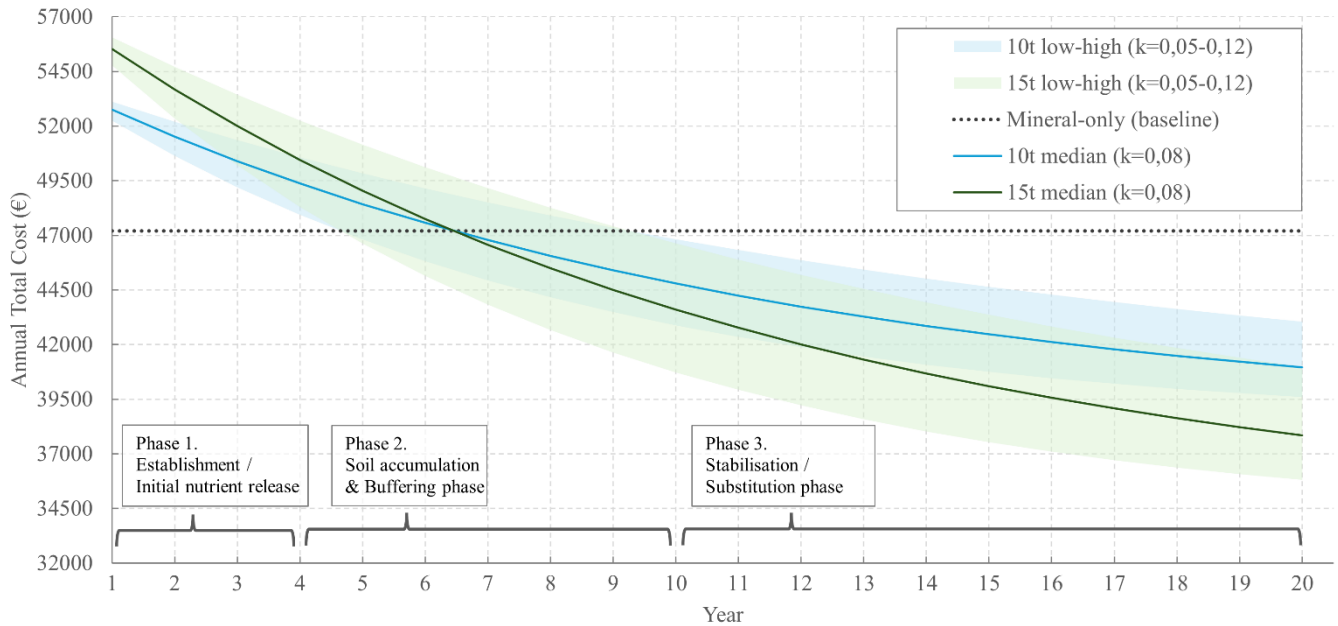
This poster presents a 20-year nutrient and cost projection comparing two compost application rates with a mineral-only fertilisation baseline. The analysis is based on a multi-EU-country dataset on compost nutrient availability and current mineral fertiliser prices, with the aim of highlighting compost's value as a primary soil amendment for long-term soil health and fertility. Scientifically differentiated availability assumptions for nitrogen, phosphorus, and potassium were applied, explicitly accounting for gradual nutrient release, residual carry-over, and soil-mediated effects for nitrogen and phosphorus, rather than first-year availability alone. The framework is embedded within a broader set of fact sheets, which synthesise soil health and fertility improvements from long-term compost trials and a rigorous literature review.

Results show that repeated compost application can significantly reduce mineral fertiliser requirements while maintaining balanced nutrient supply. Nitrogen and phosphorus accumulate in plant-available soil pools and contribute to both immediate and residual supply through mineralisation. When considered cumulatively, compost demonstrates a substantial fertiliser-sparing effect and a progressive reduction in input costs over 20 years due to reduced mineral top-ups.

These findings underline the importance of time-explicit nutrient accounting for recycled nutrient sources in compost. They support compost's role as a foundational component of integrated fertilisation strategies that combine nutrient recycling, soil health and quality improvement, and targeted mineral supplementation.

Topic: 2) Agronomy; 3) Sustainability

Keywords: compost; long-term fertilisation; nutrient recycling; cost reduction



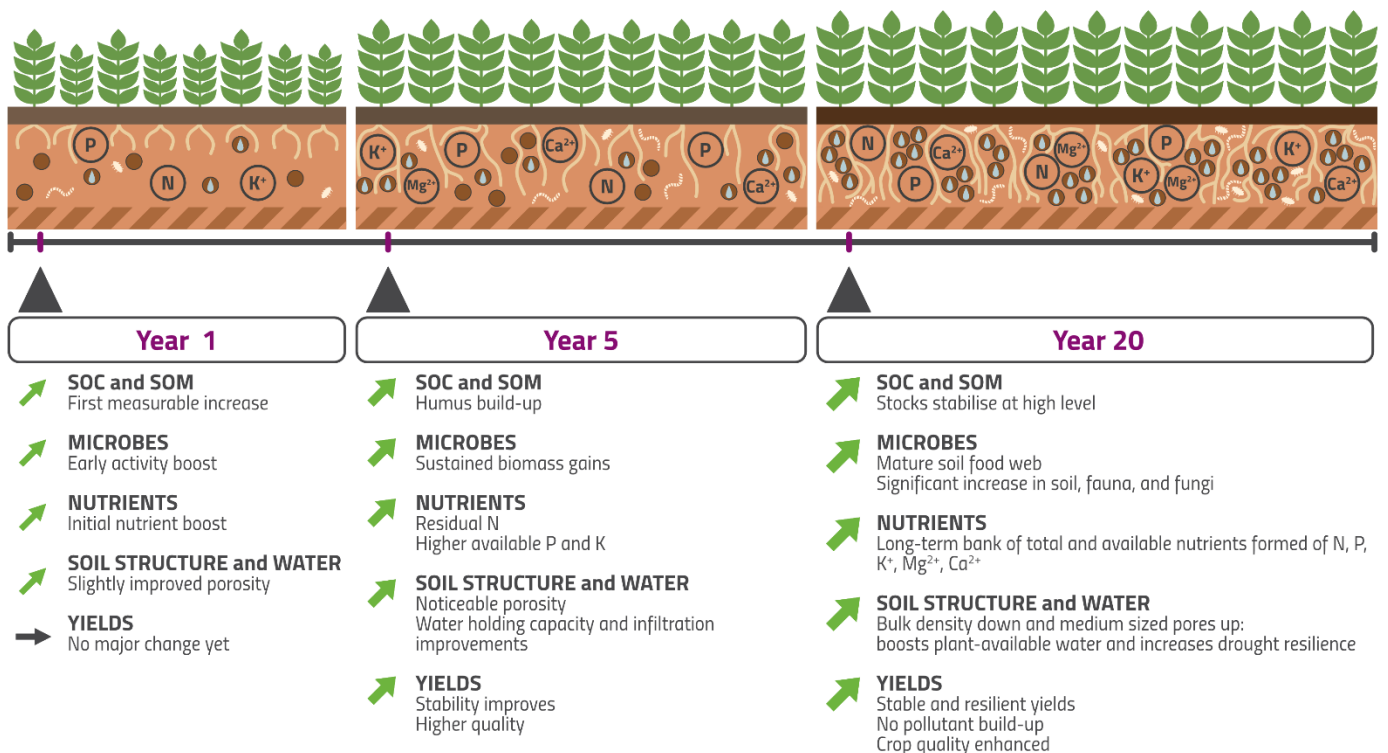
Long-Term Cost Projection of Crop Fertilisation Plans with Compost and Mineral Inputs (N, P₂O₅, K₂O) on a 100 ha Farm

Comparison of two compost application rates with decreasing mineral top-ups and a mineral-only baseline under low, median, and high mineralisation scenarios

Note: Cost projections account for cumulative soil accumulation and annual release of residual nitrogen (N) and phosphorus (P₂O₅) from compost.

IMPROVEMENT IN LONG-TERM SOIL FUNCTION

Annual Compost Application Builds Soil Health and Crop Resilience



Vibrational shear enhanced system to increase the efficiency of the membrane filtrations in nutrient processing

Nora Pap^{*1}, **Johanna Laakso**¹, **Elina Tampio**¹, **Sari Luostarinen**¹, **Niina Honkala**¹, **Henri Malmi**², **Riina Kallio-Kujala**², **Aws Al-Tayawi**³, **Szabolcs Kertész**³

¹Natural Resources Institute Finland (Luke), Latokartanonkaari 9, FI-00790 Helsinki, Finland
surname.lastname@luke.fi

² Jeppo Biogas Ab, Kiitolantie 1, 66850 Jepua, Finland

surname.lastname@jeppobiogas.fi

³University of Szeged, Faculty of Engineering, Moszkvai krt. 9. 6725 Szeged, Hungary

awsaltayawi@uomosul.edu.iq

kertesz@mk.u-szeged.hu

Short Abstract

One aim of CiNURGi project is to showcase the most promising nutrient recycling solutions and to promote practices that can be replicated or scaled up within and beyond the Baltic Sea region. In this context, the project collaborated with the Finnish Jepua Biogas Ltd, preparing to invest in membrane filtration of digested liquid fraction to produce a nutrient concentrate.

Jepua Biogas Ltd biogas plant digests primarily pig slurry and other livestock manure, along with slaughterhouse waste, fur animal feed mill washing waters, industrial wastewaters, and other organic residues. With an annual capacity of 150 000 tons, the plant produces about 40 GWh of energy. Digestate is mechanically separated with a screw press, from which the liquid fraction was collected.

Two samples were prepared: one with a tannin-based biopolymer and one control. The biopolymer improved solid binding and separation before membrane filtration. After dosing and agitation, both samples were sieved and decanter centrifuged. Membrane processing included ultrafiltration (UF) and reverse osmosis (RO) using a vibrational shear enhanced system. A polylactic acid spacer was tested to enhance turbulence and permeate flux. UF tests covered polymer + spacer, polymer only, and control; RO tested permeates from polymer-treated and untreated samples.

The vibrational shear-enhanced membrane system was successfully applied for the clarification of digested liquid fractions. The use of the spacer had a clear positive effect on membrane performance.

Permeate fluxes for the biopolymer-treated and untreated samples without a spacer were similar, averaging 34–35 L m⁻² h⁻¹. In contrast, the biopolymer-treated sample with the spacer reached an average flux of 81 L m⁻² h⁻¹, representing a 238% increase. This improvement was also reflected in energy use: the specific energy requirement decreased to 0.56 kWh m⁻³ with the spacer, compared with 0.97 kWh m⁻³ for the untreated sample and 1.18 kWh m⁻³ for the biopolymer-treated sample without a spacer. These results demonstrate that the combined use of biopolymer addition, high vibration amplitude, and spacer geometry significantly enhances UF efficiency.

The planned membrane filtration investment improves the plant's circularity by concentrating nutrients into a transport-efficient product with potential to lower environmental impacts and enabling enhanced nutrient recycling across wider regions.

Topic: 1) Technologies

Keywords: nutrient recycling; recovery technologies; membrane filtration

Valorization of fish processing wastewaters to produce microbial biomasses

Lorenzo Siroli, Davide Gottardi, Daniele Alberoni, Chiara Braglia, Diana Di Gioia, Rosalba Lanciotti, Francesca Patrignani*

Department of Agricultural and Food Sciences, viale Fanin 44, 40126, Bologna, Italy
lorenzo.siroli2@unibo.it; davide.gottardi2@unibo.it; daniele.alberoni@unibo.it;
chiara.braglia4@unibo.it; diana.digioia@unibo.it; rosalba.lanciotti@unibo.it;
francesca.patrignani@unibo.it

Short Abstract

The seafood industry generates 2 – 5 m³ wastewaters/ton of fish that currently are treated as waste. However, process waters contain valuable nutrients that have the potential to be recycled into biomass for different purposes such as microalgae for alternative protein extraction, or plant growth promoting microorganisms. One of the main limitations of the use of fish processing wastewaters as substrate is their composition variability that can affect the availability of nutrients provided by the bio-waste and can also show potential inhibitory effects for microbial biomasses growth. In the framework of the ReLEAF CBE project (GA n.101156998), different types of fish wastewaters provided by Ecodesce, SME involved in the project, were analyzed and adjusted in composition by fish and agri-food wastes to permit the growth of several Plant Growth Promoting Bacteria (PGPB) to be reused in chitosan-based formulations for Bio Based Biostimulants. The fish wastewaters were adjusted mainly in carbon source (0.5%, 1%, 2%), throughout the addition of fruit by-product concentrates, and soluble protein content by the adding of fish waste hydrolysate (8%), produced using Ecodesce fish wastes. The modified wastewaters were used in 15L bioreactor to produce microbial biomasses, using microbial strains previously selected in the framework of ReLEAF project. The used fish wastewaters were also analyzed before and after the growth of the strains for pH, total solids, total N, proteins, sugars, dry matter, BOD and COD and micronutrients in order to understand the percentage of biovalorization of the employed fish wastewaters and potentially re-use. The products obtained were characterized for yield in biomasses and microbial cell loads in order to select the most performing for biostimulant formulations. The data obtained, in terms of microbial biomasses, showed *Lactiplantibacillus plantarum* Dan 39, *Bacillus licheniformis* SP9, and *Bacillus amyloliquefaciens* SP43 as good candidates. In fact, the yield in biomasses was 1.24 g/L, 2.5 g/L and 1 g/L for Dan 39, SP9 and SP43, respectively, while the microbial cell loads, reached after fermentation, were 8.3 log cfu/ml, 8.3 lof cfu/ml and 8.0 g/L., respectively. These data suggest a good approach for fish waste valorization to obtain microbial biomasses.

Topic: 1) Technologies; 2) Agronomy; 3) Sustainability

Keywords: Up-cycling, fish waste waters, microbial biostimulants, circular approach

Use of BBFs as a measure to mitigate nutrient losses in agriculture

Sandra Galea-Outón^{1*}, Yasmina Chourak¹, Laura Díaz-Guerra¹, Guillem Verdaguer-Susin¹, Carla Bisbal-Font¹, Rosa Vilaplana¹

¹ BETA Technological Center (TECNIO Network), University of Vic – Central University of Catalonia (UVIC-UCC), Ctra. de Roda 70, 08500 Vic (Barcelona), Spain. * Corresponding author, e-mail: sandra.galea@uvic.cat

Short Abstract

In line with the EU Zero Pollution action plan, Nutribudget is a Horizon Europe project that will contribute to systemically optimizing nutrient management across different agricultural production systems and regions to reduce pollution due to the excessive use of nutrients and its losses to the environment. The NutriBudget will develop an integrated nutrient management platform, called Nutriplatform, as a decision-support tool for farmers, advisors, policymakers, and regional authorities. The Nutriplatform will be based on existing data and new field-tested agronomic measures combined with cutting-edge models on nutrient budgets, data standards and indicators. Thus, a wide range of mitigation measures are being tested in 5 pilot regions in the EU. BETA Technological Center (UVICUCC) is the leader of the Mediterranean pilot, where 5 mitigation measures are being studied. One of them consists of optimizing fertilization using upgraded pig manure products to avoid nutrient excess in soil. The objective is to optimize nutrient use while promoting a circular economy, applying biobased fertilizers (BBFs) and tailor-made fertilizers (TMFs). To this aim, this work compared the application of four treatments: TMF (a combination of two BBFs: manure dried fraction and manure-derived ammonium sulphate), a mineral fertilizer (ammonium sulphate), raw manure, and unfertilized control. The three fertilizers (TMF, Mineral, and Raw Manure) were each applied at different doses (50, 75, and 100% of the recommended N rate) on an experimental field of winter wheat during the crop seasons of 2024–2025. Macro- and micronutrients were analyzed in soil and plants, along with biomass production and grain quality. Results showed the best fertilizer use-efficiency at 50% dose for all treatments in the first year, while efficiencies dropped in the second year. Similarly, N uptake in wheat was better in the first year than in the second one, with no significant differences in biomass production. Thus, in the second year, biomass contained a lower proportion of N, while losses by N-leaching tended to be higher. The lack of significant differences among treatments suggests that manure-derived TMF can replace the use of mineral fertilizers, obtaining similar crop performances. Using BBFs is a good measure to mitigate the nutrient excess, promoting sustainability of farms by recycling their waste and reducing the environmental impact derived from the production of mineral fertilizers.

Topic/s: Agronomy and Sustainability

Keywords: Nutrient losses; bio-based fertilizers (BBFs); Nitrogen use efficiency; nutrient circularity; *Triticum aestivum*.

Acknowledgments: NutriBudget is a Horizon Europe project (ID 101060455) funded by the European Union. Website: <https://www.nutribudget.eu/>

Recycling-derived fertilizer combinations with struvite or hydrochar and vinasse are suitable substitutes to mineral fertilizers for potato cropping

Tasfia Mostafa¹, Achim Schmalenberger^{1*}

¹Department of Biological Sciences, Faculty of Science and Engineering, University of Limerick, Limerick, Ireland.

Short Abstract

The study objectives are to assess the suitability of recycling-derived fertilizers (RDF) to fulfil the nutrient requirements of potato through the support of microbial driven nutrient cycling. RDF has the potential to reduce i) mineral fertilizer economic dependencies, and ii) nutrient losses through slow-release and improving plant availability, with the microbial soil/rhizosphere community playing a critical part in nutrient mobilization.

Soil column experiments with two potato varieties were carried out to test the efficacy of two RDF blends 1) struvite-vinasse and 2) hydrochar-vinasse and tested against conventional mineral fertilizer and a no-fertilizer control. Kerr's Pink and Golden Wonder were grown in soil columns for 12 weeks in 2024 and 2025 respectively. Shoot biomass and tuber formation was recorded at time of harvest and availability of soil phosphorus and acid/alkaline phosphatase activity was measured. Rhizosphere soil was used to determine the abundance of phosphonate and phosphate ester utilizing bacteria; extracted DNA was used to study the bacterial community structures and functions.

Shoot and tuber yields under struvite-vinasse fertilization were similar to conventional mineral fertilizer application for Kerr's Pink. Hydrochar-vinasse RDF performed significantly worse than struvite-vinasse for Kerr's Pink, but the opposite was the case for Golden Wonder. Struvite-vinasse RDF resulted in the highest nitrogen and phosphorus uptake rate for both potato varieties, exceeding that of the mineral fertilizer. The mineral fertilizer treatment resulted in the significantly highest acid and alkaline phosphatase activity for Kerr's Pink. In contrast, significantly highest acid and alkaline phosphatase activity by hydrochar-vinasse fertilization has been observed for Golden Wonder. Abundance of phosphonate utilizing bacteria was highest in struvite-vinasse and hydrochar-vinasse for Kerr's Pink, while abundances were similar across the treatments for Golden Wonder. Bacterial community analysis revealed that both RDF treatments are responsible for communities distinct from both controls. The conclusion of the study is that the struvite-vinasse RDF combination is a suitable replacement for mineral fertilizer for Kerr's Pink, while hydrochar-vinasse RDF is a potential alternative for Golden Wonder potato cropping. The present findings indicate the importance of variety (genotype) selection for sustainable fertilization with RDF.

Keywords: bacterial community structure; Kerr's Pink, Golden Wonder; sustainable nutrient cycling; ReNu2Cycle

Combination of extrusion, infra-red drying, milling and pelletization in valorisation of solid fraction of anaerobically digested municipal biowaste

*Ari-Matti Seppänen, Science Expert. Natural resources institute Finland, Helsinki. ari-matti.seppanen@luke.fi

**Ilmari Laaksonen, Science Expert. Natural resources institute Finland, Jokioinen. Ilmari.laaksonen@luke.fi

Short Abstract

Pelletization of digestates as bio-based fertilizers enhances transportation, storage and usability of the product. With biowaste-based digestates the thermal drying has faced challenges in the form of stickiness and forming of crust. Currently the biowaste of Finland's capital region is digested anaerobically, centrifuged and then composted. In this study as an alternative to composting the technical suitability of combination of extrusion, infra-red drying, milling and pelletization was studied.

The material of the study was the solid fraction of centrifugal separation of municipal biowaste digestate (Helsinki regions, HSY). Twenty-six 10-25kg drying experiments were conducted with Nanopar PSS SPD 250-infrared dryer with different drive settings and combinations of technologies to enhance water extraction and handling of the material. After successful drying, the pelletization of samples was tested utilizing Amandus Kahl 14-175 laboratory pellet press. Electricity consumption, temperatures, masses, time and speed of processing were recorded. Samples were collected throughout the process chain for dry matter (DM) and nutrient content analyses. DM was determined at 105 °C by TGA701 (Leco), Nitrogen content by Kjeldahl, Phosphorus and Potassium by ICP-OES analyses.

Feeding of the undried solid fraction to the conveyor of the infra-red dryer wasn't possible with conventional hopper feeder due to stickiness of the material. Solution to the feeding issue was to feed the material with extruder screw into uniform and even "pasta". The wet pasta (DM= 28-30%) tolerated radiative infrared heating well (42 ± 8 °C) but charring and combustion of the material limited the drying power below maximum. Crust formed on the surface during the first phase of drying trapping moisture inside the pasta (DM->45%). As a solution to the trapped moisture the dried pasta was milled with Robot-Coupe R10 knife mill.

For the second drying phase the milled powder was suitable to the hopper feeder and a uniform 15mm material bed was formed. Second drying succeeded to reach the pelletization moisture (DM 85%) in similar drying temperatures (43 ± 10 °C). Dried material pelletized successfully with 2:1 compression ratio at 45°C. Where the process chain was found technically suitable, energy consumption results were considerably high in the drying: 2,2kWh/l H₂O in the first phase and 2,8kWh/l H₂O in the second phase.

Topic: 1) Technologies

Keywords: Digestate; Extrusion; Drying; Pelletization

Holistic Solution for Nutrient Recovery in Wastewater Treatment Plants

Sergi Durán-Videra^{1*}, Rubén Rodríguez-Alegre¹, Jarod Enrique Erreyes Piloza¹, David Carmona-Fernández¹, Laura Pérez Megías¹, Xialei You¹, Carlos Andecochea Saiz¹

¹Leitat Technological Center, Circular Economy & Decarbonization department, Carrer de La Innovació 2, 08225, Terrassa, Barcelona, Spain. sduran@leitat.org, rodriguez@leitat.org, jerreyes@leitat.org, dcarmona@leitat.org, lperez@leitat.org, xyou@leitat.org, candecochea@leitat.org

Short Abstract

Sewage sludge is a widely generated biowaste, with over 10 million tons of dry solids produced annually in the EU27. Although it is generated in a necessary process (wastewater treatment), it remains a biowaste that requires management. Furthermore, it contains significant amounts of recoverable nutrients (phosphorus and nitrogen) and humic and fulvic substances (HFS), which act as biostimulants. Phosphorus is listed as a critical raw material in the EU due to limited reserves, causing strong dependence on its import. It is estimated that around 300,000 tons of phosphorus per year could be recovered from sewage sludge (European Sustainable Phosphorus Platform, 2022). Similarly, nitrogen fertilisers rely on ammonia produced via the energy intensive Haber–Bosch process, making it dependent on imported natural gas, while up to 73% of nitrogen is lost within WWTP (Tang et al., 2024) instead of being recovered. Regarding HFS production, there is a lack of standardised methods for their recovery from sludge, so this presents an opportunity for their implementation. In this context, the ReLEAF project aims to use sewage sludge as a secondary feedstock for a circular economy approach in the agricultural sector.

Total P recovery reached 89.7%, by struvite precipitation with kinetics similar to those reported in the literature, with the struvite forming typical wedge-shaped crystals. A 1:1 P:Mg ratio was optimal, since higher magnesium doses yielded no significant improvement. However, an excess of calcium in the sample caused hydroxyapatite formation; a two-step crystallisation is recommended to separate it from struvite. Struvite formation was confirmed by FTIR.

Nitrogen recovery was achieved via transmembrane chemisorption. The process reached 96.7% ammonium recovery, and the transfer coefficient was similar to previously reported values. The resulting ammonium salt showed high purity (98.15%), meeting REACH standards for its use as a high-quality fertilizer.

Optimisation of HFS extraction showed that it decreases as pH is lowered from the reference value of pH 13 (70.23 g/kg). The extraction curve showed an S-shaped trend, with the sharpest change occurring between pH 11 (24.9 g/kg) and 12.5 (67.9 g/kg). Below pH 11, extraction levels stabilise with <1% variation, though small amounts of HFS still appear at pH 10–10.5 due to humic substances. Above pH 12.5, no further gains occur, indicating near-complete extraction and full sludge depletion.

These results confirm that sewage sludge can be used as an effective feedstock for nutrients and biostimulants recovery. Overall, the integrated approach offers a viable pathway to advance circular nutrient management in wastewater treatment plants.

References:

European Sustainable Phosphorus Platform. (2022). ESPP Phosphorus Fact Sheet (p. 7). ESPP.

Tang, M., Du, R., Cao, S., Berry, M., & Peng, Y. (2024). Tracing and utilizing nitrogen loss in wastewater treatment: The trade-off between performance improvement, energy saving, and carbon

footprint reduction. *Journal of Environmental Management*, 349, 119525.
<https://doi.org/10.1016/j.jenvman.2023.119525>

Topic: 1) Technologies; 2) Agronomy; 3) Sustainability

Keywords: Sewage sludge; Ammonium sulphate; Struvite; Humic and Fulvic substances; Circular economy

Acknowledgement: This project is supported by the CBE JE and its members. Views and opinions expressed are, however, those of the author(s) only and do not necessarily reflect those of the funding body. Neither the European Union nor the granting authority can be held responsible for them. Project number 101155998.

Optimisation and acclimatisation of *Chlorella vulgaris* grown on the liquid fraction of digestate

Shruti Katti^{*1}, Marcella Fernandes De Souza¹, Erik Meers¹

¹Laboratory for Bioresource Recovery (Re-Source), Department of Green Chemistry and Technology, Ghent University, Coupure Links 653, 9000 Ghent, Belgium

* Corresponding author, E-mail: shruti.katti@ugent.be

Short Abstract

The liquid fraction of digestate generated from the anaerobic digestion of cow manure in agricultural biogas plants represents a nutrient-rich alternative medium for microalgae cultivation. It provides essential macronutrients and trace elements necessary for algal growth, potentially reducing dependence on conventional synthetic media. However, its direct use is often constrained by high ammonium concentrations, turbidity, and bacterial contamination, which can inhibit microalgal biomass production. This study investigated pre-treatment and operational strategies to enhance the suitability of digestate for the cultivation of *Chlorella vulgaris*.

Stepwise acclimatisation combined with increased inoculum density effectively reduced lag phases and improved growth performance relative to control conditions grown in standard Bold Basal Medium (BBM). Cultivation at 4% (v/v) digestate revealed signs of ammonia toxicity, which was mitigated through ammonia stripping of the digestate. Stripping, conducted without active pH control and relying solely on the natural digestate pH, removed $55 \pm 3\%$ of $\text{NH}_4^+\text{-N}$ at 60 °C. Following the stripping process, the pH was adjusted to 8.5 to restore optimal growth conditions. The removal of ammonia toxicity enabled stable cultivation of *C. vulgaris* at higher digestate concentrations than previously achievable, demonstrating improved tolerance and nutrient utilisation.

Overall, the combined application of pre-treatment and acclimatisation strategies significantly enhanced microalgal productivity while reducing the need for digestate dilution. These findings confirm the feasibility of using anaerobic digestate as a cost-effective nutrient source for sustainable microalgae cultivation. The ultimate goal is to achieve higher digestate concentrations, potentially up to 20% or more, supporting its potential integration into agricultural biogas systems for circular resource recovery and bio-based production.

Keywords: acclimatisation; digestate; microalgae; pre-treatment

FertiCovery: best available technologies for bio-based fertilisers.

Sterre van der Voort^{1*}, Martijn Vis¹

¹ BTG Biomass Technology Group B.V., Enschede, the Netherlands

* Corresponding author: vandervoort@btgworld.com

Short Abstract

The FertiCovery project investigates how bio-based fertilisers produced from secondary raw materials can effectively be integrated into the European agricultural sector. A diverse range (> 160) of bio-based fertiliser technologies has been identified, and a selection of 25 case studies has been made based on a scoring methodology that considers, among other factors, commercial availability and costs, feedstock availability, efficiency, and the regulatory and market framework.

Within FertiCovery, the selected case studies cover several groups of nutrient recovery technologies, including biologically derived products (such as digestate- and compost-based fertilisers), chemically derived products via processes like nutrient precipitation (e.g., precipitated phosphates) and ammonia recovery (e.g., ammonium salts), as well as thermochemical conversion pathways producing carbon-based fertilising products and soil amendments (e.g., biochar).

For these selected cases, several detailed analyses are carried out. Fertiliser products will be characterised through laboratory analyses, focusing on nutrient composition, contaminants and other quality parameters relevant for use and regulatory compliance. The product characterisations are complemented by assessments of environmental impact, upscaling potential, regulatory barriers, production costs, and market potential. All aspects will be considered in a multi-criteria analysis to identify the ten best available technologies, which will be presented in dedicated technology datasheets. In parallel, the practical implementation of fertilisers will be addressed by translating technical results and stakeholder input into user guidelines that aim to support farmers and other end-users in the appropriate application of bio-based fertilisers.

By integrating fertilising product characterisation, detailed case study analyses, user perspectives and policy assessments, FertiCovery provides evidence-based results that will contribute to supporting informed decision-making by practitioners, technology developers and policymakers for advancing bio-based nutrient recycling practices.

Topic: Technologies

Keywords: Technology assessment; case studies; user guidelines; bio-based fertilisers; nutrient recycling

Advanced Thermodynamic Analysis of Phosphate Adsorption toward Sustainable Phosphorus Recovery

Tijana Ivanovic^{1,*}, Florian Mittermayr¹, Martin Dietzel²

¹Unit of Material Technology, University of Innsbruck, Technikerstraße 13, A-6020 Innsbruck, Austria
tijana.ivanovic@uibk.ac.at; Florian.Mittermayr@uibk.ac.at

²Institute of Applied Geosciences, Graz university of technology, Rechbauerstraße 12, 8010 Graz, Austria, martin.dietzel@tugraz.at

Short Abstract

In contrast to the soil where phosphorus is needed for plant nutrition, it is responsible for eutrophication in aquatic systems. Thus, phosphate removal is obligatory for wastewater to be discharged into lakes, shallow watercourses etc. This research integrates fundamental science with sustainable application by combining theoretical insights and material valorization to enable phosphorus recovery and reuse as a geopolymer-based fertilizer within the FWF-funded project *Phosphorus Recovery by Clay: Thermodynamics and Reuse*. The challenge addressed by this research is the lack of precise methods for determining the thermodynamic parameters of the adsorption process involved in phosphate removal from water. This limitation hinders process optimization and leads to higher energy and material consumption. The proposed methodology provides both an accurate and reliable approach to determine these parameters and a more comprehensive understanding of thermodynamics of the adsorption process. Following the adsorption of phosphate, the solution may contain various ionic species due to dissociation, hydrolysis, or desorption. The equilibrium composition of the post-adsorption solution can be determined by analyzing the ionic concentrations and verifying electroneutrality. To account for non-ideal behavior in the system, the activity coefficients of the relevant ions, used in the thermodynamic adsorption constant, are calculated using the Pitzer ion-interaction model, enabling accurate representation of real post-adsorption environments. Since electrolyte solution thermodynamics calculations are performed using the molality scale, it is necessary to convert electrolyte molar concentrations to molality. This conversion requires knowledge of the densities of both pure and mixed electrolyte solutions. Once converted, the activity coefficient can be expressed in various concentration scales. This procedure is applied when ion concentrations exceed the maximum permissible levels, with approximations and simplifications used for lower concentrations. Using the obtained thermodynamic parameters to optimize the process conditions can improve the efficiency, reduce the energy and material consumption and increase the economic feasibility of the adsorption system.

Topic: Technologies

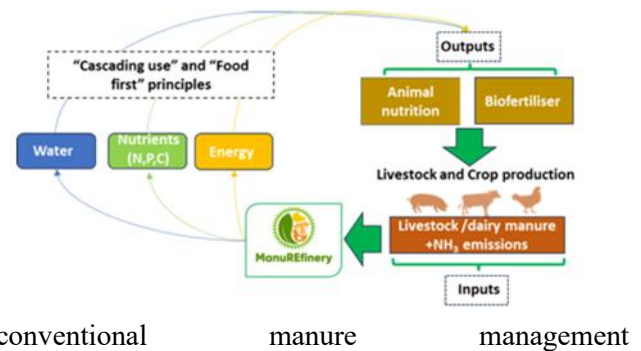
Keywords: phosphorus; recovery; thermodynamic modeling; Pitzer-ion interaction model

ManuREfinery - Convert livestock manure into added value biobased feed and bioingredients for fertilisers

Anke Valvekens*, Wouter Naessens*, Lynn Backers*, Denis De Wilde*

Short Abstract

European farms produce over 1.4 billion tonnes of manure annually, contributing to greenhouse gas emissions, ammonia release, soil degradation, and water pollution. The **ManuREfinery project**, funded under the EU **Horizon programme (HORIZON-JU-CBE-2023)**, develops mobile, modular biorefineries to transform livestock manure into high-value biobased feed and fertilizer ingredients, addressing the environmental and economic challenges of conventional manure management



ManuREfinery implements **gas, liquid, and solid valorisation lines**. Gas valorisation includes ammonia recovery and biofiltration to produce sodium nitrate fertilizer. Liquid valorisation uses anaerobic digestion, while solid valorisation converts manure solids into bio-based fuels and microbial protein for feed. Within the liquid valorisation line (see Figure 1), an **Ammonia Mining Unit (AMU) supplied by Detricon** recovers ammonia from digestate, converting it into ammonium fertilizer and simultaneously reducing phosphorus content by electro-coagulation. The ammonium sulphate fertilizer will be further upgraded to an ammonium bicarbonate solution with higher N concentrations. A **digital twin** of each process line enables real-time optimization of efficiency, safety, and resource recovery.

The project focuses on **flexible, small-scale, and portable systems** applicable to pig, poultry, and cattle farms, promoting scalable solutions across Europe. ManuREfinery also emphasizes **circularity, sustainability, and community engagement**, ensuring that all byproducts are valorised and solutions are relevant to farmers and rural stakeholders.

Expected impacts include reduction of GHG and pollutant emissions, improved nutrient circularity, adoption of innovative bio-based technologies, diversification of rural incomes, and enhanced social acceptance. ManuREfinery contributes to the **European Green Deal**, demonstrating sustainable, economically viable, and scalable circular bioeconomy solutions for livestock manure management.

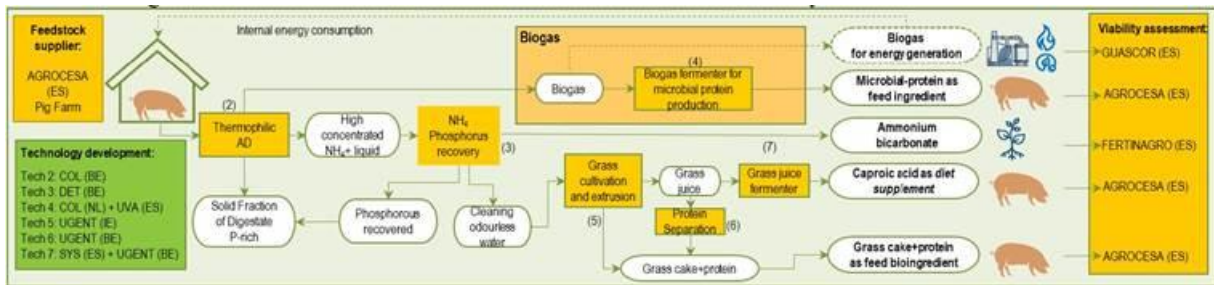


Figure 1: Liquid valorisation line

Topics: 1) Technologies; 2) Agronomy; 3) Sustainability; 4) Policy / Path to market

Keywords: manure valorisation; ammonia recovery; circular bioeconomy; sustainable agriculture

Cow manure digestate as an alternative sustainable cultivation medium for sulfide-oxidizing bacteria aimed at biogas desulfurization

Yali Zhu^{1,2,*}, Çağrı Akyol¹, Patricia Ruiz-Ruiz², Hongzhen Luo¹, Erik Meers¹, Jo De Vrieze^{2,3}

1 Laboratory for BioResource Recovery (Re-Source), Department of Green Chemistry and Technology, Faculty of Bioscience Engineering, Ghent University, Coupure Links 653, Ghent 9000, Belgium, email of *corresponding author: yali.zhu@ugent.be

2 Center for Microbial Ecology and Technology (CMET), Ghent University, Frieda Saeystraat 1, B-9052 Gent, Belgium

3 Centre for Advanced Process Technology for Urban Resource recovery (CAPTURE), Frieda Saeystraat 1, B-9052 Gent, Belgium

Short Abstract

Sulfide-oxidizing bacteria (SOB) can play a key role in the biological desulfurization of biogas for downstream utilization. However, their cultivation typically relies on chemically defined media, which substantially increases operational costs and limits economic and environmental sustainability. This study investigated the feasibility of cultivating SOB using recycled nutrients from cow manure digestate as a sustainable alternative to mineral medium. Undiluted and diluted centrate from a cow manure digester (0–10×) were used as culture media to grow an enriched SOB culture, in order to assess sulfide removal and microbial dynamics. High ammonia concentrations and the presence of indigenous microbial communities in the digestate were identified as major challenges. The results showed that NH_4^+ were negatively correlated with SO_4^{2-} production and positively correlated with $\text{S}_2\text{O}_3^{2-}$ accumulation. The sulfate concentration in diluted centrate ranged from 849 and 1252 $\text{mg}\cdot\text{L}^{-1}$ (2–20× dilution), which was comparable to sulfate production in the mineral medium (1259 $\text{mg}\cdot\text{L}^{-1}$). Although sulfate production was limited in the undiluted centrate and in the abiotic control, the H_2S release to the gas phase was reduced through non-biological mechanisms. The pH of the culture grown in the mineral medium decreased from 7.98 ± 0.02 to 6.04 ± 0.06 due to H_2S oxidation, whereas lower dilution factors (0–10×) provided buffering capacity and mitigated rapid pH drops. *Psychrobacter*, an aerobic denitrification bacterium, accounted for $34.8 \pm 4.5\%$ and $37.2 \pm 0.5\%$ of the microbial community in centrate and 2× dilution centrate, suggesting that NH_4^+ removal may be prioritized over desulfurization under high NH_4^+ conditions. In contrast, *Ciceribacter* dominated the 5 and 10× dilution groups, accounting for $22.5 \pm 6.1\%$ and $30.8 \pm 2.3\%$ of the community, and exhibited the capability to reduce nitrate and oxidize thiosulfate. Overall, cow manure digestate can serve as a sustainable nutrient source for SOB cultivation, particularly at 5×, and 10× dilution, which showed higher species richness and evenness compared to the control (mineral medium) group. The buffer capacity provided by cow manure digestate can prevent sharp decreases in pH, thereby supporting stable SOB growth and providing a promising strategy for cost-effective and sustainable biogas desulfurization.

Topic: Sustainability

Keywords: Cow manure digestate; hydrogen sulfide; nutrient recycling; sulfide oxidizing bacteria

NENUPHAR project: Valorisation of wastes to recover nitrogen and phosphorus

Barbara Palacino^{1*}, Ľuboš Jurík², Marta Lenartowicz², Elena Aydin², Tatiana Kaletová², Jānis Zviedris³, Sandis Dejus³, Iveta Grudovska⁴, Darta Gatere⁴, Inga Berzina⁴, Trinidad De Marco¹, Alessandro Carmona¹, István Kulmány⁵, Balázs Ásványi⁵, María Pérez⁶

¹CIRCE Foundation, Parque Empresarial Dinamiza, Avda. Ranillas, Edificio 3D, 1a planta, 50018, Zaragoza, Spain, bpalacino@fcirce.es

²Slovak University of Agriculture, Institute of Landscape Engineering, Hospodárska 7, 949 76 Nitra, Slovakia

³Latvian Water and Wastewater Works Association, Lielirbes Street 1, Riga, LV-1046, Latvia

⁴Farmers' Parliament Union, Republikas Laukums 2, Central District, Riga, LV-1010, Latvia

⁵Széchenyi István University, 1 Egyetem Square, Győr, 9026, Hungary

⁶Gestcompost SL, Calle San Blas 3, 50750 Pina de Ebro, Zaragoza, Spain

Short Abstract

The NENUPHAR project aims to demonstrate and evaluate innovative technologies for recovering nutrients, mainly nitrogen and phosphorus, from pig manure slurry, sewage sludge and dairy wastewater. By closing nutrient cycles, the project seeks to reduce diffuse pollution, improve water quality in sensitive river basins, and promote a circular economy approach to nutrient management across Europe. NENUPHAR is structured around three demonstration sites in agriculturally intensive and vulnerable river basins: the Ebro River Basin (Spain), the Lielupe River Basin (Latvia and Lithuania), and the Danube River Basin (Hungary and Slovakia). Each demonstration addresses a specific waste stream and applies technologies adapted to local environmental, regulatory, and socio-economic conditions.

In the Ebro River Basin, pig manure and digestate are treated using ammonia stripping to recover nitrogen as ammonium sulphate. This process reduces nitrogen losses to soil and water and helps mitigate nitrate pollution in vulnerable areas, while producing a marketable mineral fertiliser. In the Lielupe River Basin, sewage sludge from wastewater treatment plants is composted by mixing dewatered sludge with organic bulking materials under controlled conditions. The resulting stable, nutrient-rich compost is suitable for agricultural use, improves soil fertility and reduces dependence on mineral fertilisers. In the Danube River Basin, dairy wastewater is addressed through two complementary approaches. In Hungary, whey is treated using ozone pretreatment followed by ultrafiltration, enabling protein recovery for ricotta cheese production and generating reusable process water. In Slovakia, an algae-based nature-based solution biologically removes and recovers nitrogen and phosphorus, producing algal biomass that can be further processed into biofertilisers (Figure 1).



Figure 1. Top left: Gestcompost plant (Spain); top right: compost process (Latvia–Lithuania); bottom left: Tebike facilities (Hungary); bottom right: SUA facilities (Slovakia).

The NENUPHAR project demonstrates innovative nutrient recovery technologies at pilot and industrial scale across Europe. The resulting biofertilisers, rich in nitrogen, phosphorus, and other nutrients, are being tested in field trials to evaluate their agronomic benefits and environmental impact. NENUPHAR shows that nutrient recovery is feasible, scalable, and a practical step toward circular and sustainable agriculture.

Topic: Technologies

Keywords: nutrient recovery, waste valorisation, circular economy, nitrogen, phosphorus.

Acknowledgement: This research has received funding from the European Union's Horizon Europe research and innovation programme, under grant agreement No. 101082169, within the project NENUPHAR: "New governance models to enhance nutrient pollution handling and nutrients recycling". Funded by the European Union. Views and opinions expressed are however those of the author(s) only and do not necessarily reflect those of the European Union. Neither the European Union nor the granting authority can be held responsible for them.

SINFERT: from Biowaste to Inorganic Phosphate Fertiliser and Phosphorus Chemicals

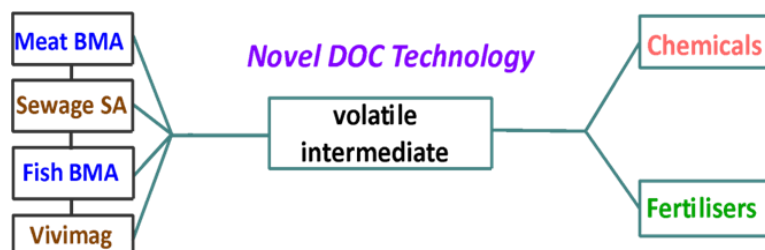
Rajan Choudhary¹ (rajan.choudhary@ucd.ie), Sara Guigui¹ (sara.guigui@ucd.ie), Simon Hodge² (simon.hodge@ucd.ie), Kirill Nikitin*¹ (kirill.nikitin@ucd.ie)

¹ UCD School of Chemistry, University College Dublin, Belfield, Dublin 4, Ireland

² UCD School of Agriculture and Food Science, University College Dublin, Belfield, Dublin 4, Ireland

Short Abstract

Phosphorus is a crucial nutrient, yet its availability from phosphate rock reserves is limited.¹ Current recovery methods aimed at reducing strain on these reserves face challenges due to high energy and chemical demands, as well as contamination from heavy metals and organic residues.² To address these challenges, the SINFERT project has developed a novel deoxychlorination (DOC) chemical process³ capable of recovering phosphorus from biowastes (meat and bone meal, fish, sewage sludge, manure). The process operates under mild conditions (30–70 °C, atmospheric pressure, 1-24 h), achieving >90% extraction efficiencies. For the first time, the key intermediate (volatile phosphorus oxychloride) was isolated by fractional distillation and hydrolysed to form 99%+ white phosphoric acid. After neutralisation with ammonia, high-purity MAP and DAP fertilisers (ppm levels of metals) were obtained. In greenhouse trials, these fertilisers have shown to perform similarly to conventional MAP and DAP fertilisers. The extraction has been validated on the kilogram scale in industrial settings. A preliminary life cycle assessment shows that fully developed DOC technology could produce these fertilisers with up to 75% less greenhouse gas emissions than conventional process from phosphate rock.



SINFERT approach furnishes high-purity phosphates suitable for agriculture, food production and industrial applications. New process addresses EU critical raw materials and circular economy objectives. This work demonstrates a viable, scalable pathway for closing the phosphorus loop and reducing dependence on non-renewable phosphate resources, contributing to long-term global food and resource security.

Topic: 1) Technologies. **Keywords:** Phosphorus recovery; biowastes; nutrient recycling; phosphoric acid; fertilisers

¹ Witek-Krowiak, A., Gorazda, K.; Szopa, D., Trzaska, K., Moustakas, K.; Chojnack, K. *Bioengineered*, **2022**, 13(5), 13474-13506.

² Geeson, M. B., Cummins, C. C. *Science*, **2018**, 359, 1383–1385.

³ Patent Application GB2507431.1, UCD Dublin, **2025**.

CiNURGi - Circular nutrients for a sustainable Baltic Sea Region

Paula Biveson*, Helen Honkasaari**, Paula Biveson, and Helen Honkasaari*, Centrum Balticum, Vanha suurtori 7, 20500 Turku, Finland. paula.biveson@centrumbalticum.org and helen.honkasaari@centrumbalticum.org,

Short abstract

Circular economy for nutrients is facing many barriers. The project CiNURGi seeks to recycle nutrient-rich biomass from agricultural, municipal, and industrial sources into safe fertilizers, and provide authorities with roadmaps to further facilitate reducing nutrient losses in future. CiNURGi is funded by the Interreg Baltic Sea Region Programme under the Priority Climate-neutral societies and the Objective Circular economy and has results to present from several initiatives.

CiNURGi's initiatives include:

- Mapping and quantifying recyclable biomasses, including manure, sewage sludge, and biowaste to assess the potential for nutrient recycling to improve national and regional nutrient balances. Results available, including a proposal for a national nutrient recycling strategy.
- Developing and promoting standards for safe and sustainable recycling of nutrients. Results from evaluation of standards for quality control and agronomic value of recycled nutrient fertilizers forthcoming in April. Including comparisons of the efficiency of recycled nutrient fertilizers with mineral fertilizers and results from both pot and field trials.
- Policy recommendations to support HELCOM Contracting Parties, i.e. Baltic Sea countries, in fulfilling their commitments regarding nutrient recycling. These include especially Action E32 in the HELCOM Baltic Sea Action Plan (Enhance the use of recycled nutrients in agriculture making use of best available technologies and fertilize according to crop needs) and the overall HELCOM Regional Nutrient Recycling Strategy.
- Evaluating market opportunities and barriers for recycled nutrients. Results available on the socioeconomic cost of developing recycled nutrient fertilizers, and market and governance barriers.
- Supporting companies in nutrient recycling. CiNURGi offers help and resources to companies interesting in developing their product. 6 partners in 4 different countries offer support for development through analysis and testing. CiNURGi has 4 direct investments to increase the production of recycled nutrients to test and support the development of different technologies for nutrient recycling.

Topic: Policy / Path to market

Keywords: Nutrient recycling; Fertilizers; Phosphorus; Circular Economy; Governance or Policy Recommendations

Practice-Oriented Innovations for Nutrient Management in Livestock-Intensive Regions: Evidence from NUTRI-KNOW

Anna Bagó-Mas*, Hongzhen Luo, Beatriz Medina***, Maria Pascual Sánchez***, Victor Carbajal Perelló*, Erik Meers****

* Fundació Centre Tecnològic en Biodiversitat, Ecologia i Tecnologia Ambiental i Alimentària (Fundació BETA) – UVIC-UCC, Vic, Spain. Corresponding author: anna.bago@uvic.cat

** Laboratory for Bioresource Recovery (RE-source Lab), Department of Green Chemistry and Technology, Ghent, Belgium.

*** Water, Environment and Business for Development, Sant Cugat del Valles (Barcelona), Spain.

Short Abstract

Effective nutrient management is a key pillar of sustainable agriculture, requiring a balance between ensuring optimal crop productivity and minimising the environmental impacts and nutrient losses associated with inappropriate management. The EU-funded project NUTRI-KNOW addresses this challenge by strengthening transnational collaboration and enhancing knowledge flows across Europe. By engaging 12 Operational Groups (OGs) from four Member States (Belgium, Spain, Italy and Ireland) the project aims to improve nutrient management practices and support a more efficient and resilient European agri-food sector.

The participating OGs are closely embedded in their regional contexts and address concrete challenges faced by farmers, highlighting the importance of shared innovation and practice-based learning. To better understand current farming practices, policy frameworks and market needs, two qualitative surveys were conducted: one targeting OG consortia and another addressing a wider group of stakeholders, including practitioners and policymakers. The OG survey identified two main challenges related to manure management: (i) excessive nitrogen and phosphorus loading on agricultural land in livestock-intensive regions, particularly in Belgium, Italy and Spain, with negative effects on water and air quality; and (ii) persistent gaps in translating research outputs into practical, farm-level solutions. These challenges were strongly confirmed by the stakeholder consultation carried out in the four Member States, pointing to an urgent need for accessible, practice-oriented knowledge tailored to end users.

In response, the OGs propose a set of innovative solutions, including technologies for nutrient recovery and up-concentration from manure, slurry and digestate (e.g. nutrient concentrators, struvite recovery, stripping and scrubbing), the integration of farm-scale anaerobic digestion to support renewable energy production, and innovative nutrient application and monitoring strategies such as injection techniques, sub-irrigation with drip lines and crop diagnostic tools. Through multi-level engagement activities and the development of tailored practice-oriented materials, NUTRI-KNOW demonstrates how collaborative innovation can accelerate the uptake of sustainable nutrient management solutions and contribute to a more environmentally sound European agriculture.

Topic: Technologies

Keywords: Nutrient recovery, Manure management, Sustainability, Anaerobic digestion, RENURE, Struvite.

Biogenic CO₂ and Digestate as Resources for Sustainable Microalgal Cultivation

M. Konucu^{1,*}, J.-B. Joos¹, A. Chamaa², B. Willems¹

¹, Innolab, Marechalstraat 70, 8020, Oostkamp, Belgium *merve.konucu@innolab.be

²Innolab France 11 rue Marie Curie, 10000 Troyes, France

Short Abstract

The integration of microalgae cultivation with biogas production may represent an efficient and sustainable biorefinery strategy that valorises waste streams and supports a circular economy. In this integrated system, anaerobic digestate, particularly its liquid fraction, can be utilized as a growth medium for microalgae due to its high content of essential nutrients such as nitrogen (N) and phosphorus (P) (Bauer et al., 2021). Simultaneously, CO₂ released during the biogas production process can be recovered and supplied as a carbon source, thereby supporting microalgal growth (Yang et al., 2022). As part of the Horizon Europe SEMPRES-BIO project, microalgae cultivation was assessed within an integrated system where digestate was applied as a growth medium and biogenic CO₂ from biogas upgrading was supplied as a carbon source. The selected strain, *Desmodesmus denticulatus*, was cultivated at pilot scale in a tubular photobioreactor under controlled nutrient conditions to evaluate biomass production, nutrient recovery, and CO₂ fixation. Comparable growth performance was achieved when microalgae were cultivated in synthetic medium supplied with either commercial or biogenic CO₂, reaching similar biomass concentrations (~0.5 g L⁻¹) on the same day and comparable daily biomass productivities (around 0.06 g L⁻¹ d⁻¹). Digestate was evaluated as an alternative growth medium at different concentrations, resulting in biomass productivities ranging from 0.094 to 0.275 g L⁻¹ d⁻¹, while the biomass protein content varied between 14.3% and 42.2%. The elemental composition of the harvested algal biomass was found to remain within established safety thresholds, and the effluent quality indicated its potential reuse for microalgae inoculation. These outcomes underline the suitability of digestate and biogenic CO₂ as a sustainable substrate for microalgal cultivation, promoting nutrient recycling and value-added biomass production.

References:

Bauer, L., Ranglová, K., Masojídek, J., Drosig, B., & Meixner, K. (2021). Digestate as Sustainable Nutrient Source for Microalgae—Challenges and Prospects. *Applied Sciences*, 11(3), 1056. <https://doi.org/10.3390/app11031056>

Yang, W., Li, S., Qv, M., Dai, D., Liu, D., Wang, W., Tang, C., & Zhu, L. (2022). Microalgal cultivation for the upgraded biogas by removing CO₂, coupled with the treatment of slurry from anaerobic digestion: A review. *Bioresource Technology*, 364, 128118. <https://doi.org/10.1016/j.biortech.2022.128118>

Topic: Sustainability

Keywords: Sustainable algal biomass; digestate; biogenic CO₂; microalgae cultivation, waste valorization