NUTRI•KNOW

6 Booklets on Nutrient Management

D3.1

June 2024

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Technical References

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Deliverable summary

Deliverable 3.1 (D3.1) *6 Booklets on Nutrient Management* is part of the NUTRI-KNOW work package (WP) 3. The objectives of WP3 *Practice-oriented material creation* are to translate, format, and conceptualise the collected outcomes from relevant EIP-AGRI OGs, including developing outreach material that aims at making farmers, advisors, technology providers, and policy makers use the information actively in promoting changes in nutrient management processes. Specifically, Task3.1 has the objective of translating the content produced in the OGs from a technical language into a direct and easy understandable language to be easily understood by all types of end-users.

The core content of D3.1 consists of in total, six booklets (one per each step of the nutrient value chain) on nutrient management. The booklets have been created based on the content produced in the EIP-AGRI Operational Groups (OGs). As the objective dictates, the material is translated from a technical language into a direct, narrative, and straightforward language to promote easy uptake by end-users. The six booklets have been set up graphically to be appealing and with a common structure to be recognizable. Each booklet has links and QR codes leading to more information about the relevant OGs, to the NUTRI-KNOW project website, and to its social media profiles.

D3.1 is divided into 5 chapters: Introduction, Methodology, Results, Conclusions and Future Perspectives. A first introduction of the NUTRI-KNOW project, Work Package (WP) 3 and Task 3.1 objectives, then the methodological approach used to partially complete the task. The first results of the task are then showcased. Finally, conclusions have been made and future perspectives have been elaborated.

The six booklets cover the individual steps of the value chain of nutrient management, where the name of the booklet is aligned with the specific step. The topics (following the value chain of nutrient management) and the main responsible beneficiaries of the six booklets are:

1. **Livestock Farming** (CRPA)
2. **Storage Systems** (AU)
3. **Processing Technologies** (BE)
4. **Fertiliser Production** (TEAGASC)
5. **Transport** (UVIC-UCC)
6. **Application** (UGENT)

In this way, the booklets can be read individually or in sequence.

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1. Introduction

In complementing knowledge generation, EU-funded projects are becoming more and more important as instruments of advancing knowledge on agricultural practices, technologies, and products. Despite significant progress on development and knowledge generation, a significant gap exists between the generation of such knowledge and its practical implementation and adoption by end-users in the agri-food system. The lack of awareness on actual available solutions, accessibility problems, and resistance to change (including change of mind) are significant obstacles to knowledge uptake, preventing the potential and full benefits to be achieved by innovations originating from research, specifically EU projects.

The key backbone of the NUTRI-KNOW project is the EIP-AGRI Operational Groups (OGs), which are addressing the above mentioned gap by promoting collaboration among diverse stakeholders. The key to unlocking the full potential of innovative practices lies in developing effective knowledge transfer mechanisms and enhancing collaboration to align the generated knowledge with the practical needs of the agricultural sector.

The NUTRI-KNOW project actively contributes to bridging this gap by disseminating and expanding the outcomes of EIP-AGRI OGs beyond borders. This project focuses on collecting, translating, and sharing user-friendly knowledge to support the adoption of innovative practices. Notably, the NUTRI-KNOW project addresses urgent needs, challenges, and opportunities in the agri-food sector. It promotes trust and connections between stakeholders while intensifying cooperation and the implementation of innovative solutions. Specifically, NUTRI-KNOW focuses on nutrient management, addressing the various steps of the nutrient management value chain, including livestock farming, storage systems, fertiliser production, processing technologies, transport, and application. The overarching goal is to modernise the agri-food sector and promote nutrient management best practices among farmers, practitioners, and end-users.

Work Package (WP) 3 Practice-oriented material creation will translate, format, and conceptualise the collected outcomes from relevant EIP-AGRI OGs. It will also develop outreach materials that aim at making farmers, advisors, technology providers, and policy makers use the information actively in promoting changes in nutrient management processes that fulfil societal demands toward circularity with the aim of reducing climate impacts and overall sustainability. The specific objectives include: (i) develop a storytelling on the topic of nutrient management including the solutions developed by the OGs; (ii) translate, structure and homogenise collected information for regional use; and (iii) Create ready-to-use, useful, accessible and extractable material for end-users and stakeholders for educational and training purposes.

Task 3.1 within WP3 will adapt the practice-oriented knowledge collected in WP1 to the end-users needs analysed in WP2. The knowledge and experience of the engaged OGs will be treated and homogenised to present it as a whole in a storytelling way that enables response to the urgent needs, challenges and opportunities of practitioners in the field of nutrient management. This task will summarise and present the information and best practices in each step of the value chain obtained in the OGs with a focus on outcomes that are "near to be put into practice", but not sufficiently known yet by practitioners. The content produced in the OGs will be translated from a technical language into a direct, narrative, and easy understandable language to be easily understood by all types of end-users. In total, six booklets (one per each step of the value chain, Fig 1) are created and they will be available in the following languages: English, Spanish, Catalan, Flemish, French, Italian and Danish.

Deliverable 3.1 is divided into 4 chapters: Introduction, Methodology, Results, Conclusions and future perspectives. A first introduction of the NUTRI-KNOW project, Work Package (WP) 3 and Task 3.1 objectives, followed by the methodological approach. Then a results section, where the booklets are presented. Finally, a conclusion section and future perspectives are outlined.

2. Methodology

The methodological approach of this report aims to describe the method of translating the core the content of specific selected Operational Groups (OGs) into a narrative and easily understandable by end-users and present this in the form of specific booklets. In this context, a **booklet** was defined as a small, thin book or pamphlet, consisting of a limited number of pages. In this case, the booklet is designed for informational and promotional purposes. They vary in size, but they are designed to be compact and easy to handle.

The six booklets cover the individual steps of the nutrient value chain, as shown in Figure 1, where the name of the booklet is aligned with the specific step.

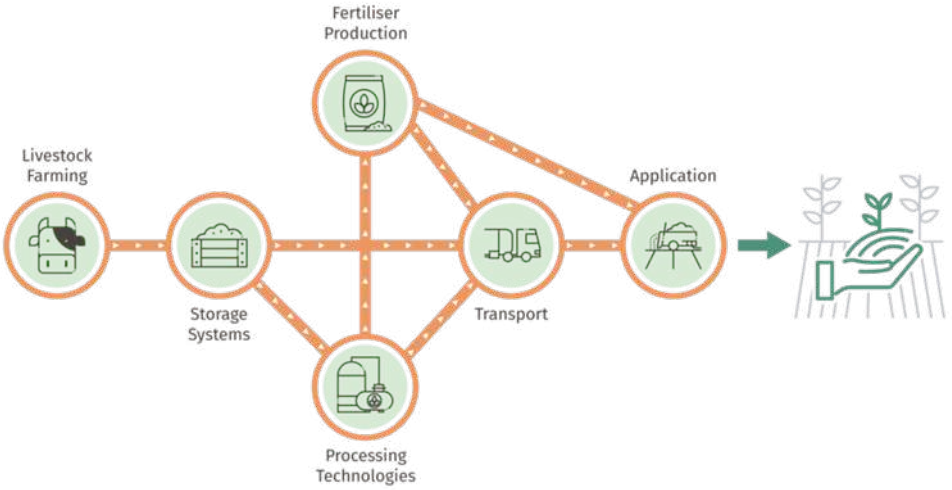


Figure 1 – The value chain of nutrient management.

Individual partners were allocated the responsibility of the individual booklets, specifically related to relevant Operational Groups (OGs) for that partner – see below. The topics (following the value chain of nutrient management) and the main responsible beneficiaries of the six booklets are:

1. **Livestock Farming** (CRPA)
2. **Storage Systems** (AU)
3. **Processing Technologies** BE)
4. **Fertiliser Production** (TEAGASC)
5. **Transport** (UVIC-UCC)
6. **Application** (UGENT)

Next step involved deliberations among the WP3 partners about the common structure and content of the booklets. The resulting general outline included contextualization in terms of general nutrient management in agriculture, specifically in relation to the nutrient value chain. For the individual value chain steps, it is explained how the information are derived from NUTRI-KNOW's Operational Groups (OGs) and what specific methods and technologies are described in the individual booklet. The targeted methods and technologies are described in terms of function, usage, and recommended best practices. Additionally, the benefits and current status of these technologies and methods are outlined tools supporting the decision-making process of farmers and other end-users. The graphic design of the booklets, developed by our ESCI partner, has been deemed highly significant.

3. Results

This section presents the six booklets produced as part of Task 3.1.

Table 1 below summarizes the six booklets, detailing their titles, specific nutrient value chain steps, associated NUTRI-KNOW Operational Groups (OGs), and the responsible partners.

Table 1. Details of the six booklets

Booklet no.	Title and Value Chain Step	Related OGs	Partner
1	Livestock Farming	OG3, OG6, OG10	CRPA
2	Storage Systems	OG2, OG4	AU
3	Processing Technologies	OG1, OG4, OG5, OG7, OG6, OG8, OG10, OG9	BE
4	Fertiliser Production	OG7, OG6, OG4, OG9, OG10	TEAGASC
5	Transport	OG1, OG2	UVIC-UCC
6	Application	OG4, OG7, OG1, OG2, OG5, OG12, OG11	UGENT

The six booklets refer to step by step chain identified by the NUTRI-KNOW project, and the title of the booklet align directly with the nutrient value chain step. Each booklet summaries key recommendations, benefits, and future perspectives. In the tables below, the summary of each booklet is listed. It has been agreed with the PO that the Version 1 of D3.1 contain the booklets in English and followed later by translations into the languages listed in Section 1.

Table 2. Booklet 1: Livestock Farming

Booklet 1	
Title in English	**Livestock Farming**
Summary in English	**Tools That Help Farmers to Apply Good Practices to Reduce Environmental Impact:** • Tool to evaluate the environmental benefits of reducing emissions by applying different Best Available Techniques (BATs) to the breeding phase and supporting farmers in understanding which ones best apply to their reality. **Technologies and Recommendations to Improve Nutrient Efficiency in Livestock Farming:** • BAT technologies that reduce ammonia in pig stables converting it to ammonium sulphate fertiliser and increasing animal welfare. • Innovative biorefinery approach converts freshly harvested grass into an optimised protein fibre feed for cattle and a non-GMO protein liquid concentrate feed for pigs, improving

	nutrient efficiency and reducing the carbon footprint of livestock. • Developing and putting into practice an effective model to restore, protect and enhance water quality for future catchments to foster positive relations between farmers and households. **Social and Environmental Benefits Thanks to More Sustainable Livestock Farming:** • Efficient and affordable innovations to reduce ammonia and GHG emissions from livestock housing and, at the same time, to improve animal welfare and workers health • External European feed source, like soya, is typically imported from South America. Innovations will be promoted to enhance new local feed sources for reducing transport costs, social and environmental impact and increasing the European circular economy. • The Duncannon Blue Flag Farming & Communities Scheme has been effectively put into practice and the recommendations and methodology set-up can help to resolve similar issues in other river basins.

Table 3. Booklet 2: Storage Systems

Booklet 2	
Title in English	**Storage Systems**
Summary in English	**Tools that Help Farmers Select Storage System:** • Select the optimal storage systems to minimise pollution (ammonia and greenhouse gas emissions) and enable the application of manure on land with high and predictable plant nutrient uptake, thereby reducing the risk of pollution from leachates.Use additives efficiently to improve composting processes and provide estimates of the final quality of composting after substrate addition. • Evaluate the biogas production potential when storing slurry in flexible cover ponds. **Technologies and Recommendations to Reduce Emissions from Manure:** • Reduce the emission of gases by adding acids to the slurry, covering the slurry with straw, or store it in impermeable bags • Optimise reactor technology to efficiently produce crystal struvite, which consists of ammonium, phosphorous and magnesium. Struvite is an efficient nitrogen and phosphorous fertiliser. The production of struvite will contribute to reduced ammonia emissions. **Future Benefits:** • Introduction of novel products for liquid or solid manure may reduce ammonia and greenhouse gas emissions.

	• Tests show that cleaning slurry channels and pits reduces methane emissions from livestock barns and potentially reduces emissions from manure storage facilities.

Table 4. Booklet 3: Processing Technologies

Booklet 3	
Title in English	**Processing Technologies**
Summary in English	**Tools to Optimise Manure Processing:** • Adopting processing technologies for manure or digestate management to recover nutrients allows farmers to increase the value of their agricultural waste. • Extraction of nutrients from manure or digestate to create fertilisers (e.g. struvite, ammonium salts). • Reduction of agricultural emissions (e.g. ammonia, methane) in combination with energy production. • Sustainable grass use and algae production. **Technologies for Manure Processing:** • Separation of manure to obtain a semi-liquid phase and liquid phase can minimise transport costs and optimise nutrient application to the soil. • Digestate treatment to recover nitrogen and phosphorus as struvite. • Digestate microfiltration to make it suitable for injection in fertigation with drip lines instead of mineral fertilisers. • Nitrogen recovery from ammonia emissions into ammonium sulphate fertiliser, which can replace synthetic fertilisers and reduce GHG emissions. • On-farm digestion of manure to produce biogas for electricity and heat and digestate as organic fertiliser, thereby reducing GHG emissions linked to manure storage and fossil energy use. • Valorisation of grass to produce press cake, prebiotics and protein rich monogastric feed, increasing the value of low-quality roadside grass. • Valorisation of low-value grass by biorefineries and separation technologies to produce nutrient-rich grass juice for algae cultivation as alternative animal feed, improving the sustainability of algae production and increasing farmers' income. **Future Benefits:** • Decreasing dependencies on mineral fertilisers and fossil energy, reducing import costs, transport costs and electricity costs, therefore, contributing to the circularity of the bioeconomy.

	• Decreasing agricultural emissions by implementing (nutrient) processing technologies (e.g. pocket digestion, stripping-scrubbing) and sustainable manure management. • Further development and implementation of local (nutrient) processing technologies at farm scale (e.g. biorefineries). • Bringing farmers together in knowledge cooperatives, providing guidance and creating hands-on information to positively impact the awareness, implementation and improvement of nutrient management technologies.

Table 5. Booklet 4: Fertiliser Production

Booklet 4	
Title in English	**Fertiliser Production**
Summary in English	**Tools to Help Farmers:** • Valorise grass from field margins or other low-quality grass that cannot be used as feed and is often deemed as waste. • Capture of N from animal housing ammonia emissions as ammonium salts which is a by-product of air treatment. • Assess struvite production using manure or digestate as the P feedstock. **Technologies and Recommendations:** • Reducing ammonia and GHG emissions by converting ammonia emissions into ammonium sulphate fertiliser and limiting emissions by producing slow-release renewable recovered fertiliser as struvite, which has the potential to replace conventional mineral N and P fertilisers. • Production of nutrient-rich grass juice by biorefineries and separation technologies has the potential to replace mineral fertilisers and slurry, supporting the sustainable growth of algae and grass production. **Future Benefits:** • Locally produced fertilisers ensure that the nutrients remain on the farm, harnessing a zero-waste approach. • Potential to increase farmers' income by converting waste by-products into high-value nutrient-rich fertilisers. • Encourage the balancing of the nutrients from manure between regions characterised by a surplus or a deficit. • Decreasing dependencies on mineral fertilisers, reducing import and transport costs, therefore, contributing to the circularity of the bioeconomy.

Table 6. Booklet 5: Transport

Booklet 5	
Title in English	**Transport**

Summary in English	**Products to Provide a Cost-Effective Advantage for Transportation:** • High-quality, tailor-made pelletised fertilisers offer economic transport benefits and practical advantages for farmers using existing chemical fertilisation machinery. **Tools to Optimise Manure Transport Logistics:** • The use of specialised software can significantly streamline fertiliser transport logistics by optimising routes, accurately registering applications and ensuring traceability of fertiliser applications on the plot. **Technologies to Optimise Nutrient Transport From an Economic and Environmental Perspective:** • The innovative slurry concentrator produces two liquid fractions with fertiliser potential: a concentrated fraction to be transported and applied to distant fields where nutrients are not available; and a diluted fraction to be applied in nearby fields. The differentiated management of the two phases is designed to minimise transport costs and optimise the application of nutrients to the soil from the agronomic and environmental perspectives. • Understanding the spatial patterns of surplus manure in specific regions and their economic implications for logistics is crucial for identifying opportunities to reduce transport distances. **Future Benefits:** • Pelleted biofertilisers concentrate nutrients, reducing transport costs, while slow-release properties minimise leaching and increase plant uptake efficiency. • Specialised software optimises routes, reducing fuel consumption, and ensures precise nutrient application, enhancing efficiency and reducing environmental impact. • The Slurry Concentrator minimises the total number of journeys required to transport manure, resulting in significant reductions in fuel consumption and greenhouse gas emissions. • This makes it possible to generate the fertilisation plans more quickly and accurately.

Table 7. Booklet 6: Application

Booklet 6	
Tittle in English	**Application**
Summary in English	**Technologies to Develop Novel Products With Higher Nutrient Efficiency and Lower Environmental Impact:** • Struvite precipitation from digestate significantly reduces ammonia and greenhouse gas emissions after the fraction has been treated prior to application.

- Ammonium salts recovery from stripping and scrubbing of manure or digestate show high potential as chemical fertiliser substitutes.

Tools to Optimise the Fertilisation Plan and Reduce Cost:

- The innovative slurry concentrator produces two liquid fractions for use as fertilisers, reducing operational costs and enabling precision fertilisation for improved soil health and productivity.

Recommendations for Integrated Soil, Crop, Fertiliser and Water Managements:

- Innovative agrosystems integrating minimal tillage, fertigation with derivatives from the liquid fraction of digestate, and injection through drip lines in sub-irrigation.
- A simple, cost-effective management plan for water protection improvement, equipped with the Pollution Potential Zone (PPZ) maps.
- Short-term (2-6 months) incorporation of green manure to support the development of summer and winter cash crops in organic vegetable production.

Outlook:

- Struvite and ammonium salts recovered from manure as alternative fertilisers can reduce the fertiliser cost and minimise the environmental impact.
- On-site tools for nutrient monitoring and implementing support precision fertilisation strategies can reduce costs and time, increase nutrient use efficiency and productivity.
- Fertiliser application involves the integration of soil, crop, fertiliser and water management practices.

3.1. Booklets

This section presents each of the 6 booklets produced by the NUTRI-KNOW project.

NUTRI•KNOW

Livestock Farming

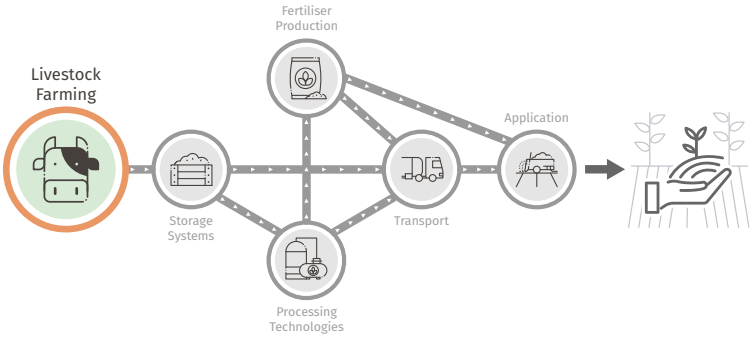
Technologies, tools and recommended practices from NUTRI-KNOW's EIP-AGRI Operational Groups

Introduction

Never before have the media, the general public, and policymakers discussed the future of livestock farming and its environmental and social sustainability as much as they do now. The European livestock sector, aware of its role, is seeking knowledge and innovation from research to face future challenges.

The main outcomes from the EIP-AGRI Operational Groups involved in the NUTRI-KNOW project support a shift towards more sustainable systems. These systems focus on issues concerning the environment, health, and animal welfare. Key strategies to reduce the environmental impact of livestock farming include improving production efficiency, reducing the use of external inputs like nutrients and energy, and replacing industrial fertilisers with recycled ones.

Moreover, livestock farming is crucial for managing nutrients throughout the value chain. This includes improving the efficiency of nitrogen and phosphorus use in animal feed, finding new feed sources, and reducing nutrient losses from livestock housing.



Livestock Farming

This booklet offers an overview of the decision support tools, technologies, and recommended practices that are the outcomes of key EIP-AGRI Operational Groups involved in the NUTRI-KNOW project and related to the livestock farming step of the nutrient value chain.

By applying the results from these regional groups across Europe, the livestock sector can adopt good practices to reduce ammonia and greenhouse gas emissions during the breeding phase, improve breeding conditions, recover nutrients and reduce losses to the environment (such as nitrogen emissions and nitrogen and phosphorus leaching), and utilise new feed sources to lower the carbon footprint of livestock farming. For more information see the links to the home pages of the Operational Groups presented below.

Bio-Based Products and **Organic Farming**

The creation of bio-based products can help to encourage more closed-loop supply chains through the recycling of organic manures and other waste materials. They can also stimulate innovative practice uptake and new business opportunities in the organic sector. Sustainable biogas production, for instance, has the potential to reduce methane emissions from the storage of manure, generate renewable energy, and support crop yields through digestate application. Processing technologies and materials used to produce bio-based products must be in line with organic principles and standards. Bio-based products, for example, derived from animal waste obtained from permanently housed operations are not permitted in organic farming owning to potential contamination risk. Furthermore, some innovations reported in this booklet may not be applicable or economically sustainable in extensive or organic farming systems.

A Tool to **Assess** and **Support Farmers** in **BATs Application**

The main objective of the Operational Group FERTICOOP was to develop innovative tools to help the farmers to understand, evaluate and apply the best technologies available (BAT) to reduce environmental impacts of livestock farm, manure management and agricultural fertilisation. The focus was on reducing phosphorus, improving the agricultural management of slurry, to enhance the valorisation and the quality of the extensive crops produced.

Pig livestock cooperative involved in FERTICOOP

One of the goals of the FERTICOOP tool is the assessment of the emissions in pig and poultry farms and then promote strategies to minimise ammonia and GHG emissions through the application of good techniques at livestock farm level.

Benefits

- Evaluation of different BATs depending on the characteristics of the different fields and training farmers on them.
- Provide knowledge and advice to farmers on the best available techniques to reduce ammonia and GHG emissions from livestock farm.
- Reduction of GHG and ammonia emissions by optimizing fertilisation and adopting measures in the management of livestock droppings on the farm.
- Utilise livestock manure effectively by understanding its precise fertiliser content.
- Adapt the technological and digital tools available to the needs of the technical advisors in fertilisation and environment technicians of the cooperatives.
- Advice and give support to the cooperative's technicians.

Pig livestock cooperative involved in FERTICOOP

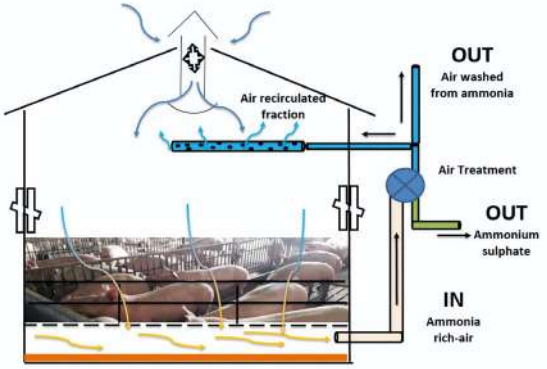
Current Status

The Operational Group finished and innovation is near to practice. The analysed tools and methodologies are implemented on the cooperatives' farms of the Operational Group and continued to be applied and developed.

More information can be accessed at the home page of the Operational Group **FERTICOOP-GO**

An **Air Washing** System That **Removes Ammonia** From **Pig Stables**

GAS LOOP has developed and tested for one year (in a pig house for Parma ham PDO heavy pigs) an air washing system designed to tackle the issue of ammonia emissions in pig farming. By drawing air from beneath the slatted floor of pig stables and treating it with sulfuric acid, the ammonia emissions are captured and prevented from spreading into the room. The treatment is based on the chemical absorption of ammonia by counter-current washing with an acid reagent sprayed into a tower scrubbing. As a result, the recovered ammonia is transformed into ammonium sulphate fertiliser.



Ammonia Washing Machine layout

Sant'Anna pig farm, partners of the Gas Loop operational and experimental site

Benefits

- Treatment reduces ammonia emissions from pig livestock for 1.94 kg NH_3 per animal place per year.
- Results in improvements in the indoor air quality, reducing the ammonia concentration inside the treated room by 62% compared to the control room.
- Positive effects of the treatment on the productivity of pigs by increased animal welfare.
- Better health of the pig's lung at the slaughterhouse
- Ammonium sulphate solution recovered by capturing ammonia, reduces nitrogen inputs for the farming crops and consequently the GHG emissions generated by their industrial production: 66 kg CO_2 equivalents saved per year per t of pig live weight housed.
- More sustainable pig livestock, less odour emissions.

Current Status

Gas Loop has implemented the system up to a technological maturity level equal to Technology readiness level (TRL) 8. The device is installed by all the pig livestock partners in the Operational Group.

More information can be accessed at the home page of the Operational Group **GAS LOOP**

New Feed Source for **Cattle** and **Pigs** From **Grass**

Biorefinery Glas focused on the demonstration of a small-scale grass biorefinery with farmers in Southwest Ireland to diversify farmer produce while resolving significant challenges in traditional agriculture. The biorefinery converts freshly harvested grass from low-quality or surplus sources into novel and innovative animal feed streams. A solid fraction press-cake fibre feed for cattle produced from grass and a liquid green fraction protein concentrate can serve as pig feed.

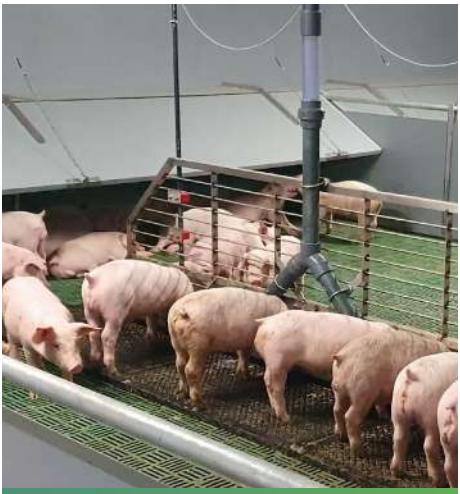
Grass biorefinery, South West Ireland

Fresh grass is loaded into the biorefinery, crushed and pressed to separate up to 50% of the protein into a liquid juice fraction. The remaining 50% is pressed into a high solid fibre press cake that can be fed directly to cows. The solid grass press-cake can be baled into silage for cattle to increase the shelf life of the feed. The liquid protein concentrate can be dried and used as an import replacement feed for monogastrics.

Grass biorefinery feed products

Benefits

- Press cake silage can partially replace grass silage in dairy cows' diet. Milk yield and milk quality were not affected by replacing grass silage with press cake silage.
- Reduction in invitro methane production was observed by replacing grass silage with press cake silage compared to grass silage only.
- Nitrogen excreted in the milk increased, but N and P excretion decreased in press cake feed compared to grass silage. Nitrogen use efficiency (NUE) increased in press cake compared to grass silage.
- Dry grass protein concentrate performed better than the control diet in terms of daily intake and weight gain in weaner pigs, replacing soybean meal and barley.



Supplementing pigs' diets with protein concentrate dried grass juice, improves weaner pig feed intake and weight gain

- The dried and pelletised protein-rich liquid grass juice can be used to supplement pigs' diets, resulting in improved feed intake and weight gain while reducing reliance on imported soya of up to 50%.
- Dry grass protein concentrate was quite comparable to soybean meal and other protein sources from the compositional analysis.

Current Status

The project demonstrated the feasibility of this innovative business model for farm diversification in the circular economy. This innovation is at a pilot stage. Individual or groups of farmers or contractors would have capacity to take up the technology.

More information can be accessed at the home page of the Operational Group **Biorefinery Glas**

Livestock Farming **Good Practices** to **Enhance Water Quality**

The main objective of Duncannon Blue Flag and Communities Scheme is to decrease bacterial contamination originating from agriculture in the Duncannon catchment that discharges into Duncannon Beach. The scheme is to reduce nutrient discharges from livestock, agricultural and domestic sources. This should contribute to the recovery and long-term retention of the Blue Flag status at Duncannon beach. The scheme focuses on addressing rural point sources of faecal (and associated phosphorus) contamination. However, it does this within a framework of integrated catchment management, whereby a range of pollution sources and types are considered in unison, for multiple benefits in an integrated, holistic manner. A total of 35 farmers participated in this project, encompassing four dairy, eight tillage, and 23 drystock farmers, covering an extensive area spanning over 975 hectares. Rewards based Pollution Potential Zone (PPZ) maps were utilised to evaluate farm conditions and management practices. Farmers were empowered to select and implement measures tailored to their livestock farms. Several water protection improvement measures were successfully implemented.

Water troughs moved 20m from waterways to reduce leaching

Benefits

- Positive relations between the farmers and householders in the catchment area and the local natural landscape, particularly the water environment were fostered
- The development of reward-based farm-specific PPZ maps which can be used as education and engagement tools to show farmers in a simple visual way, the water-quality risks specific to their farms.
- Demonstration and training on a range of innovative and cost-effective farm management practices for water-quality protection.
- A template for a water-quality-focused, results-based reward scheme which could be used to improve water quality in particularly sensitive catchments.
- A dedicated sustainability manager led the farmers to evaluate and choose which measures to implement or apply to achieve results, also from a cost-benefit point of view.
- Fencing off 15.5 km of watercourses to preserve water from faecal contamination.
- Moving water troughs 20 m from waterways to have a filter area to reduce nutrient leaching into waterways.

Water protection and improvement measures were implemented on participating farms in the Duncannon region

Current Status

This cooperation project provides pilot-based evidence that the methodologies developed for results-based land payments in protecting water courses and biodiversity are transferable and can protect other resources such as water quality and rural tourism assets.

More information can be accessed at the home page of the Operational Group **Duncannon Blue Flag Farming & Communities Scheme**

Summary

Tools That **Help Farmers** to **Apply Good Practices** to **Reduce Environmental Impact**

- Tool to evaluate the environmental benefits of reducing emissions by applying different Best Available Techniques (BATs) to the breeding phase and supporting farmers in understanding which ones best apply to their reality.

Technologies and Recommendations to **Improve Nutrient Efficiency** in **Livestock Farming**

- BAT technologies that reduce ammonia in pig stables converting it to ammonium sulphate fertiliser and increasing animal welfare.
- Innovative biorefinery approach converts freshly harvested grass into an optimised protein fibre feed for cattle and a non-GMO protein liquid concentrate feed for pigs, improving nutrient efficiency and reducing the carbon footprint of livestock.
- Developing and putting into practice an effective model to restore, protect and enhance water quality for future catchments to foster positive relations between farmers and households.

Social and **Environmental Benefits** Thanks to More **Sustainable Livestock Farming**

- Efficient and affordable innovations to reduce ammonia and GHG emissions from livestock housing and, at the same time, to improve animal welfare and workers health
- External European feed source, like soya, is typically imported from South America. Innovations will be promoted to enhance new local feed sources for reducing transport costs, social and environmental impact and increasing the European circular economy.
- The Duncannon Blue Flag Farming & Communities Scheme has been effectively put into practice and the recommendations and methodology set-up can help to resolve similar issues in other river basins.

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NUTRI•KNOW

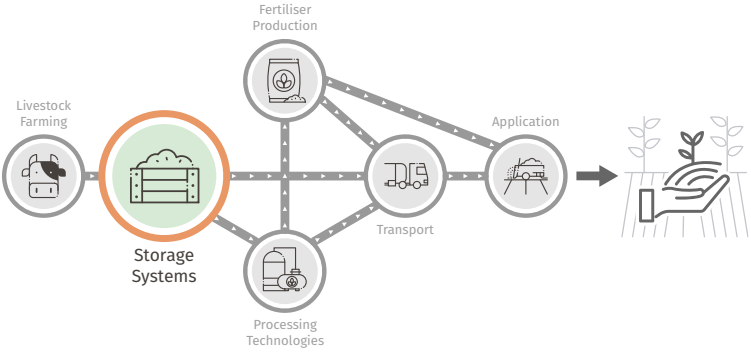
Storage Systems

Technologies, tools and recommended practices from NUTRI-KNOW's EIP-AGRI Operational Groups

Introduction

It is essential to have sufficient capacity for storing manure in order to facilitate its application on land at optimal times. Manure should be applied when crops require nutrients, such that the risk of loss to the environment is minimised. Storing manure is also an integral component of processing and treating animal slurry, enhancing the efficient utilisation of plant nutrients contained within the manure.

This booklet provides an overview of decision support tools, technologies, and recommended practices that are the outcomes of key Operational Groups dedicated to improving manure storage and management. These groups and associated projects have concentrated on refining manure storage processes and providing knowledge to farmers regarding management and treatments that mitigate environmental pollution, particularly ammonia and greenhouse gas emissions. They also contribute to the efficient and predictable use of nutrients in manure.



Manure Storage

This booklet focuses on tools, recommendations, and Best Available Technologies (BAT) for manure storage. These tools aim at promoting the most environmentally friendly management of manure as a fertiliser to ensure sustainable and secure food production. The innovations encompass processes, technologies, or facilities designed for the storage of animal manure from livestock farming. This allows for its use at a later stage in the manure management chain, either untreated or following valorisation through biogas or fertiliser production. For more information see the links to the home pages of the Operational Groups presented below.

Organic Farming and **Recycled Manures**

processing can play an important role in supporting soil fertility on organic farms. As well as helping to maintain a sustainable nutrient status, manure recycling seeks to build soil organic matter and biological activity. Materials and processing technologies used in handling and processing must be in line with organic principles and standards. Materials, for example, derived from animal waste obtained from permanently housed operations are not permitted in organic farming owing to potential contamination risk. Under EU organic legislation application of organic manures and other waste materials must be authorized for use in organic production.

Slurry Storage – Decision Making Tools

The Operational Group 'Manure Management Tools' has developed decision support systems that provide farmers with key knowledge to install the best storage systems for manure management. The systems include the use of tools (such as conductivity meters or computer applications) that provide information to the decision making of best livestock manure management. The recommendations are based on the fact that storage is an integrated part of the management of manure. Safe storage of animal manure is necessary in order to make it possible to spread the manure in optimal time, when the crops can take up the required nutrients at a reduced risk of environmental impacts.

The National Emission Ceiling Directive 2016/2284/EU sets national limits for the emissions of ammonia from countries in the European Union. Therefore, technologies that reduce emissions during slurry storage can be an important consideration in supporting farmers' decision-making. One such method is acidification which can potentially reduce emissions of ammonia and greenhouse gases, while another involves the addition of straw to create a surface barrier that reduces ammonia emission. Both methods are considered relatively inexpensive ways to mitigate emissions. Additionally, storing liquid manure in large flexible closed bags is a technology to produce biogas and reduce emissions.

Benefits

- The use of conductivity meters during application for the in-situ determination of the NPK content allows the fertilisation to be optimised.
- A computer application has been tested to generate the livestock management book as well as fertilisation plans more quickly and accurately by using devices installed in transport tanks. The

Biogas production – stored slurry covered and methane collected

computer application also generates real-time monitoring, control of the vehicle's location, routes, timetables, number of operations per loading and unloading point, total kilometres travelled, etc.

- Application of emission reduction strategies during slurry storage, such as acidification and the addition of plant material (straw), is relatively economical
- These methods, as well as the use of flexible bags, allow for the reduction of ammonia and greenhouse gas emissions,
- Improvements to be implemented in the management of livestock manure, mainly slurry, have been identified. This includes the use of hose equipment to apply liquid manure; the use of conductivity meters to estimate the nutrient content of slurry; the application of liquid manure in crop cover; and the adequacy of the dose of nutrients to be applied to crops.

Current Status

The development project is finalised, and the decision support system is being used by involved farmers for consultancy purposes.

More information can be accessed at the home page of the Operational Group **Manure Management Tools**

Biogas Production - **Flexible Ponds**

The Manure Management Tools Operational Group has developed a decision support tool that assesses the potential for biogas production when storing slurry in flexible ponds. This tool assesses the transformation of organic matter in the slurry, the production of methane, the production of heat and power, that substitutes energy production from fossil fuels and reduces greenhouse gas emissions. The novelty of this tool lies in its inclusion of the effects of organic nitrogen being transformed into ammonium and the potential increase in ammonia emissions due to the rise in pH in the anaerobically digested slurry (digestate). Furthermore, biogas plants are constructed on the farm, so the farmer avoids manure transport, which reduces costs. Methane emissions from stored digestate will be lower due to a reduced organic matter content if the digestate is cooled down to ambient temperatures with heat exchangers. The project provides recommendations about the efficiencies of technologies that reduce emissions. This includes a calculation of total emissions from the fractions produced when separating the slurry into a liquid fraction with little dry matter and a solid high dry matter fraction.

Training of farmers about analysed BATs

The project helps to assess ammonia emissions from solid manure being composted. It includes the effect of addition of a range of substrates to improve composting and provides a calculation of the final quality of compost after having added substrates.

Benefits

- Valorisation of slurry based on its fertilising capacity, making it a competitive and attractive product for agricultural use.
- Savings in mineral fertilisers due to the calculations of the nitrogen needs, the treatment systems, and the tasks of advice and optimisation of the contributions in cases of double harvest.
- Rationalisation of nitrogen inputs in crops with the consequent minimisation of nitrate losses due to leaching and precise applications to the soil.
- Minimisation of emissions and discomfort due to bad smells, have a consequent positive impact.

Current status:

The development project is finalised, and the decision support system is used by involved farmers, but is not available in the market.

More information can be accessed at the home page of the Operational Group **Manure Management Tools**

Digestate Less Emissive if Treated by **Struvite Process**

Digestate from biogas plants must be stored and applied to crops when there is a need for its excellent content of plant nutrients. However, the downside is the high emissions potential from the liquid digestate during the storage phase. Ammonia emissions are high because there is a significant amount of nitrogen in ammonia form in the digestate, and greenhouse gases (methane) are emitted due to the high organic matter content, even if it is less than in untreated slurry. The goal of the Struvite Operational Group was to reduce the nitrogen and phosphorus content in the digestate by producing struvite, a fertiliser product consisting of ammonium, phosphorus, and magnesium in a stable crystalline form.

Recovering nutrients from digestate into a stable, small-volume product (precipitated) resulted in a clarified treated fraction characterised by reduced nitrogen, phosphorus, and organic matter content compared to the untreated digestate.

Digestate treated and stored

Emissions monitoring activity

Tests proved that struvite treatment with the prototype was effective in reducing ammonia and greenhouse gas emissions, particularly methane, from stored treated digestate compared to emissions from stored untreated digestate.

Benefits

- Struvite produced contributes to recycling phosphorous and nitrogen.
- Facilitates the relocation of nutrient surplus from high livestock areas to areas in need of mineral fertiliser.
- The reduced ammonia nitrogen content in the treated digestate reduced ammonia emissions by 42% from the storage.
- The limited organic matter content in the treated digestate resulted in an 86% reduction in methane emissions from the digestate liquid storage phase.
- Tests at real farm scale were conducted and technology implemented to ensure the accurate dose to make the process more efficient.

Current Status

The project has ended - The prototype for the crystallisation of struvite was installed at the Colombaro farm for the treatment of pig digestates.

More information can be accessed at the home page of the Operational Group **STRUVITE**

Summary

Tools that **Help** Farmers **Select Storage System**

- Select the optimal storage systems to minimise pollution (ammonia and greenhouse gas emissions) and enable the application of manure on land with high and predictable plant nutrient uptake, thereby reducing the risk of pollution from leachates.
- Use additives efficiently to improve composting processes and provide estimates of the final quality of composting after substrate addition.
- Evaluate the biogas production potential when storing slurry in flexible cover ponds.

Technologies and Recommendations to **Reduce Emissions from Manure**

- Reduce the emission of gases by adding acids to the slurry, covering the slurry with straw, or store it in impermeable bags.
- Optimise reactor technology to efficiently produce crystal struvite, which consists of ammonium, phosphorous and magnesium. Struvite is an efficient nitrogen and phosphorous fertiliser. The production of struvite will contribute to reduced ammonia emissions.

Future Benefits

- Introduction of novel products for liquid or solid manure may reduce ammonia and greenhouse gas emissions.
- Tests show that cleaning slurry channels and pits reduces methane emissions from livestock barns and potentially reduces emissions from manure storage facilities.

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NUTRI•KNOW

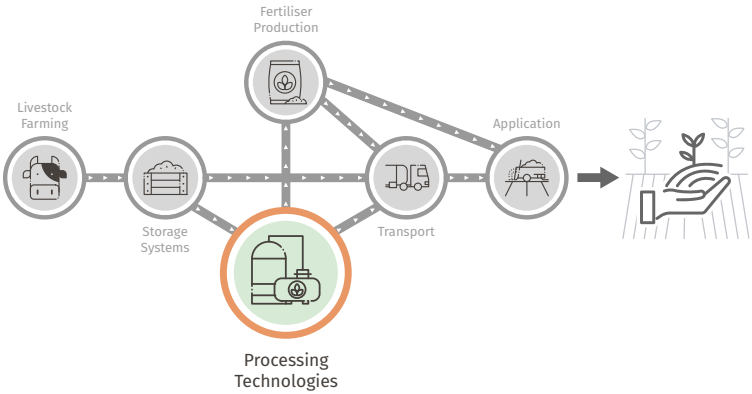
Processing Technologies

Technologies, tools and recommended practices from NUTRI-KNOW's EIP-AGRI Operational Groups

Introduction

The restrictions on nutrient application on the fields combined with the presence of intensive livestock, nutrient scarcity (e.g. phosphorus) and volatile prices for fossil-based mineral fertilisers drive farmers to invest in (nutrient) processing technologies. Processing technologies mainly refer to technologies used to process agricultural products to a better quality, or to treat agricultural waste for fertiliser production, energy generation or to mitigate their environmental impact. Examples of such technologies include anaerobic digestion, composting, solid-liquid separation, thermal drying, incineration, nitrification-denitrification etc.

The booklet gives an overview of decision support tools, technologies and recommended practices that are the outcomes of key EIP-AGRI Operational Groups. These groups and associated projects have focused on improving processing technologies to recover nutrients and provide knowledge about innovations and the advantages and challenges of adopting them.



Processing Technologies

This booklet highlights innovations and improvements in technologies for agricultural waste processing. The technologies presented here support the management of livestock manure as well as the circular economy on farms. For more information see the links to the home pages of the Operational Groups presented below.

Bio-Based Products and **Organic Farming**

The creation of bio-based products can help to encourage more closed-loop supply chains through the recycling of organic manures and other waste materials. They can also stimulate innovative practice uptake and new business opportunities in the organic sector. Sustainable biogas production, for instance, has the potential to reduce methane emissions from the storage of manure, generate renewable energy, and support crop yields through digestate application. Processing technologies and materials used to produce bio-based products must be in line with organic principles and standards. Bio-based products, for example, derived from animal waste obtained from permanently housed operations are not permitted in organic farming owing to potential contamination risk.

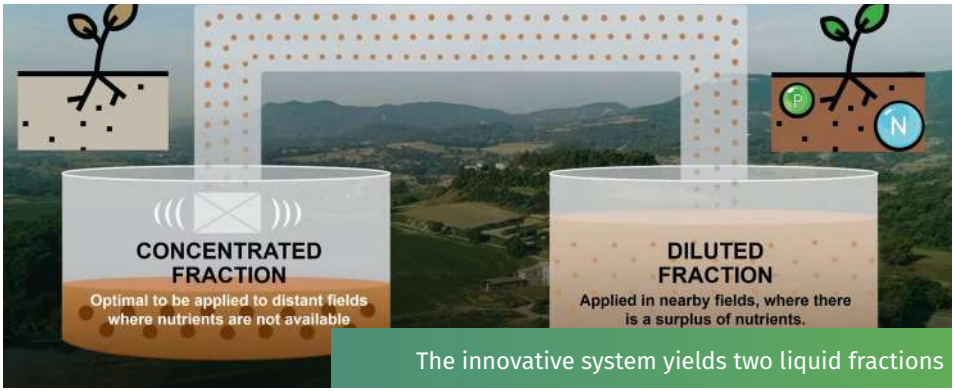
Livestock **Manure Management**

Livestock manure management poses environmental and economic challenges for farmers, especially in high-density livestock areas. The Slurry Concentrator addresses this by separating manure into a nutrient-rich semi-liquid phase and a low-nutrient liquid phase. It concentrates 85-95% of solids, 45-55% of nitrogen, and 85-95% of phosphorus, reducing total volume by 20-30%. The nutrient-rich semi-liquid fraction is ideal for long-distance transport, cutting costs and enabling nutrient export to non-vulnerable areas, while the liquid fraction, with higher volume and lower nutrients, is suitable for nearby fields. This process is cost-effective, minimises emissions, and uses minimal energy.

How it works: The slurry concentrator technology is installed in a slurry pond, with floats ensuring it is positioned on the surface of the pond. An additional pond is required near the slurry pond to collect the diluted slurry discharged from the concentrator. The remaining equipment is therefore located between these two ponds, with a connecting pipe directing the flow to the additional pond.

Benefits

- Efficiency and environmental impact: Its low maintenance requirements and energy efficient operation result in reduced resource consumption and lower energy costs over time. In addition, the concentrator's ability to efficiently separate and apply nutrients minimises waste and environmental impact, in line with sustainable farming practices and regulatory standards.
- Versatility and ease of use: Simple installation with minimal infrastructure needs. Requires two separate ponds, but its mobile design allows easy transport between farms, suiting both individual and cooperative use.



The innovative system yields two liquid fractions

- Cost savings and profitability: Shared use of equipment for both liquid fractions cuts investment and operating costs, leading to significant long-term savings.
- Enhanced Monitoring and Precision Fertilisation: Integrated monitoring systems provide real-time nutrient data, enabling precise fertilisation tailored to soil and crop needs, optimising soil health, minimising nutrient loss, and reducing emissions. The slurry concentrator's integrated monitoring systems enable farmers to track and manage nutrient application more effectively. Online devices provide real-time data on nutrient content in the liquid fraction, allowing for precise fertilisation practices tailored to specific soil and crop requirements. This capability optimises soil health and productivity and minimises nutrient losses and reduces emissions, promoting sustainable agricultural practices and environmental stewardship.

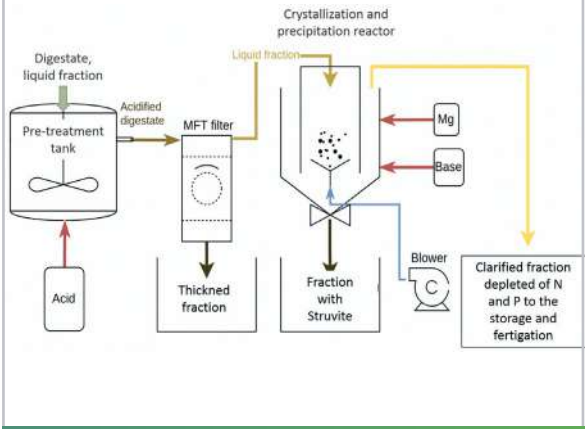
Current Status

Operation at pilot scale demonstrated the technological and economic viability of the proposal for use on farms and by the cooperative for efficient manure management. Additionally, the Cooperative Plana de Vic offers a free simulation to assess the viability of the slurry concentrator on your farm.

More information can be accessed at the home page of the Operational Group **Slurry Concentrator**

Digestate Treatment to **Produce Struvite**

The Operational Group STRUVITE designed and implemented a farm-scale prototype capable of recovering struvite (hydrated ammonium magnesium phosphate - $NH_4MgPO_4 \cdot 6H_2O$) from agricultural digestate. This way, a nutrient surplus from high livestock areas can be relocated to regions with a demand for chemical fertilisers. The digestate treatment consists of a solid-liquid separation by a screw press. The liquid fraction with a pH of 8.5 is then acidified up to a pH of 7.5 to mineralise the organic phosphorus. Microfiltration at 40 microns partially removes suspended solids and organic matter that hinders the struvite formation. In the end, in a crystallisation and precipitation reactor, magnesium and a base (to bring the pH to 9) are added to promote the formation of struvite crystals and efficient nitrogen and phosphorus recovery.



Treatment plant layout

Benefits

- The prototype struvite system effectively recovered phosphorus and nitrogen from the digestate, providing technical feasibility.
- The precipitate containing struvite can be exploited by fertiliser producers or it could be used as a “raw material” to produce phosphate fertilisers to replace finite phosphate minerals.
- Tests involving acidification, basification, and microfiltration reveal reduced nitrogen and phosphorus levels in the supernatant-treated fraction.
- By reducing P, N and dry matter content in livestock manure and digestate, ammonia, methane and nitrous oxide emissions were reduced from the liquid digestate storage and soil application phase.

Pilot treatment plant for struvite recovering from digestate

Current Status

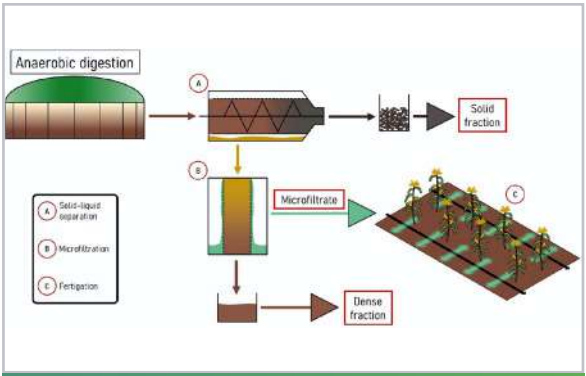
The struvite-containing precipitated fraction requires additional refinement by a fertiliser manufacturer to replace phosphate minerals with recovered P from digestate. The high concentration of solids and organic matter in the digestate, even if microfiltered, is still a critical issue in treatment efficiency.

More information can be accessed at the home page of the Operational Group **STRUVITE**

Digestate Microfiltration for Fertigation in Subsurface Drip Lines

Fertigation with digestate from biogas plants is a practice that significantly enhances nutrient use efficiency in growing crops. However, it is not yet widespread because of the chemical-physical characteristics of digestate. Even when clarified, it can cause nozzle clogging in a fertigation line.

SOS_AQUA tests and promotes an innovative integrated system to valorise the liquid fraction of digestate in fertigation, aiming to maximise nutrient reuse efficiency and reduce the need for mineral fertilisers. Initially, the digestate undergoes common solid-liquid separation, resulting in a solid fraction and a clarified liquid fraction. The clarified fraction is then microfiltered at 50 µm, thereby producing microfiltered digestate. This is then transferred to the field and mixed with water for fertigation on growing crops and injected into a subsurface drip irrigation system with drip lines buried at a depth of 25-30 cm.



SOS_AQUAE technologies layout

Benefits

- Microfiltered digestate in sub-fertigation drip lines is a technically and economically viable solution with low filtration costs.
- The microfiltration process avoids the clogging and fouling of the nozzles of the fertigation line. The drip lines have been specially developed for this purpose.
- The liquid fraction of the digestate (the most present and most problematic fraction to be valorised) is mixed with water in fertigation for efficient use of nutrients and to save mineral fertiliser and water.
- Odour, ammonia emissions and nitrate leaching are reduced.
- Chance of extending the agronomic period for digestate spreading.

Digestate Microfiltration unit

Fertigation with microfiltered digestate from slurry tank

Current Status

The microfiltered digestate that can be injected with fertigation drip-line technology is now on the market. Other applications also exist.

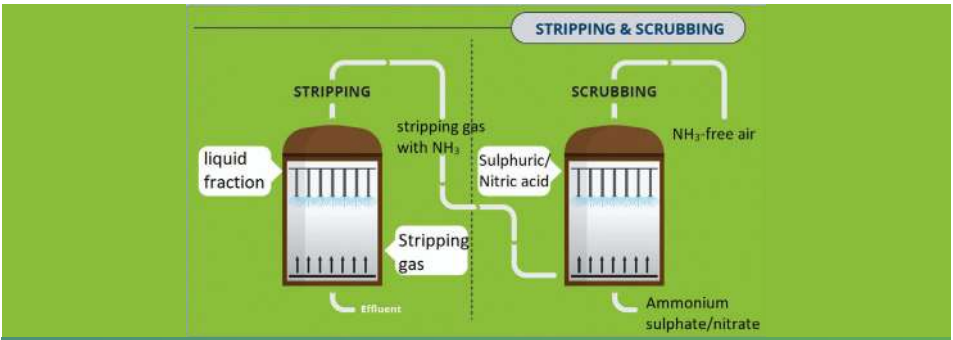
More information can be accessed at the home page of the Operational Group **SOS_AQUAE**

Recovery of **Ammonium Salts** From Manure

Stripping and scrubbing as a market-ready, innovative technology makes it possible to recover ammonium salts (ammonium nitrate and ammonium sulphate) from manure and use them as RENURE (REcovered Nitrogen from manuRE) products. The process consists of two steps:

- Stripping: Air is blown into the first compartment to remove the gaseous ammonia released from the thin fraction of manure or digestate due to increased pH and/or temperature.
- Scrubbing: The ammonia-rich air is sprayed with a strongly acidic solution, such as sulfuric acid or nitric acid, to form ammonium sulphate or nitrate, respectively.

Ammonium sulfate (left) and ammonium nitrate (right) recovered from manure stripping and scrubbing process



Theoretical scheme of stripping and scrubbing process for recovery of ammonium sulphate/nitrate from manure and digestate

The estimated price of the operational installation is approximately €100-150/m³. It requires an annual manure processing capacity of 20,000 tons to achieve the desired economic viability.

In 2020, the European Commission proposed the "RENURE" criteria to allow the safe use of recovered nitrogen from manure to replace chemical fertilisers. This way, a nutrient surplus from areas with high livestock density can be redistributed to regions with a demand for (chemical) fertilisers. Ammonium salts recovered through stripping and scrubbing process are recognised RENURE candidates that have a high potential to fully replace chemical fertilisers at field application.

Current Status

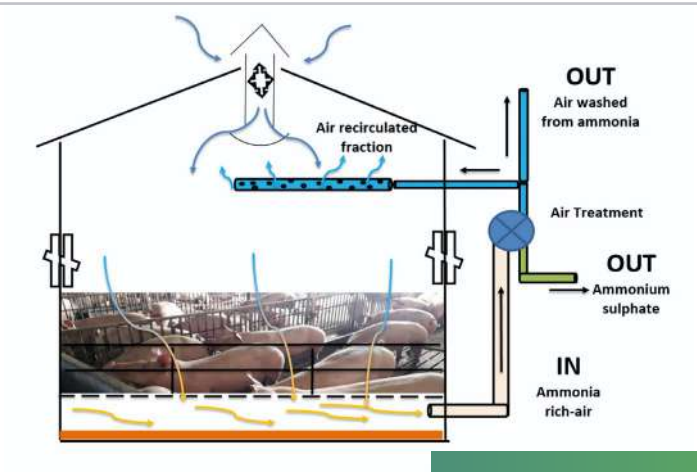
Several pioneers are currently producing these products in Flanders (Belgium). The European Commission is currently working on how to allow the use RENURE, including extensively treated digestate, above the limit of 170 kg N/ha/year for animal manure. The draft amendment under Annex 3 of the Nitrates Directive 1/676/EEC, would give Member States the option to allow a separate additional limit of 100 kg N/ha/year for RENURE products on top of the current limit.

More information can be accessed at the home page of the Operational Group **RENURE**

Ammonia Air Washing in Pig Livestock

Gas Loop has developed an advanced air treatment system to effectively reduce ammonia emissions from pig livestock. Air washing systems remove ammonia from the air inside the pig rooms and recover it in an ammonium sulphate solution. The device draws ammonia-rich air from the stable through suction ducts located below the slatted floor. In this way, the ammonia emissions are captured and prevented from spreading into the environment above where the animals are housed. The air treatment is based on the chemical absorption of ammonia by counter-current acid washing into a tower. Sulfuric acid solution (H_2SO_4) is used to react with ammonia (NH_3), thereby forming a stable suspension of ammonium sulphate ($(NH_4)_2SO_4$) which accumulates in a tank at the base of the tower. A significant emission reduction with lower treatment flow rates was observed (14 m^3/h per pig). This increases animal welfare and productivity due to better air quality. The treatment was tested for 2 years in stables of fattening pigs for the PDO Parma ham supply chain.

Sant'Anna pig farm, partners of the Gas Loop operational and experimental site



Treatment process layout

Benefits

- The air treatment reduces ammonia emissions from pig livestock by 1.94 kg NH_3 per animal housing per year.
- The air treatment improves the indoor air quality, reducing the ammonia concentration inside the treated room by 62% compared to the control room.
- Positive effects of the treatment on the productivity of pigs by increased animal welfare and health.
- Ammonia present in the air inside the pig house is recovered as ammonium sulphate solution. This solution can then be valorised as mineral nitrogen fertiliser.

Current status:

Gas Loop has implemented the air treatment system to capture ammonia in pig livestock up to a technological maturity level equal to technology readiness levels (TRL 8). The device is installed in the pig housing of the Operational Group partners. The innovative air treatment system is ready for practical application.

More information can be accessed at the home page of the Operational Group **GAS LOOP**

Green Energy Production From On-Farm **Biomass**

Small-scale digesters, or pocket digesters, can produce biogas from on-farm biomass to meet the farm's energy demands. These installations are almost exclusively located on dairy farms due to the easily fermentable properties of cattle slurry. After digestion, biogas and digestate are produced. The biogas is valorised to electricity and heat using a combined heat and power unit (CHP). The electrical power of the CHP linked to a pocket digester does not exceed 200 kW. The digestate can be spread on fields as a high-quality organic fertiliser or soil improver. Greenhouse gas emissions are reduced by (partly) avoiding long-term manure storage and by replacing (part of) the fossil fuels required to meet the farm's energy demand.

Tips sheet - available online

Although the technology initially boomed when introduced in Flanders (Belgium), several bottlenecks emerged, including technical imperfections, biological challenges, limited knowledge and experience, communication difficulties, and a high administrative burden. The Operational Group

Pocketboer II aims to address these persistent and common issues with pocket digesters. The project promotes the implementation of solutions at existing and future plants to enhance digester performance and efficiency. By creating and disseminating hands-on information, it has increased awareness and interest among farmers in this technique.

Pocket digester with nitrogen stripper (©Biolectric)

Current Status

Pocketboer II has been able to improve digester performance. In 2022, there were 55 pocket digesters in Flanders (Belgium). The uncertainty regarding nitrogen and investment support has a major impact on the investment climate and the economic feasibility of existing and new projects.

More information can be accessed at the home page of the Operational Group **Pocketboer II**

Grass Circular Economy

Efficient use of raw materials will help reduce imports of biofuels, proteins and fertilisers. By diversifying grass production and resolving significant challenges in traditional agriculture, a small-scale on-farm grass biorefinery was established in Southwest Ireland to help meet those market needs.

Grass biorefinery crush, press & separator

Fresh grass was cut, transported and loaded into the grass biorefinery hopper. The grass was crushed and pressed using an extruder to separate over 50% into a high-solid fibre press cake. This solid fraction contains all the proteins that ruminants need while removing the components that they do not use very effectively. This solid fraction can be bailed and fed directly back to the cows, allowing farmers to continue to feed their cattle with reduced emissions.

Grass being crushed and pressed inside the biorefinery

Three co-products are also produced in the biorefinery process from the liquid juice fraction, which contains the other 50% of the total protein content. It may increase the overall farm efficiency.

- High-protein product that can be used to feed chickens and monogastrics.
- High-value stream of sugars that are prebiotic and can be used in animal nutrition.
- The remaining residues contain a lot of monosaccharide sugars and nutrients that can be used for biogas production or the production of biobased fertilisers.

Dried high-protein monogastric feed

These types of small-scale biorefineries are being developed with built-in automation, making this type of technology more accessible to farmers. It also allows farmers to increase resource efficiency while addressing key emissions challenges. The biorefinery model could allow farmers to continue to feed their cattle, with reduced emissions, while producing three co-products which can increase their overall farm efficiency and income.

Current Status

A pilot-scale grass biorefinery is currently in operation on a farm in Southwest Ireland, where grass press cake and the three co-products are produced at the farm level.

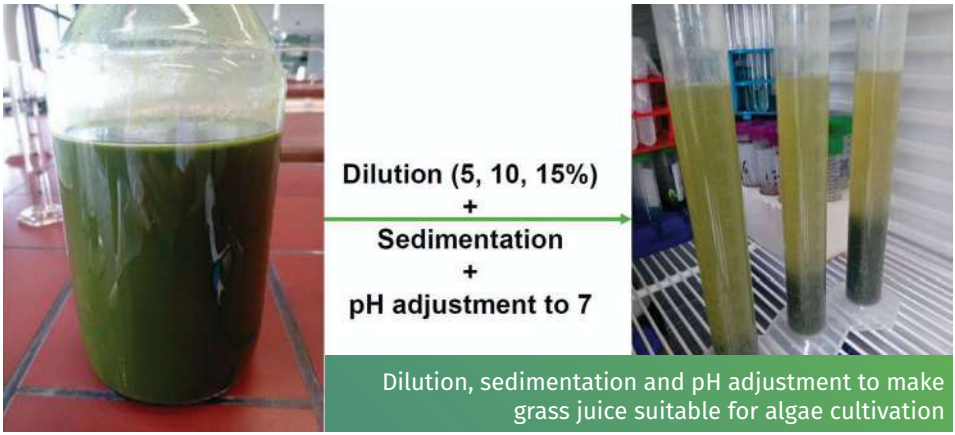
More information can be accessed at the home page of the Operational Group **Biorefinery Glas**

Grass Juice for Growing Microalgae

Grass2Algae uses grass juice to grow microalgae, which can be an additional source of income for farmers and ensures a circular economy on their farms. Through a sequence of sedimentation, coarse filtration and pH adjustments, grass juice is separated from the fibers of roadside grass or low-quality grass that cannot be used as animal feed. The grass juice accounts for 40-60% of the total grass weight and is an excellent source of nutrients, being rich in macro- and micronutrients that are necessary for the growth of microalgae.

Microalgae cultivation using grass juice at lab-scale

Results from microbial analysis and the algae product showed that the quality of the produced biomass is up to spec for food application resulting in a new source of income for farmers. Still, future studies are needed to further explore the potential of grass juice as fertiliser and the produced algae biomass as animal feed.



Dilution, sedimentation and pH adjustment to make grass juice suitable for algae cultivation

Microalgae cultivation using grass juice at pilot scale - Picture taken on Kris Heirbaut's farm

Current Status

Currently the grass juice is mainly produced at the farm level and used at the same farm for algae cultivation at a pilot scale.

More information can be accessed at the home page of the Operational Group **Grass2Algae**

Summary

Tools to **Optimise Manure Processing**

- Adopting processing technologies for manure or digestate management to recover nutrients allows farmers to increase the value of their agricultural waste.
- Extraction of nutrients from manure or digestate to create fertilisers (e.g. struvite, ammonium salts).
- Reduction of agricultural emissions (e.g. ammonia, methane) in combination with energy production.
- Sustainable grass use and algae production.

Technologies for **Manure Processing**

- Separation of manure to obtain a semi-liquid phase and liquid phase can minimise transport costs and optimise nutrient application to the soil.
- Digestate treatment to recover nitrogen and phosphorus as struvite.
- Digestate microfiltration to make it suitable for injection in fertigation with drip lines instead of mineral fertilisers.
- Nitrogen recovery from ammonia emissions into ammonium sulphate fertiliser, which can replace synthetic fertilisers and reduce GHG emissions.
- On-farm digestion of manure to produce biogas for electricity and heat and digestate as organic fertiliser, thereby reducing GHG emissions linked to manure storage and fossil energy use.
- Valorisation of grass to produce press cake, prebiotics and protein rich monogastric feed, increasing the value of low-quality roadside grass.
- Valorisation of low-value grass by biorefineries and separation technologies to produce nutrient-rich grass juice for algae cultivation as alternative animal feed, improving the sustainability of algae production and increasing farmers' income.

Future Benefits

- Decreasing dependencies on mineral fertilisers and fossil energy, reducing import costs, transport costs and electricity costs, therefore, contributing to the circularity of the bioeconomy.
- Decreasing agricultural emissions by implementing (nutrient) processing technologies (e.g. pocket digestion, stripping-scrubbing) and sustainable manure management.
- Further development and implementation of local (nutrient) processing technologies at farm scale (e.g. biorefineries).
- Bringing farmers together in knowledge cooperatives, providing guidance and creating hands-on information to positively impact the awareness, implementation and improvement of nutrient management technologies.

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NUTRI•KNOW

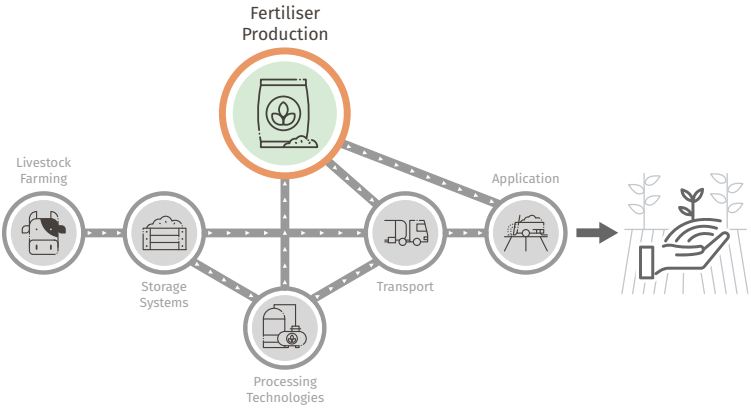
Fertiliser Production

Technologies, tools and recommended practices from NUTRI-KNOW's EIP-AGRI Operational Groups

Introduction

Agricultural by-products such as animal manure and processing by-products are rich in essential nutrients including nitrogen (N), phosphorus (P) and potassium (K). Although they are considered agricultural by-products, they have the potential to be used raw or be further processed into products to displace mineral fertiliser reliance. In some cases, nutrients such as N which can be lost to the environment as ammonia-N for example can be captured and retained as fertiliser. Using recycled and recaptured nutrients as fertilisers in agriculture helps to close the nutrient cycle loop and can develop the local bioeconomy.

This booklet gives an overview of the fertiliser production experiences, decision support tools, technologies and recommendations that are the outcomes of five EIP- AGRI Operational Groups related to nutrient management. These groups and associated projects have focused on producing fertilisers from agricultural by-products such as grass and manure. Furthermore, they provide knowledge on nutrient management and how the production of biobased-recycled fertilisers can reduce environmental pollution. They do this by capturing mineral fertiliser equivalent nutrients, which would otherwise be lost in the form of ammonia and greenhouse gas (GHG) emissions and contribute to the efficient and predictable use of nutrients.



Fertiliser Production

Innovative and environmentally conscious management of agricultural by-products as fertilisers can help to empower farmers and change their role in the bioeconomy from being suppliers of cheap biomass into producers of bio-based products. Fertilisers presented here are produced from low-quality grass or animal manure using cutting-edge technologies, which have undergone various treatment stages that can be used directly on the farm. For more information see the links to the home pages of the Operational Groups presented below.

Bio-Based Fertilisers and **Organic Farming**

The development of bio-based fertilisers is a promising approach to support nutrient management needs on organic farms, particularly on stockless farms, where links between arable and livestock enterprises may not be established. In contrast to many non-organic farms, organic crop nutrition is primarily based on biological aspects of soil fertility rather than a focus on nutrient supply. As a result, the import of bio-based fertilisers should be part of a farm's broader management strategy which aims to maintain long-term soil fertility for yield optimisation but avoids dependency on external inputs. Under EU organic legislation all bio-based fertilisers must be authorised for use in organic production.

Nitrogen Fertiliser From **Manure**

Stripping-scrubbing is an innovative approach that can be applied locally on the farm to process nutrients from manure to ammonium salts as RENURE (REcovered Nitrogen from manuRE) products. Ammonium salts are high in N in a form that is readily available to the crop. Production of RENURE products as a substitution for synthetic nitrogen fertilisers addresses issues of nutrient surplus from animal sources at a local level and reduces fertiliser costs.

Stripping-scrubbing installation

Field trials to assess ammonium nitrate as a fertiliser on potato and maize plots after an initial application of animal manure indicated that it can perform just as well as artificial fertiliser (urea and calcium ammonium nitrate) in terms of effectiveness and nutrient value.

Benefits

- In some cases, crops treated with ammonium nitrate performed better than the reference, although this was partly due to heterogeneity due to the dry growing season.
- Ammonium nitrate was compatible with a row tiller for fertilising potatoes and for injection with a seeder when sowing maize.

- Presently, these fertilisers are classified as animal manure and must therefore comply with the Nitrates Directive 91/676/EEC. At the time of writing (May 2024) a consultation process is in place by the European Commission to amend the Directive to permit the use of specific RENURE fertilisers to improve substitution of chemical fertilisers by organic fertilisers. This includes ammonium salts, reverse osmosis mineral concentrates and struvite.
- Although stripping scrubbing-derived ammonium nitrate has a lower N content than synthetic N fertiliser, it has excellent potential as a substitution for synthetic fertiliser, as it can be produced locally on the farm, and it also has the potential to increase the farmer's income.

Ammonium salts are produced from the Stripping-scrubbing process

Application of ammonium salts to grass through injection

Nutrient Content

The nutrient value of ammonium nitrate (10-15% N) as a fertiliser, after an initial application of animal manure performed comparably to artificial fertiliser.

Current Status

The ammonium salts are produced at a pilot scale and used on arable farms with full-scale operations taking place in Belgium, Detricon, at Gistel (Flanders) and Strocon, at Hooglede (Dutch) as part of the NITROMAN project. Results of a meta-analysis in this Operational Group suggested that the capacity of a stripping-scrubbing installation should be at least about 20,000 tons of manure per year to achieve the desired economies of scale.

More information can be accessed at the home page of the Operational Group **RENURE**

Nitrogen Fertiliser From the **Air** of **Pig Housing**

The Gas Loop Operational Group has developed an innovative technology to remove ammonia from the air of pig housing and recover it in an ammonium sulphate solution closing the N cycle loop. Nitrogen, an essential nutrient is often emitted as harmful ammonia which can have negative effects on animals, the environment and human health. This technology captures ammonia-N and repurposes it into fertiliser, preventing its escape. The air treatment is based on the chemical absorption of ammonia by backwashing with an acid reagent in a tower. Sulfuric acid solution (H_2SO_4) reacts with ammonia (NH_3) to form a stable suspension of ammonium sulphate ($(NH_4)_2SO_4$) (typically 6% N and 8% S) which accumulates in a tank at the base of the washing tower.

The treatment was tested for 2 years in fattening cycles of pigs for the PDO Parma ham supply chain, and it produced ammonium sulphate fertiliser using air-washing technology and a chemical characterisation was conducted. The ammonium sulphate solution recovered reduced GHG emissions by replacing N industrial fertilisers.

Ammonium sulphate fertiliser

Benefits

- This “air washing system” improves animal welfare and increases productivity due to better air quality inside the pig housing.

- Ammonia present in the air inside the pig house is recovered as an ammonium sulphate solution and this solution can then be valorised as a mineral N fertiliser. The ammonia capture system from the air of a pig livestock house allows the recovery of 14.5kg of N per year and per tonne of pig live weight housed and therefore avoids 66kg CO2 equivalent per tonne of pig live weight per year by evading the production of the same quantity of synthetic N fertiliser.

Ammonium sulphate produced

- The production of the ammonium sulphate solution (230 litres per tonne of pig live weight per year) is characterised by pH 4, by a Total Nitrogen content of 6% (99% as ammonia-N) and by a Total Organic Carbon of 1% in weight.
- Up to 14.5 kg N per tonne of live weight per year was recovered and up to 1.94kg ammonia per animal place per year of ammonia emissions into the atmosphere was prevented.
- In a pig farm with an average live weight of 1,150 tonnes (around 10,500 fattening places), 16.8 tonnes of N per year could be recoverable.

Nutrient Content

Total Nitrogen content of 6% (99% as ammonia-N).

Current Status

The air treatment is presently running, and the ammonium sulphate produced is currently used at farm scale. The ammonium sulphate fertilisers recovered are classified under the EU fertiliser regulation as liquid inorganic N fertilisers under Product Function Category 1,

More information can be accessed at the home page of the Operational Group **GAS LOOP**

Production of **Struvite Fertiliser** From **Manure** and **Digestate**

In Italy, there are areas with a high level of livestock where optimal management of manure and digestates could lead to a reduction in emissions. Digestate or manure treatment can favour the delocalisation of the N and P surpluses from areas with high livestock farming towards areas characterised by a demand for chemical fertilisers, following the principles of Nutrient Recovery and Reuse.

New technology has been developed to produce an organic fertiliser, namely struvite ($NH_4MgPO_4 \cdot 6H_2O$). This slow-release renewable recovered fertiliser is high in key nutrients P, N and magnesium (Mg), which can be used to replace synthetic fertilisers in areas characterised by nutrient deficiencies. The efficiency of recovering P and N was higher with pre-acidification of the digestate (digestate pH reduced to 7.5 from the starting value of 8.5) followed by microfiltration to remove the solids. The addition of Mg and alkaline (to increase pH from 7.5 to 9) promoted the development of crystals and their precipitation. The P, N and Mg were concentrated in the precipitate. At this stage, the P and N were suspended in saline, in a stable form and no longer in an orthophosphoric and ammonia form.

Struvite production pilot treatment plant

Benefits

- The precipitate containing struvite can be utilised by fertiliser producers or used as a raw material for producing phosphate fertilisers.
- By reducing P, N and dry matter content of livestock manure and digestates, ammonia, methane and nitrous oxide emissions were reduced from the liquid digestate storage and the soil application phase.

Current stage of struvite refinement, struvite-rich precipitate

Nutrient Content

P, N and magnesium (Mg), respectively 13%, 6% and 11%, in case of refined and pure products. The precipitate containing struvite is currently in a liquid form and should be dried according to the water content.

Current Status

The struvite-containing precipitate fraction requires additional refinement—such as drying, cleaning, and granulation by a fertiliser manufacturer—to replace phosphate minerals with phosphorus recovered from manure or digestate. This ensures it better meets the new European fertiliser regulation's P Component Material Categories and users' needs. The high concentration of water, solids and organic matter in the recovered matrices rich in struvite is still a critical issue. The OG Struvite has ended, but the research and activities are not concluded, they will be continued in a new Struvite project.

More information can be accessed at the home page of the Operational Group **STRUVITE**

Using **Grass Juice** to **Cultivate Algae**

Grass2Algae has developed a novel approach to increase the value of roadside grass or low-quality grass, which typically has poor animal feed value and is often treated as waste. This new farm-based technology allows the liquid fraction of grass to be separated from the fiber fraction by a sequence of sedimentation, coarse filtration and pH adjustments. This nutrient-rich grass juice can be used by farmers as an alternative fertiliser to cultivate algae that can be produced locally on the farm and sold as high-protein animal feed displacing protein imports.

Microalgae cultivation using grass juice at lab-scale

Microalgae cultivation using grass juice at pilot scale - Picture taken on Kris Heirbaut's farm

Benefits

- Grass juice is rich in macro and micronutrients that are necessary for the growth of microalgae.
- It can replace mineral fertilisers and increase the sustainability of algae production.
- Results from microbial analysis and the algae product showed the quality of biomass produced is up to specifications for food application resulting in a new source of income for farmers.

Nutrient Content

- The carbon content and nutrients in grass juice included total carbon 6717mg/l, total nitrogen 520mg/l, ammonium (NH4-N) 97mg/l, nitrate (NO3-N) 11mg/l, P 192mg/l and K 2215mg/l.
- The produced algae biomass had 17% moisture (partially dried), 41% total protein, 27% total carbohydrates, 12% total fat, 3% crude fibre and 17% inorganics.

Current Status

Currently the grass juice is mainly produced at the farm level and used at the same farm at a pilot scale for algae cultivation.

More information can be accessed at the home page of the Operational Group **Grass2Algae**

Grass Whey Fertiliser

Biorefinery Glas developed a system to increase the value of grass using a small-scale biorefinery. This is useful where the feedstock scale required for integration with anaerobic digestion may not be achievable. In the biorefinery, the grass is crushed, and the solid press cake can be used as feed for cattle. The liquid by-product or grass whey is nutrient-rich and can be recirculated back to the land in the form of fertiliser. This fertiliser is produced and spread locally on the farm, ensuring the nutrients remain on the farm.

GRASSA small-scale biorefinery located in the West Cork Region, Ireland

Grass whey from crushed and pressed grass is produced in the biorefinery

Field trials to evaluate the use of whey as a fertiliser compared to slurry were conducted, using a spreading rate of 30 m^3/ha and low-emission slurry spreading.

Benefits

- Grass whey performed comparably to cattle slurry as a fertiliser for grass.
- Grass treated with whey was 'deeper' in colour compared with the slurry-treated grass, possibly due to more chlorophyll being available, as grass whey also acts as a bio-stimulant.
- A sweet and pleasant smell was also noticed from the spreading of whey compared with the slurry.
- Grass whey production can increase the value of grass for farmers and reduce their fertiliser costs.

The liquid grass whey is collected and spread as a bio-based fertiliser

Nutrient Content

The nutrient values (N, P and K) of the grass whey and slurry were comparable.

Current Status

Grass whey is currently produced on a farm level at a pilot scale.

More information can be accessed at the home page of the Operational Group **Biorefinery Glas**

Summary

Tools to **Help Farmers**

- Valorise grass from field margins or other low-quality grass that cannot be used as feed and is often deemed as waste.
- Capture of N from animal housing ammonia emissions as ammonium salts which is a by-product of air treatment.
- Assess struvite production using manure or digestate as the P feedstock.

Technologies and **Recommendations**

- Reducing ammonia and GHG emissions by converting ammonia emissions into ammonium sulphate fertiliser and limiting emissions by producing slow-release renewable recovered fertiliser as struvite, which has the potential to replace conventional mineral N and P fertilisers.
- Production of nutrient-rich grass juice by biorefineries and separation technologies has the potential to replace mineral fertilisers and slurry, supporting the sustainable growth of algae and grass production.

Future Benefits

- Locally produced fertilisers ensure that the nutrients remain on the farm, harnessing a zero-waste approach.
- Potential to increase farmers' income by converting waste by-products into high-value nutrient-rich fertilisers.
- Encourage the balancing of the nutrients from manure between regions characterised by a surplus or a deficit.
- Decreasing dependencies on mineral fertilisers, reducing import and transport costs, therefore, contributing to the circularity of the bioeconomy.

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NUTRI•KNOW

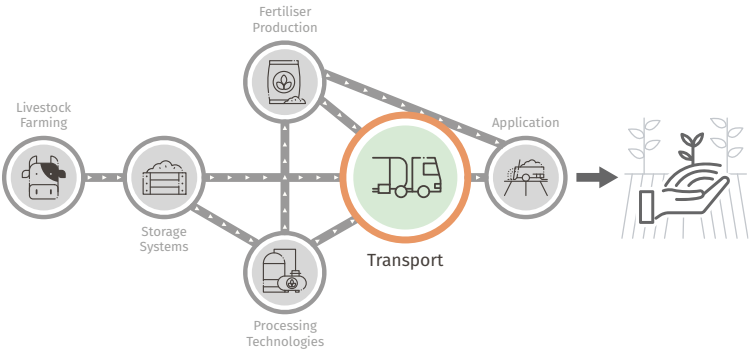
Transport

Technologies, tools and recommended practices from NUTRI-KNOW's EIP-AGRI Operational Groups

Introduction

Nutrient Management stands as a paramount concern for farmers across Europe and efficient transport is a key link in the nutrient value chain. Efficient transport of nutrients not only reduces logistical burdens, but also plays an important role in minimising environmental impacts. From optimising routes to using innovative technologies, the transport step aims to streamline the flow of nutrients from source to application site.

This booklet explores strategies and technologies to improve nutrient transport efficiency, minimise emissions and maximise nutrient use efficiency, thereby promoting a more sustainable and economically viable agricultural landscape.



Transport

This booklet explores innovative strategies and technologies aimed at optimising nutrient transportation processes in alignment with sustainability and resource efficiency goals. The Operational Groups featured here concentrate on minimising slurry transport expenses, employing computer algorithms to optimise transport logistics, and producing pelletised biofertilisers. For more information see the links to the home pages of the Operational Groups presented below.

Organic Farming and **Nutrient Management**

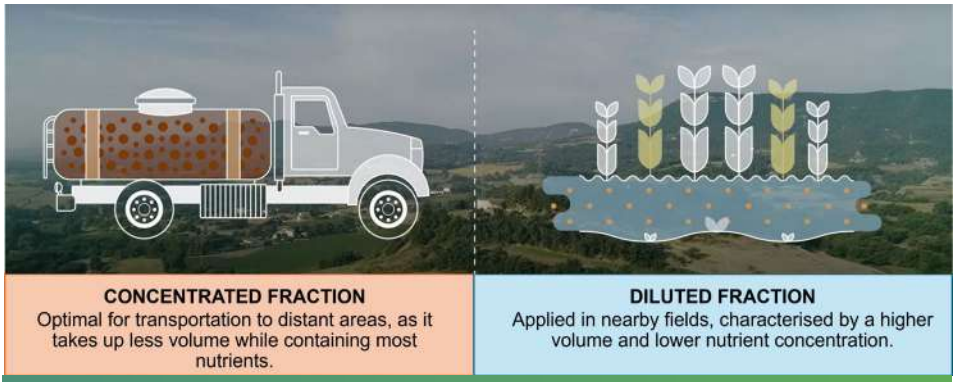
Nutrient management on organic farms is based on working with ecological processes as well as the recycling of existing nutrients to build soil fertility, including soil organic matter and biological activity that promotes circular systems and helps to minimise dependence on external inputs. Alongside good soil management, efficient use of nutrients is critical, owing to their limited availability. Additional sources of organic materials outside the farm may be needed to secure sufficient nutrient levels, particularly on stockless farms, where links between arable and livestock enterprises may not be established. Under EU organic legislation, application of organic manures and other waste materials must be authorised for use in organic production.

Slurry Concentrator to **Reduce Transport Costs**

In regions with high livestock density, there is an imbalance between the volume of nutrients generated and the farmland available for their application. Manure and slurry management is a particular challenge for farmers, especially those with small and medium-sized farms. There is an urgent need for effective solutions that improve and simplify the application of these materials as fertilisers and, when necessary, facilitate their transport to nutrient-deficient areas.

The Slurry Concentrator has tried to provide an innovative solution to this challenge that consists of separating manure into two phases: a semi-liquid phase (concentrating the majority of the organic matter and nutrients) to be transported and applied to distant fields where nutrients are not available; and a liquid phase (with a low nutrient concentration) to be applied in nearby fields. The differentiated management of the two phases is designed to minimise transport costs and optimise the application of nutrients to the soil from the agronomic and environmental perspectives.

Top view of the concentrator and the two ponds



Slurry concentrator produces a concentrated fraction and a diluted fraction for decoupled transport and application

Benefits

- The Slurry Concentrator improves manure management and farm sustainability. It is a mobile unit, allowing shared use, reducing investment costs, and making management more efficient compared to fixed systems.
- Transporting treated slurry instead of untreated over 135 km can lead to significant annual savings. Breeding farms see benefits at 350 m^3 of treated slurry, while fattening farms benefit at almost 500 m^3.
- The system requires two ponds for storing liquid fractions, but it is versatile, climate-independent, and suitable for any farm producing livestock slurry.
- Initial investment is quickly recovered through savings and efficiencies. It has low maintenance, minimal energy consumption, no building work needed, and very low installation costs.

Current Status

Operation at a pilot-scale demonstrated the technological and economic viability of the technology for farms and the cooperative to manage manure more efficiently.

More information can be accessed at the home page of the Operational Group **Slurry Concentrator**

Development of Tools to **Optimise Manure Transport Logistics**

Appropriate and efficient manure management involves optimising transport to reduce distances, working time, fuel consumption and overall costs, thus minimising the environmental impact and economic burden on farmers.

Conductivity meter installed in the transport tank

In Catalonia, livestock manure transport vehicles (such as tanks, trailers, and tractors) are required to have an electronic global positioning system (GPS) and a unit for receiving, recording, and transmitting data about the origin, destination, and characteristics of the manure. This data must be sent in real-time to the platform managed by the department responsible for agriculture and livestock farming in Catalonia. The Operational Group Manure Management Tools has improved management logistics by using computer tools to optimise transport routes, register applications and ensure the traceability of fertiliser applications on the plot. The aim was to optimise transport routes and accurately locate and record both loading points and fertiliser application sites.

Benefits

- To make long-distance manure transport more economical, it is advantageous to transport manure with a high nutrient content, either from the source or after treatments. This was achieved by determining the nutrient content of manure through the use of conductivity meters installed in the transport tanks, which measure electrical conductivity and the levels of various nutrients.
- The online monitoring devices installed in transport tanks record information including the location and routes of the application vehicle, timetables, number of operations per loading and unloading point, the total kilometers traveled, etc. This makes it possible to generate the livestock manure management book as well as the fertilisation plans more quickly and accurately.

Field Use of a Manual Conductivity Meter to Determine Slurry Application Rates Based on Nutrient Content

Current Status

Several transversal actions have been carried out in coordination between the participating Catalan cooperatives, and the management tools are near-to-practice.

More information can be accessed at the home page of the Operational Group **Manure Management Tools**

Tailor-Made **Pelletised Biofertiliser** to **Cut Transport Costs**

The main objective of the Operational Group Bioferti+ is the conversion of a bovine manure composting plant into a plant producing high-quality tailor-made fertilisers in the form of pellets to be used to fertilise woody crops (e.g., vineyards and apple orchards).

Benefits

The pelleting process offers an economically competitive benefit in terms of transport. Also, it represents an advantage from a practical point of view for farmers, since it allows them to use the machinery they already use for chemical fertilisation.

- The formulation is adapted to the specific needs of each crop, considering factors such as production type, soil characteristics, and local climate conditions.
- Pellets provide a sustained release of nutrients, gradually decomposing to nourish soil and crops over extended periods. Long-lasting pellets reduce the need for frequent applications, contributing to more sustainable farming practices.

The main objective is the conversion of a composting plant into a high quality tailor-made fertiliser production to be used in the fertilisation of woody crops

The pelleting process provides a cost-effective advantage for transportation

Current Status

Significant improvements have been made to the cow manure composting process, resulting in the production of a tailor-made fertiliser specifically formulated for vineyards and apple orchards. The pellets derived from this process are currently undergoing evaluation to assess their agronomic efficacy.

Manure Transport Models and Smart Logistics

The regions of Flanders, Gelderland, Catalunya and Oberpfalz, although geographically distant, share common challenges associated with livestock farming, manure production, and environmental sustainability and associated limitations on manure application.

The FERTIMANURE project sheds light on critical aspects of manure management, including spatial patterns of surplus manure, economic implications for logistics, and the potential for innovative technologies to reduce transport distances and mineral fertiliser input. It has developed a tool to determine the potential for the implementation of such innovative technologies.

Benefits

- Implementation of pilot technologies focused on nutrient recovery can significantly reduce the costs associated with manure and fertilisation management.
- By using innovative technology to recover nutrients from animal manure, substantial amounts of valuable nutrients can be recovered as an alternative to mineral fertilisers. This not only reduces the external demand for nutrients, but also minimises the costs associated with manure transport.
- Cost reductions achieved outweigh the increased processing costs in several municipalities with excess nutrients in three regions (Flanders, Gelderland and Oberpfalz) except for Catalunya, where the technology is considered too costly. As a result, the newly produced bio-based fertilisers have gained acceptance in the market, capturing a market share ranging from 20% to 40%.

Current Status

The primary objective of this tool is to address regional policy decisions concerning manure management, serving as a comprehensive database for the regions under study. The tool has been expanded to include additional regions such as Bretagne, Lombardy, all provinces of the Netherlands, and some regions of North-West Germany. While it can potentially be adapted for new regions, its use requires specific paid-for software (General Algebraic Modelling System), which limits accessibility, particularly for non-academic users.

Summary

Products to Provide a **Cost-Effective Advantage** for **Transportation**

- High-quality, tailor-made pelletised fertilisers offer economic transport benefits and practical advantages for farmers using existing chemical fertilisation machinery.

Tools to **Optimise Manure Transport Logistics**

- The use of specialised software can significantly streamline fertiliser transport logistics by optimising routes, accurately registering applications and ensuring traceability of fertiliser applications on the plot.

Technologies to **Optimise Nutrient Transport** From an Economic and Environmental Perspective

- The innovative slurry concentrator produces two liquid fractions with fertiliser potential: a concentrated fraction to be transported and applied to distant fields where nutrients are not available; and a diluted fraction to be applied in nearby fields. The differentiated management of the two phases is designed to minimise transport costs and optimise the application of nutrients to the soil from the agronomic and environmental perspectives.
- Understanding the spatial patterns of surplus manure in specific regions and their economic implications for logistics is crucial for identifying opportunities to reduce transport distances.

Future Benefits

- Pelleted biofertilisers concentrate nutrients, reducing transport costs, while slow-release properties minimise leaching and increase plant uptake efficiency.
- Specialised software optimises routes, reducing fuel consumption, and ensures precise nutrient application, enhancing efficiency and reducing environmental impact.
- The Slurry Concentrator minimises the total number of journeys required to transport manure, resulting in significant reductions in fuel consumption and greenhouse gas emissions.
- This makes it possible to generate the fertilisation plans more quickly and accurately.

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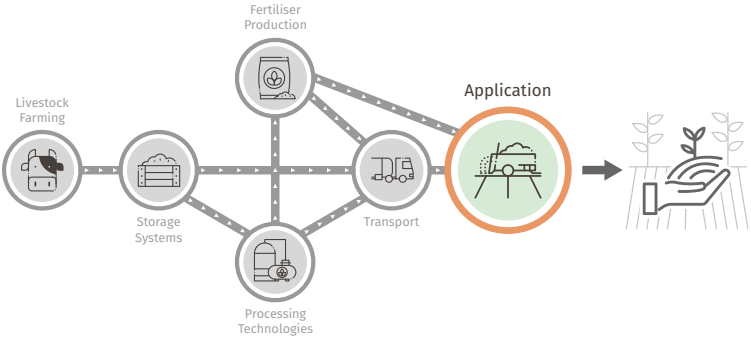
NUTRI•KNOW

Application

Technologies, tools and recommended practices
from NUTRI-KNOW's EIP-AGRI Operational Groups

Introduction

Nutrient Management is one of the most important areas of interest for farmers in several countries in Europe. Along the nutrient management value chain, sustainable and efficient application is a crucial step to optimise nutrient use efficiency while minimising the environmental impact. This booklet discusses state-of-the-art nutrient application in agricultural systems, followed by an overview of the innovative technologies, tools and recommendations for improved application practices. It highlights the key outcomes derived from the EIP-AGRI Operational Groups engaged in the NUTRI-KNOW project, including the use of technologies and fertilising products such as struvite and ammonium salts recovery from manure, on-site tools such as slurry concentrator and conductometer, as well as recommended practices integrating soil, fertiliser and water management. Furthermore, the booklet explores the benefits and current status of these technologies, tools and recommended practices in the representative regions, supporting the decision-making process of farmers and practitioners.



Application

In response to the challenges of increasing fertiliser cost but low nutrient use efficiency in traditional application practices, 7 of the 12 engaged operational groups in the NUTRI-KNOW project demonstrated different approaches for improved nutrient application strategies. This section summarises the key outcomes, including two technologies for the recovery of struvite and ammonium salts from manure/digestate and the application of the derived products, two innovative tools (i.e. slurry concentrator, conductometer) to support fertilisation decisions, and three recommendation schemes integrating soil, crop, fertiliser, and water managements. The involved activities, results and the current status are discussed to provide practical guidance for future implementation by end-users crossing Europe.

Organic Farming and **Nutrient Management**

Nutrient management on organic farms is based on working with ecological processes as well as the recycling of existing nutrients to build soil fertility, including soil organic matter and biological activity that promotes circular systems and help to minimise dependence on external inputs. Alongside good soil management, efficient use of nutrients is critical owing to their limited availability. Additional sources of organic materials outside the farm may be needed to secure sufficient nutrient levels, particularly on stockless farms, where links between arable and livestock enterprises may not be established. Under EU organic legislation application of organic manures and other waste materials must be authorised for use in organic production.

Struvite Precipitation to **Reduce Ammonia Emissions** From Digestate Application

Application of manure and digestate derivatives releases less ammonia (NH_3) and greenhouse gas (GHG) emissions than raw materials. The Operational Group Struvite developed and implemented a prototype for a farm-scale system to recover nitrogen and phosphorus from digestate in a small volume of stable matrix, with a reduced nutrient and organic matter content in the remaining fraction. The recovered nitrogen forms a slow-release renewable recovery fertiliser (Struvite) which can replace synthetic fertilisers in areas characterized by nutrient deficiencies due to a reduced livestock presence.

Pilot treatment plant for struvite precipitation from digestate

On-site measurement of ammonia emissions by Wind tunnel technique (left) and GHG emissions by static Chamber (right)

Benefits:

- Due to depleted content of N, soil application of the treated digestate led to a 19% reduction in the N emissions (counted as sum of N-ammonia and N-nitrous oxide) as compared to the untreated digestate.
- Thanks to the saline and stable forms of nitrogen and phosphorus, application of the precipitated struvite resulted in a 63% of N emissions reduction as compared to the untreated digestate.
- The circular management of pig manure and transformation into Struvite shifts the problem of climate-altering gas emissions from the manure into a resource.

Current Status:

Building on these findings, research and activities will continue in a newly funded Struvite project. The precipitate containing struvite will be further refined/evaluated to effectively replace the phosphate minerals in accordance with the EU fertilising product regulation.

More information can be accessed at the home page of the Operational Group **STRUVITE**

Applying **Recovered Ammonium Nitrate** as **Alternative Fertiliser**

The Flemish agricultural sector faces a paradoxical scenario of nutrient demand in the form of fertilisers despite nutrient surplus from manure. In 2020, the European Commission proposed the “RENURE” criteria to allow the safe use of recovered nitrogen from manure to replace chemical fertilisers. Ammonium salts (ammonium sulphate or nitrate) recovered from manure through a stripping and scrubbing process show the potential to be used as a priority RENURE product. The agronomic performance of the recovered ammonium nitrate was evaluated in five field trials set up in 2022 and one in 2023.

Ammonium nitrate recovered from manure stripping and scrubbing process

Benefits:

- The ammonium nitrate recovered from manure showed comparable effectiveness and fertilising value as artificial fertilisers.
- Applying ammonium nitrate with a row tiller or with injection is preferred as a low-emission method over using a spray boom.
- A more realistic alternative is to apply it with a spray machine under the right conditions and immediately working it into the soil.

Application of ammonium salts to grass and vegetable crops through injection to reduce ammonia emissions

Current Status:

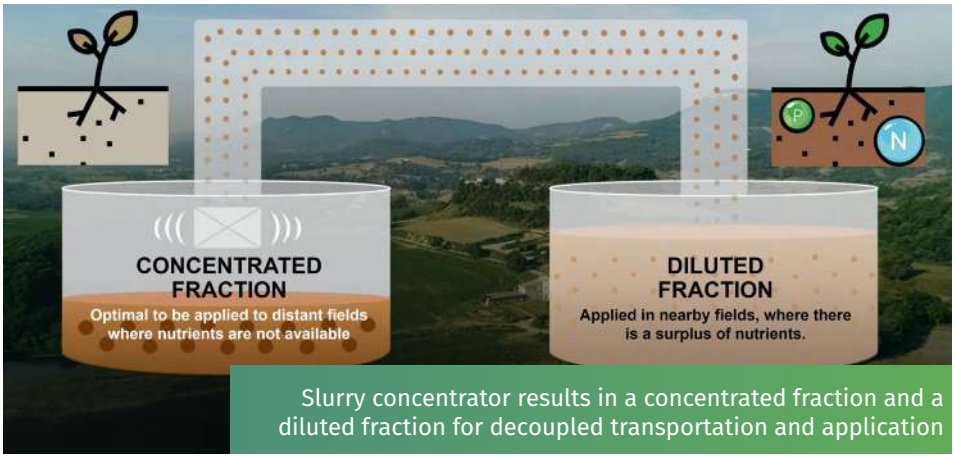
The lower nitrogen content in the recovered ammonium nitrate than the artificial fertiliser is one main bottleneck in practice, requiring a larger application volume that the fertiliser machine has to be replenished more often, as the storage is located far from the application plot. In addition , the status of animal manure in the current regulations is limited for ammonium nitrate application.

More information can be accessed at the home page of the Operational Group **RENURE**

Slurry Concentrator for Enhanced Soil and Fertiliser Management

Conventional manure separation results in a liquid and a solid fraction, each requiring different application machinery, which increase the complexity of application. The innovative slurry concentrator yields two liquid fractions: one with concentrated organic matter and nutrients to be transported and applied to distant fields where nutrients are not available; and the other with a low nutrient concentration to be applied in nearby fields.

The innovative slurry concentrator separates manure into two liquid fractions, which are stored in dedicated ponds for optimised nutrient application



Slurry concentrator results in a concentrated fraction and a diluted fraction for decoupled transportation and application

Benefits:

- Using the same equipment for both fractions derived from the slurry concentrator reduces both investment and operating costs and the time required for management.
- The system enables easier monitoring of the applied nutrients through online devices capable to facilitate precision fertilisation, minimise nutrient losses and reduce emissions, thereby optimising soil health and productivity.
- The proposed new separator is a mobile device that can be shared with a group of farmers or a cooperative on different farms.
- The device is designed for low maintenance and energy consumption, with minimal electricity usage. Additionally, it requires no building work and has very low installation costs, making it easy to set up.

Current Status

The Cooperative Plana de Vic offers a free simulation of the viability of the slurry concentrator on your farm.

More information can be accessed at the home page of the Operational Group **Slurry Concentrator**

Manure Management Tools for **Optimised Fertilisation** Plan

Within the Operational Group Manure Management Tools, innovative tools including conductivity meters, precision machinery, and computer applications have been validated for the optimisation of livestock manure management and agricultural fertilisation, from both an economic and environmental perspective. Slurry was applied before sowing using a fan equipment to bury the slurry at a depth of 0-30cm, and when crops were less than 10cm in height, using hoses. Farmers received advice and training for crop variety options, pest control, climate, bottom and cover fertiliser applications, etc.

Application of slurry before sowing

Benefits

- The employment of a conductivity meter enables in-situ and real-time monitoring of the nutrient content that is applied to the crop.
- The online monitoring devices installed in transport tanks record information including the location and routes of the application vehicle,

timetables, number of operations per loading and unloading point, the total kilometres travelled, etc., making it possible to generate fertilisation plans more quickly and accurately.

- The use of hose equipment to apply liquid manure during crop growth brings the supply of nutrients closer to the moment of maximum nutrient uptake by the crops and improves the efficiency of the nutrients applied.

Application of slurry when crop is growing

Current Status

Several transversal actions and pilot experiences have been carried out, and the management tools are near-to-practice.

More information can be accessed at the home page of the Operational Group **Manure Management Tools**

Sustainable Farming Techniques to Apply **Renewable Fertilisers**

SOS_AQUAE developed an innovative system to increase the use of the liquid fraction of digestate by mixing it with water in fertigation, offering an interesting option in regions where crops require water.

Three innovative agrosystems stand out compared to traditional practices looking at soil management, chemical fertiliser input, conventional application and sprinkler irrigation. This includes:

- Non-tillage based on spring-summer crops (sorgum and maize) alternating with autumn-winter cover crops, fertigated with ammonium sulphate from stripping treatment of digestate, injected through drip lines in sub-irrigation.
- Minimal tillage based on double crops, the first for food and the other for biogas, fertigated with microfiltered digestate injected through drip lines in sub-irrigation.
- Conventional production methods for food and non-food but fertigated with microfiltered digestate spread through a rainger irrigator.

Fertigation with microfiltered digestate from slurry tank

Benefits

- Thanks to minimum tillage, the sub-irrigation drip lines have a multi-year duration.
- Distributing the nutrients mixed with the irrigation water on growing crops reduces nitrogen leaching and ammonia emissions to almost zero.
- The efficient distribution of water in sub-irrigation avoids water saturation of the soil and the emission of nitrous oxide.
- These innovative techniques for applying digestate extend its spreading periods and avoid soil compaction due to the passage of the slurry tanker.
- The sub fertigation avoids ammonia and odor emissions compared to conventional digestate application.

Microfiltered digestate mixed with irrigation water and applied through a rainger irrigator on maize crop

Current Status

The digestate microfiltered injected in sub fertigation drip-lines technology is now on the market. There is also a follow-up project with the development of a demonstration case in the Italian region of Sicily.

More information can be accessed at the home page of the Operational Group **SOS_AQUAE**

Sustainably Restoring, Protecting and **Enhancing Water** Quality

Elevated bacteria levels of bathing water quality at Duncannon beach, Wexford, together with the loss of its 'Blue Flag' status of environmental excellence in 2007 had a major impact on the tourism potential of the area. As a result, 35 farmers from 4 dairy, 8 tillage and 23 dry stock farms, covering a catchment area over 975 hectares, came together to contribute to the recovery and long-term retention of the Blue Flag status at Duncannon beach. With the guidance of a dedicated sustainability manager, farmers developed a results-based reward scheme to assess the pollution risks on the farms and develop Pollution Potential Zone (PPZ) maps using a traffic light system.

The overall farm PPZ status ranged from:

- "Red" poorly managed – posing a moderate/ high risk
- "Yellow" well managed – but still posing a low risk
- "Green" very well managed - no/ minimal risk

Improvement in PPZ scores requires water protection and enhancement works on farms and the catchment area including:

- Fencing off 15.5km of watercourses.
- Moving water troughs 20m from waterways.
- Conducting soil sampling and developing nutrient management plans for all farms.
- Placing sediment traps on farms to trap and filter run-off.
- Improving farm roadways.

- Encouraging native riparian zones and planting native hedgerows.
- Sowing winter cover crops.
- The participating farmers also received advice on lime applications, soil nutrient assessment, hedgerows, native woodland planting and water quality.

Benefits

- At a farm level, catchment farms became more efficient, the number of septic tank failures reduced and compliance above the Nitrates Directives was observed.
- At a local level, a reduction in bacterial pollution at Duncannon beach was recorded and there was an improvement in ecological quality.
- At a community level, the participants reported a sense of ownership, responsibility and appreciation for the local water environment.

Sediment trap established on a local farm in Wexford

Fencing on Irish farms

Current Status

This cooperation project provides pilot-based evidence that the methodologies developed for results-based land payments in protecting water courses and biodiversity are transferable and can protect other resources such as water quality and rural tourism.

More information can be accessed at the home page of the Operational Group **Duncannon Blue Flag Farming & Communities Scheme**

Improving Soil and **Nutrient Management** on **Organic Horticulture Farms**

The Irish Organic Association worked with 11 Irish organic horticulture growers nationwide to optimise production methods and improve the continuity of short supply chains through grower collaboration. As part of the project, a muti-annual investigation of the effects of short-term green manures on summer and winter cash crops in organic vegetable production was conducted (July 2018 - May 2021). Over 3 years, different summer and winter green manure mixes were sown and grown for 2 and 6 months respectively alongside control plots. The green manures were incorporated into the soil, followed by the establishment of specific cash crops.

Green manure trial site in Ireland

Benefits

- Green manure application before cash crops over the three years achieved overall beneficial effects, including better weed control, more beneficial insects, more and greater functional diversity of soil bacteria, greater soil organic matter content and earlier developing crops compared to control plots

- Low-growing green manures e.g., clover, ryegrass support more beneficial insects, while high-biomass green manures e.g., cereals, phacelia, and buckwheat help to increase soil organic matter.
- Integration of green manure mixes into rotations accelerated the growth of all four cash crops and thus demonstrated the potential for growers to extend the growing period for crops under Irish conditions.

The MOPS Growers Report provides an overview of the green trials results

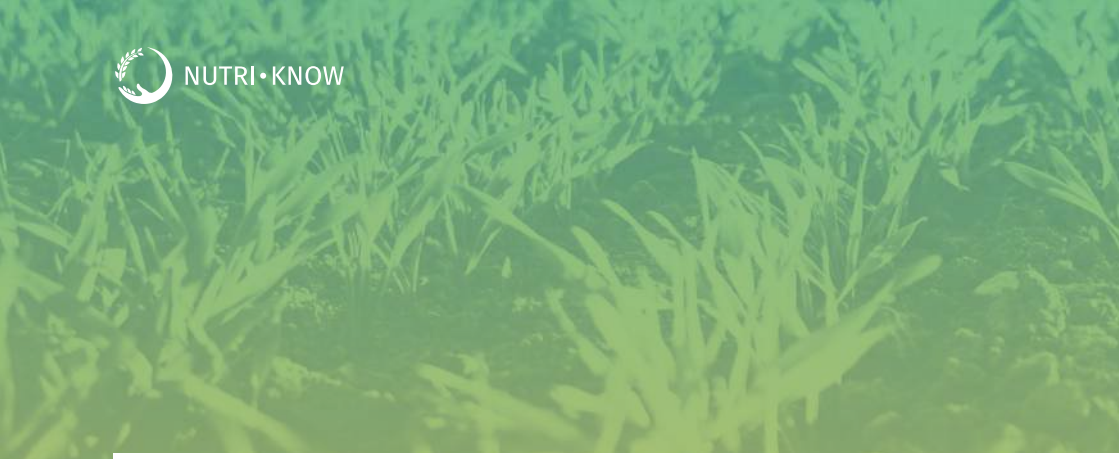
Table: Green Manure Trial Mixes and Cash Crops

	Summer	Winter
Green manure mixes	1. Buckwheat/phacelia 2. Rye/phacelia 3. Persian/Egyptian clovers/ Annual ryegrass	4. Vetch/Crimson clover/ Annual ryegrass 5. Rye/vetch 6. Squarrose clover/Crimson clover/Vetch/Japanese oats/Wild rye
Cash crops	7. Brown onion 8. Pointed cabbage	9. Broccoli 10. Red oak lettuce

Current Status

A MOPS Growers Report is available as a reference for organic growers already operating in the sector and potential new entrants.

More information can be accessed at the home page of the Operational Group **MOPS**



Summary

Technologies to **Develop Novel Products** With **Higher Nutrient Efficiency** and **Lower Environmental Impact**

- Struvite precipitation from digestate significantly reduces ammonia and greenhouse gas emissions after the fraction has been treated prior to application.
- Ammonium salts recovery from stripping and scrubbing of manure or digestate show high potential as chemical fertiliser substitutes.

Tools to **Optimise the Fertilisation Plan** and **Reduce Cost**

- The innovative slurry concentrator produces two liquid fractions for use as fertilisers, reducing operational costs and enabling precision fertilisation for improved soil health and productivity.

Recommendations for Integrated Soil, Crop, Fertiliser and Water Managements

- Innovative agrosystems integrating minimal tillage, fertigation with derivatives from the liquid fraction of digestate, and injection through drip lines in sub-irrigation.
- A simple, cost-effective management plan for water protection improvement, equipped with the Pollution Potential Zone (PPZ) maps.
- Short-term (2-6 months) incorporation of green manure to support the development of summer and winter cash crops in organic vegetable production.

Outlook

- Struvite and ammonium salts recovered from manure as alternative fertilisers can reduce the fertiliser cost and minimise the environmental impact.
- On-site tools for nutrient monitoring and implementing support precision fertilisation strategies can reduce costs and time, increase nutrient use efficiency and productivity.
- Fertiliser application involves the integration of soil, crop, fertiliser and water management practices.

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4. Conclusions and future perspectives

D3.1 (the English version) in the form of six booklets based on relevant Operational Groups (OGs) has been produced and is ready to be made available for download and further dissemination to farmers and other stakeholders.

To make further increase the value, usability, and region-specificity of the booklets, the content of the six booklets will also be translated into the languages of Spanish, Catalan, Flemish, French, Italian and Danish.

Booklets are an effective way to present information concisely and attractively, making them a popular choice for organizations and individuals looking to disseminate messages clearly and efficiently. However, the In terms of further dissemination efforts and possibilities, wide distribution is key. Here, distribution through various channels such as events, mail, online downloads, and partnerships is important. Effectively disseminating booklets requires a strategic approach to reach relevant stakeholders and ensure they engage with the content. Other enhancement strategies include identify the targeted audience, choose the right channels, leverage digital platforms, feedbacks and follow-ups.

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