# RAMIRAN 2023

## 18th International Conference, Cambridge, UK

Book of Abstracts

## 18th RAMIRAN conference, 'Managing organic resources in a changing environment.'

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## Foreword

This book contains the abstracts of presentations given at the 18th international RAMIRAN conference, held in Cambridge, UK from 12–14th September 2023. The conference was jointly organised by ADAS, Rothamsted Research and Bangor University. All abstracts were reviewed by members of the Scientific Committee.

The book of over 260 abstracts is structured to follow the daily timetable, with the abstracts from the keynote speakers preceding those from the oral presentations given in the parallel sessions. The abstracts for the poster presentations are organised in a separate section by theme:

1. Policy and Regulation
2. Nutrient Utilisation
3. Soil quality
4. Air and water quality
5. Treatment and processing technologies
6. Promoting best practice.

Recycling of Agricultural, Municipal and Industrial Residues in Agriculture Network (RAMIRAN) is a research and expertise network that was set up more than 25 years ago to improve nutrient utilisation and minimise the environmental impact of livestock manure and other organic material used in agricultural systems (http://ramiran.uvlf.sk/).

## Acknowledgements

The Organising Committee are very grateful to the Scientific Committee for their diligent reviewing of and recommendations for the submitted abstracts. We wish also to thank other ADAS and RSK staff for their invaluable contribution to the administration and logistics (especially the website and design team) of RAMIRAN 2023.

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### Plenary Session 1 - Nutrient Utilisation

### Challenges and strategies for improving manure management system in China

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The largest livestock production and greatest fertilizer use in the world occurs in China. China's livestock industry has experienced a vast transition from traditional way to intensive system during the last several decades. Intensive livestock production systems have large impacts on water and air quality through emissions of greenhouse gases (GHGs) and nutrients. The aim of this study was to analysis 1) challenges of livestock transition, 2) Improvement of manure management system, 3) strategies for sustainable development goals (SDGs) for agricultural systems in China.

The livestock production has increased dramatically in the past decades. At the same time, intensive rate also increased. Just in few decades, China's livestock production lost its multifunction that have formed in the past several thousand years. Now, the main function of livestock production is mainly for produce high quality animal protein (Bai et al., 2018). This transition includes both bonus and costs. Due to the poor manure management of industrial livestock production, nutrient losses and GHG emissions increased as well. We quantified the nitrogen (N) flows from 'housing-storage-treatment-application' chain. Two third of N lost to environment (Bai et al., 2016). We also found uneven distributions of crop and livestock production at regional level. Therefore, coordinated planning is necessary to promote coupling of livestock and cropping systems at the regional scale (Bai et al., 2022).

Central government has noticed the importance of manure management. In the past ten years, two improvements were encouraged. One focus on control pollution from intensive livestock farms. Another one focuses more on options of manure application on cropland. But research needed to bring this about in the most sustainable way. In China, it is difficult to recycle manure by slurry system such as US and US. Because the livestock density is quite high in China and most of livestock farms are landless systems. Technologies development of whole manure management system, considering solid, liquid and gases, are really important. We have developed several technologies, such as NH3 mitigation, manure composting reactor, utilization of liquid manure from 'Housing-storage-treatment-application' chain (Zhang et al., 2020; Li et al., 2021; Wang et al., 2017). We also did some demonstrations (Wang et al., 2020).

Integrated food chain management strategies should be considered for SDGs (Ma et al., 2019). More products, less pollutions, efficient resources, total recycling, and ecological sustainability is the five main targets (Bai et al., 2020). Manure should be considered as good nutrient resources, therefore manure recycling technologies and circular bioeconomy play important role in redistribution and regeneration of nutrient (Bai et al., 2021). Considering multiple functions of agriculture and land use change, ecological sustainability will be more important. We think different regions may require different type of technologies and spatial planning (Bai et al., 2022). The joint efforts of different stakeholders are needed.

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**Plenary Session 1 - Soil Quality**

## Organic materials and agricultural soil quality – potential benefits, risks and implications for crop productivity

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The benefit of recycling organic materials to agricultural soils to close nutrient cycles is widely recognized and actively promoted. Indeed, RAMIRAN was first established to share knowledge on how to improve nutrient utilization and minimize the environmental impact of organic materials used in agriculture. However, as well as being a valuable source of crop available nutrients, there is an increasing volume of research which focuses on the non-nutrient benefits of such applications, which are largely linked to the organic matter they supply. Early research in this area evaluated impacts on soil 'fertility', with organic materials seen to improve soil nutrient status, pH and cation exchange capacity. Following this, the term soil 'quality' was more widely used, and aspects of soil physical condition were evaluated, with improvements in structure, aggregate stability and water retention reported. Most recently studies have evaluated impacts on soil 'health', with greater attention placed on the role and importance of soil biology and organic material additions reported to affect the size, composition and activity of the soil biological community. Organic amendments are also being explored as a potential means of sequestering carbon to mitigate climate change, although this is questionable given limitations associated with permanence, leakage and additionality, with many materials already applied to land.

Alongside these developments in soil science, there has also been an increasing diversity of organic materials applied to agricultural soils, due the drive towards a more circular economy as well as advances in processing technologies, with compost and digestates augmenting more traditional sources such as livestock manures and slurries and biosolids. The extent to which these materials impact soil properties will depend on the chemical characteristics of the material, rate of application and nature of the receiving soil (its texture, land use and location/climatic region). Not all organic matter is the same, and both the quantity of material applied and its 'quality' (e.g. labile vs recalcitrant carbon content) is important, such that the outcome desired (e.g. supplying nutrients, improving soil structure, storing carbon) can, to some extent, be determined by the choice of material applied.

Impacts of these non-nutrient benefits on crop performance have been difficult to detect due to the confounding influence of the nutritional benefits. Where these have been controlled, yield benefits are often only seen with short season or spring sown crops, such as potatoes, maize, sugar beet and spring barley, or in years where yields are low due to climatic stress (e.g. drought).

There is also an increasing desire to be able to put a financial value to organic amendments (over and above the cost savings from reduced fertilizer use), whether that this is due to increased yields, reduced energy/water use or latterly linked to the potential long-term carbon retention (sequestration) that could be achieved. However, as well as having beneficial effects, some materials can also present a risk to soil quality. Traditionally this has been due to the presence of heavy metals and organic contaminants, pest and pathogens, but 'emerging contaminants' of concern include microplastics and antibiotic resistant bacteria and genetic material from human and veterinary medicines.

Session 1 - Nutrient Utilisation

## Re-evaluating the nitrogen use efficiency of selected mineral and organic fertiliser categories based on the analysis of long-term field experiments under Swiss pedoclimatic conditions

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### Introduction

A precise evaluation of the nitrogen (N) use efficiency (NUE) potential of fertilisers is crucial to maximise crop productivity while minimising their negative environmental impact. Yet, organic fertilizers often have a residual fertilising effect that can last for years, making it difficult to quantify their NUE accurately. Long-term field experiments (LTEs) can help overcome this challenge by providing data on the N inputs and outputs of a defined system over extended timespans.

Using a selection of LTEs we investigate the N cycling and NUE trends over time, to re-evaluate the NUE of selected mineral and organic fertilisers after repeated application. The results are shared with Swiss policy makers to improve the overall fertiliser NUE at the legislation level.

### Methodology

LTEs will be selected among those located in Switzerland or in pedoclimatic conditions, comparable to the main Swiss agricultural production region. Additional criteria are the presence of selected mineral and organic fertiliser treatments, which are regularly applied in similar amounts as in farm practice; and field management based on a crop rotation. The currently selected four LTEs include fertiliser treatments with slurry, farmyard manure, green-waste compost, and combinations thereof with PK, and NPK according to Swiss fertiliser norm.

The temporal dimension of fertiliser N cycling will be visualised by calculating an approximative soil-system N balance, as defined by Oenema et al. (2003). This balance will be calculated and summarised for each complete crop rotation cycle. A selection of fertiliser NUE indicators will be calculated, to quantitatively highlight how fertiliser performance differs amongst the selected fertiliser categories. The NUE indicators will also be compared to one another for the same fertiliser type as outlined by Quan et al. (2021), to identify differences among the selected approaches. To account for location-related effects, both N balance and NUE will first be compared between fertiliser treatments within the same experiment. The results will then be standardised to compare analogous fertiliser treatments at different locations.

### Results and discussion

A critical discussion on the challenges of combining LTEs with different designs and locations, the long-term differences between the selected NUE indicators and their interrelation, or the opportunities and risks of simplifying complex N dynamics in the soil-system for simple model applications at the legislation level, are amongst the topics that will be addressed in the study's results and discussion section.

Including proper fertiliser handling prior to application is essential to maximise fertiliser utilisation. Yet, in this study the focus is given to the fertiliser NUE after application to the field. Thus, in the discussion section, it will be essential to consider how the findings can be applied in the context of overall farm-level fertiliser NUE.

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## Higher than expected: Nitrogen use efficiencies over 35 years of organic and conventional cropping

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### Introduction

Organic and conventional cropping systems differ in type and amount of nitrogen (N) inputs, which may affect efficiency and sustainability of N use. Organic N fertilizers such as animal manure differ from mineral N fertilizers in the supply of available N over time. Nitrogen budgets based on field data records of long-term experiments enable the determination of N use by crops over decades.

### Methodology

In the DOK (bio-Dynamic, bio-Organic, Konventionell) field experiment, organic and conventional cropping systems have been compared since 1978 at two fertilization levels, with level 2 being typical for the respective system and level 1 half of it (Krause et al., 2020). Fertilization in organic systems has been animal manure based while the conventional system has received both, animal manure and mineral fertilizer. At level 2, average fertilizer N inputs in kg N ha-1 yr-1 were 93 in the bio-dynamic, 96 in the bio-organic and 171 in the conventional system. Controls are a conventional treatment receiving solely mineral fertilizers (121 kg N ha-1 yr-1) and an unfertilized treatment. Symbiotic fixation by legumes cultivated in all treatments during three out of seven years of crop rotation was quantified based on 15N studies and legume N yield data (Hammelehle et al., 2018; Oberson et al., 2013). Topsoil (0-0.2 m) N stock changes were derived from the time course of total soil N concentrations that had regularly been measured. Soil surface and soil system N budgets were computed for each year of the period from 1985 until 2019, and budget derived Nitrogen use efficiency (NUE) indicators calculated (Oberson et al., under review).

### Results and discussion

The N output with harvested products regularly exceeded the N input with fertilizers, which was largely explained by symbiotic N2 fixation. With 75 to 122 kg N ha-1 year-1 of DOK experiment, symbiotic fixation was the main N input for most treatments and hardly differed between fertilization level 1 and 2. Soil surface budgets calculated by subtracting N outputs with harvests from the sum of N inputs with fertilization, symbiotic fixation, seeds and deposition resulted in balances ranging from negative values of -31 kg N ha-1 yr-1 (in non-fertilized control) to surpluses of +46 kg N ha-1 yr-1 (conventional system level 2). The corresponding NUE (N output with harvests as percentage of sum of N inputs) of treatments with negative balances resulted in values >100%, while treatments with positive balances had NUEs of 85% to 99%. Fertilizer NUE derived from the budget suggested equally high NUE for mineral fertilizer N and some manure treatments. Negative balances indicated soil N mining, while positive balances pointed to a risk of N losses and/or to N accumulation in soil. Topsoil N stock changes ranged from -26 to +9 kg N ha-1 yr-1. Topsoil N stocks had declined in the unfertilized and the mineral fertilized control and in systems receiving animal manure at level 1.

### Conclusion

Positive soil surface N balances and animal manure are needed to maintain or increase topsoil N stocks. High NUE was reached with both animal manure and mineral fertilizer based treatments.

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## Integrated dairy manure management increases nitrogen and phosphorus use efficiencies after soil application

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### Introduction

Manure management can have several objectives, such as reducing GHG emissions; reducing ammonia emissions; and increasing nutrient use efficiency, which can be conflicting and result in pollution swapping. Integrated management systems (IS), from animal house to field, were developed to limit pollution swapping from dairy manure in the whole chain. Such systems, starting with source segregation (SS) of faeces and urine, were reported by model studies to reduce all emissions simultaneously, reduce phosphorus (P) application excess and increase nitrogen (N) use efficiency (De Vries et al., 2015). These predictions, however, have yet to be verified experimentally. This study aimed at validating the application stage of two integrated dairy manure management strategies by studying the nutrient use efficiency of applying treated faeces and acidified urine to grass . By using a mesocosm experiment in the greenhouse and applying the products separately and timely, this research tested the N fertilizer replacement value (NFRV), crop P use efficiency (PUE), and nitrate leaching potential (NLP) .

### Methodology

The IS included SS of faeces and urine, processing, covered outside storage, and adapted application method and time in the field. The application stage of two IS were tested: IS1 consisted of acidified digestate of SS faeces, combined with acidified SS urine while IS2 consisted of zeolite supplemented and dried digestate of SS faeces, combined with acidified SS urine. In both IS, the digestates were applied once per cut while the SS urine was injected at 10 cm twice per cut. The IS were compared to untreated shallow-injected slurry as reference, N and P mineral fertilizers, and an unfertilized control. The test was conducted using seven replicates per treatment in a temperature and humidity controlled greenhouse during two cuts.

### Results and discussion

The IS1 had an average nitrogen fertilizer replacement value (NFRV) of 88% and crop phosphorus use efficiency (PUE) of 97%, which were respectively 73% and 62% higher compared to the slurry reference (41% NFRV and 51% PUE). This increase of NFRV and PUE obtained with IS1, compared to slurry, was substantially higher than with other singular treatment technologies of animal slurries in literature, which are typically in the range of 10 -30 % increase (Jensen, 2013; Vaneeckhaute et al., 2016). Compared to the slurry reference, IS1 also had 74% less nitrate accumulation in the 0-30cm soil layer, and 100% less P excess application compared to crop demand. These results show that a combination of selected manure treatment technologies gave higher increase of NFRV and PUE, which could be related to avoided pollution swapping. For the case of N, the SS and AD increases the available N in the digestate and liquid fraction, while the acidification retains the available N in the fractions by limiting ammonia volatilisation. The treated fractions were then applied in adapted application method and timing, possibly reducing nitrous oxide volatilization and nitrate leaching (Maris et al., 2021). For the case of P, the SS has more than 90% P separation efficiency, which results in a more adapted N/P ratio to crop demand and thus less P application excess.

### Conclusion

This study showed that the soil application of treated faeces and urine from a designed dairy manure management system can significantly reduce losses of N and P after soil application and increase the NFRV and crop PUE. Experimental findings showed that improvements of 73% in NFRV and 62% in PUE were achievable compared to an untreated slurry reference. Also, residual nitrate in the topsoil was lower suggesting less nitrate losses in the growing season. Field and long-term research is needed to further substantiate these findings.

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## Nitrogen Fertilizer Replacement Values of organic amendments should be calculated at equal N uptake and correlate with their chemical properties

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### Introduction

The nitrogen fertiliser replacement value (NFRV) quantifies the value of organic amendments as a nitrogen (N) fertiliser. It is commonly defined as the extent to which organic fertilizer N can replace mineral fertilizer N, and can be calculated based on equal N application rates or equal N uptake. Currently, NFRVs are mainly known for animal manure, whereas other organic waste products may become available as fertiliser products in a more circular economy. This study aimed to (1) assess NFRVs of a range of organic amendments; (2) compare NFRVs based on equal N application with NFRVs based on equal N uptake; and (3) assess which product characteristics explain observed variation in NFRVs.

### Methodology

A pot experiment was performed with spring wheat and different organic amendments at two N application rates (100 or 200 kg N ha-1). The organic amendments were by-products from the food industry; residual products from anaerobic digestion; manure from larvae and commonly used organic amendments. Together, these products covered a wide range of total N contents, C:N ratios, mineral N contents, potential mineralizable N, and cellulose:lignin ratios. In addition, a range of mineral fertilizer treatments was included to estimate a dose-response curve of crop N uptake vs mineral fertilizer N (from 0 to 200 kg N ha-1).

NFRVs were calculated using two methods: (1) at equal N application rates by dividing the N uptake from an organic fertilizer by the N uptake from a mineral fertilizer at the same application rate (100 or 200 kg N ha-1) and (2) at equal N uptake by comparing the N rates from mineral and organic fertilizer treatments needed to obtain the same plant N uptake.

### Results and discussion

NFRVs ranged between 7.7 and 107.6% when calculated at equal N application, whereas they ranged between 6.2 and 78.8% when calculated at equal N uptake. We show that calculating NFRVs at similar N application levels for organic and mineral fertiliser N consistently leads to an overestimation of the NFRV, because the N uptake response is subject to the law of diminishing returns. As a result, N uptake from the organic fertilizer is still in the linear part of the response curve while N uptake from the mineral fertilizer is in the non-linear part of the response curve. As it is unknown beforehand at which point N response curves start levelling off, calculating NFRVs at equal N uptake or yields is a better method for estimating NFRVs. NFRVs calculated at equal N uptake are not sensitive to the diminishing returns of N application nor to varying N application rates between experiments and farmers' practice. We argue that NFRV calculated at equal N uptake is the preferred method because its value is independent of the N application rate.

Our study shows that short-term NFRVs can be explained by characteristics of organic fertilizers, namely total N, PMN and C:N ratio. Both single- and multiple linear regressions resulted in total N content as the best explanatory variable for the NFRV, followed by PMN. We argue that it is possible to make relatively good estimations of the short-term NFRV of an organic fertilizer based on only its total N content (R2=0.86). The increased R2 suggests that including PMN and C:N ratio could lead to even better estimations (R2=0.91). However, the contributions of these characteristics were small compared to total N, and the difference between the predicted and observed values is similar between these models.

### Conclusion

We conclude that NFRVs should be calculated based on equal N uptake between organic and mineral fertilizers. N content of the organic fertilizer provides an adequate explanation of variation observed in NFRV (R2=0.86). These findings give valuable insights into the large variation in value of organic waste streams as organic fertiliser and can support decisions on sustainable N application rates, to increase crop N uptake and reduce N losses to the environment.

## Nitrogen fertiliser value of digestates and untreated cattle slurry differs by organic and conventional crop management

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### Introduction

One main obstacle to sustainable nutrient management in organic farming is the scarcity of nutrients. Further, commonly used nutrient sources in organic farming like composts or straw-rich animal manure show low nitrogen (N) fertilizer value. Anaerobic co-digestion of animal manures with biomass from green manures could increase the N fertilizer value of the animal manures while the addition of green manure would result in a higher quantity of fertilizers available in organic farming. Yet, studies investigating N fertilizer values under organic management are scarce. Therefore, this study aimed to determine the N fertilizer value of different products from anaerobic digestion (digestates, separated liquid fraction of digestates) as well as cattle manure and mineral fertilization under organic management. In addition, the difference in fertilizer value due to injection timing (before vs. after ploughing) and crop management (organic vs. conventional) was tested.

### Methodology

Two field studies were performed on loamy sand soil at the research station Foulumgaard (56o49'N, 09o58'E). Study 1 compared the effect of injected digestates (co-digestion of cattle slurry and clover grass silage), and liquid fraction from separated digestates with the effect of an unfertilized control, cattle slurry, and mineral fertilization on spring barley yield in two consecutive years under organic management. Study 2 investigated the differences in the fertilizer value of digestates , and cattle slurry due to injection timing (before vs. after ploughing), N dose (100 vs. 200 kg N ha-1), and crop management (organic vs. conventional) in spring barley. The fertilizer value was calculated as N fertilizer replacement value (NFRV) for grain N yield. NFRV is estimated as shown in the equations below from the N use efficiency (NUE) of manures relative to NUE of mineral fertilizer N (determined as the slope of the mineral N response curve). Mineral N was also used as a reference by organic crop management, despite being banned in organic farming.

(1) NUE=(Nuptake fertilized – Nuptake unfertilized)/ Napplied*100% (2) NFRV=NUEmanure/NUEmineral*100%

### Results and discussion

Study 1 revealed that injected cattle slurry, digestates, and the liquid digestates fraction had all high NFRV between 80% and 90% (based on grain N yield under organic management). Hence, co-digestion of cattle slurry with biomass from green manures can increase the quantity of digestates without lowering the quality. Within the nutrient-limited system of arable organic farming, this could increase the nutrient supply and also be a meaningful use of the biomass from green manures. The separation of the liquid fraction did not result in a higher NFRV. However, it lowered the phosphorous content relative to the N content which can prevent nutrient imbalances, when digestates are used as the only source of N. Study 2 revealed an increase of > 10% points NFRV due to anaerobic digestion (cattle slurry vs. digestate; $F(1,49)=96.00$, $p<0.001$). It also showed that injection after ploughing compared to injection before ploughing, as often done in practice, can considerably increase the NFRV independent of the kind of fertilizer by around 8% points ($F(1,49)=24.82$, $p<0.001$). This was probably due to a placement effect when the slurry band was untouched after injection. Further, the estimated NFRV was 13% points higher by organic than conventional management ($F(1,3)=36.11$, $p=0.009$) which could have caused the relatively high NFRV measured in study 1. It can be explained by a 12% points lower NUE of mineral fertilization under organic management compared to conventional management ($t30=7.06$, $p<0.001$). Yet, the NUE of cattle slurry and digestates were not affected by the type of management. A possible explanation could be that a higher weed density by organic farming benefited more from unplaced mineral N fertilizer than from injected manure and reduced crop yields.

### Conclusion

Anaerobic digestion can be a useful tool for increasing nutrient efficiency and availability in organic farming. However, when it comes to evaluating the NFRV of organic manures, the application technique and the management of the experiment should be considered. Further research is needed to determine the reasons for a reduced NUE of mineral fertilization under organic crop management while the crop response to injected organic manures seemed to be unaffected by crop management.

### Acknowledgements

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## Slurry injection to reduce nitrogen Losses and enhance nutrient use efficiency in maize cropping

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### Introduction

Agriculture in north-western Germany is characterized by intensive livestock farming based on extensive cultivation of maize. Broadcast application of the resulting animal slurries already covers the nutrient demand of maize. However, most farmers band-apply a mineral NP fertilizer close to the maize seed as a "starter fertilizer" to ensure proper early growth development. This often leads to nutrient surpluses at field level, which are at risk to be lost into non-agricultural ecosystems. Slurry injection in combination with a nitrification inhibitor (NI) below the maize seeds might be an option to replace mineral starter NP fertilizer without impairing early maize growth and yields.

### Methodology

In a 3-year field trial series (8 sites per year), slurry injection (with/without NI addition) was compared with slurry broadcast application to assess yield and N uptake (V8 growing stage and harvest). An additional 2-year field trial with 4 treatments (unfertilized control, broadcast application + NP starter fertilizer, injection and injection + NI) was conducted to investigate the spatial and temporal soil mineral N (SMN) dynamics over the growing season. N2O emissions were measured using gas-sampling chambers installed centrally above the maize row (weekly gas-samplings for 1 year).

### Results and discussion

Averaged over all experimental sites slurry injection resulted in equal (without NI) or slightly higher (with NI) dry matter yields. Addition of a NI to the slurry increased N uptake (up to + 9 %) compared to slurry broadcast application with starter fertilizer. Reasons for this NUE increase may be lower ammonia losses, as well as decreased nitrogen immobilization when manure is injected in a band due to a reduced soil/slurry interaction. The detailed studies on SMN revealed that in a year with heavy rainfall all fertilized N of the slurry broadcast treatment was leached out from the top soil layer until 6-leaf stage of the maize crop. Displacement of N was significantly smaller after slurry injection leading to an increased NUE for the maize crop after slurry injection (Federolf et al. 2016). In a year with average rainfall, no displacement of fertilized N out of the top soil layer occurred independently of treatments. The addition of a NI led to significantly increased ammonium N concentrations in the injection zone throughout the early growth stages, reduced nitrate leaching further, and finally resulted in a higher N uptake (Westerschulte et al. 2017). In addition, the plants take up more N as ammonium followed by a pH decrease in the soil surrounding the roots. This leads to an improved availability of P and micronutrients (e.g. zinc) resulting in an overall better crop growth (Westerschulte et al. 2018). Slurry broadcast application slightly increased N2O emissions compared to the control treatment without any slurry application, while injection of slurry increased N2O losses significantly. Most probably high concentrations of easy available carbon in the slurry band has led a depletion of O2 with the consequence of increased denitrification (Ruser and Schulz 2015). Addition of a NI to the injected slurry resulted in ca. 50 % lower N2O emission.

### Conclusion

Due to slurry injection, the applied nitrogen is located in a soil zone with better spatial availability for plant roots compared to broadcast application. Especially when a nitrification inhibitor is mixed into the slurry, the risk of nitrate leaching is significantly reduced. Obviously, slurry injection is a reliable option to mitigate nutrient surpluses in maize growing resulting in beneficial effects for the environment.

### Acknowledgements

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## Session 1 – Policy & regulation

### Exploring future scenarios for a circular Dutch food system

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#### Introduction

Applying circularity to food systems is increasingly seen as an important pathway to a sustainable food future. Circular food systems increase the resource use efficiency by closing the loop of materials through utilising residual streams (e.g., manure, co-products, food loss and waste), which could otherwise be lost. However, closing the loop of materials in a food system dominated by international trade of food and animal feed is challenging. Moreover, the precise contributions of circularity to the sustainability of food systems remain poorly understood and quantified.

#### Methodology

During this project we developed the FOODSOM model, an agro-ecological food system model (iterative linear optimisation) designed to develop and assess future, more circular scenarios for the Dutch food system. FOODSOM can minimise environmental objectives (e.g., greenhouse gas (GHG) emissions, nitrogen emissions, or land use) or maximise productivity objectives (e.g., animal protein production). A variety of crops (49) and animal systems (up to 7) are included in the model while human diets can be based on current consumption or new innovative diets to meet nutrient and nutritional requirements.

#### Results and discussion

Firstly, we assessed how dietary change and the feeding of food waste to animals influences environmental impacts of the food system as a whole. We found dietary change was very effective at reducing GHG emissions and land use but feeding food waste showed little climate change mitigation potential as processing food waste into animal feed is emission intensive.

Secondly, we assessed how residual streams should be optimally utilised (i.e., as animal feed, compost or anaerobic digestion) to reduce GHG emissions and land use. We found food losses and co-products should be prioritised for animal feed, while food waste should be prioritised for anaerobic digestion or composted depending on how the emissions are assigned. Assigning emissions to the energy sector favoured anaerobic digestion, while assigning to the food system favoured compost.

Finally, we assessed the implications for recoupling livestock and feed production in the Netherlands. Recoupling would create a natural ceiling for livestock production in the Netherlands. We found livestock numbers were significantly reduced without feed imports, which decreased nitrogen and GHG emissions while increasing resource use efficiency at a food system level. We further show how eliminating feed-food competition without dietary change can increase nitrogen losses and GHG emissions.

#### Conclusion

These studies present and assess opportunities to improve circularity in the food system while simultaneously reducing the environmental impact of the Dutch food system. At the same time some trade-offs are presented between interventions which favour land use and those that favour a reduction in GHG emissions.

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## Evaluating a model implementation for an improved nitrogen management regulation in Switzerland

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### Introduction

A farm-level nitrogen (N) balance surplus often indicates the need for improved nutrient management and often reflects challenges for agri-environmental ecosystems, because of potential negative impacts on water resources, plant and soil biodiversity and climate change. For national N surplus reduction in the agricultural sector a nutrient balancing system is often mandatory at legislation level. However, at this practical level, estimating the relevant nutrient flows can only be achieved, if the used and recorded parameters are simple but accurate. Direct payments represent an important lever to facilitate changes in agricultural management and production. Since 1999, Swiss farmers need to prove an even balance between N input from animal production and fertilizers and crop N demand at farm level (the Suisse-Balance). Since its introduction, changes in livestock, manure and field management have improved agricultural production and society and policy ask for more sustainable nutrient management. Yet, necessary adaptations have not been implemented, causing a mismatch between the balancing system and demands from legal and practical perspective. Based on scenarios and changes in the calculation structure, we present potential to improve the manure N fertiliser assessment in the Suisse-Balance to be applicable for decision making in innovative and efficient agriculture.

### Methodology

Two essential elements of the Suisse-Balance, the manure cascade (i.e. excretion location, livestock management system choice, storage and in field application) and the according emission factors (particularly of ammonia, but also nitrous oxide and molecular nitrogen) were reviewed. For that, a dataset of about 200 mixed Swiss farms of the Swiss agri-environmental data network (Gilgen et al. 2023) was used to calculate a model-based manure cascade (Kupper, 2019) for various scenarios. The used scenarios represent a gradient from manure N production as identified by the current Suisse-Balance system and four scenarios making use of the modelled manure cascade based on average Swiss production systems, farm specific assessment, planned legislative restrictions and a scenario describing the currently known technical potential to minimise N losses by best manure management.

### Results and discussion

Based on the simulated scenario results, currently, the Suisse-Balance is underestimating the amount of potentially available N for crop fertilisation. The evaluated and discussed scenarios reflect a gradient increase of N contained in manure and thus being available for crop fertilization based on quantitative knowledge on N reduction measures. Thus, adapting the modelling approach could not only increase the available amounts of N considered being plant available, but also facilitate true increases of N use efficiency in mixed agricultural systems. However, reaching the maximum technical potential is likely not possible in practice, therefore realistic targets will be highlighted in the discussion underlined by the results from the intermediate scenarios.

### Conclusion

A model-based manure cascade calculation reflecting the reality of on farm nutrient flows can improve nutrient balancing for legal and agri-environmental monitoring purposes. In particular, it can increase transparency and robustness for decision making on the farm and in agricultural policy level. Thus, it can help truly decreasing N losses to meet environmental quality requirements. However, the manure N fertiliser value does not end after field application. By improving the manure N content assessment up to application, we improve an essential part of the overall N fertiliser value assessment leaving "only" the long-term N release to be further improved for assessment.

### Acknowledgements

We thank T. Kupper (HAFL), I. Weyermann (AGRIDEA), A. Gilgen and J. Schneuwly (AEM at Agroscope) for their support.

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## Predicting methane emission from liquid manure and exploring mitigation options with integrated farm-scale modelling using the ABM model

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### Introduction

Manure management is a significant source of methane emission globally, and various national efforts are aimed at reducing this source through changes in management. Methane is produced by slow-growing archaea, making methane production sensitive to management and accurate prediction with simple models challenging. However, the slow growth of methanogenic archaea presents a unique opportunity for reducing emission from pig and cattle slurry pits or outside manure storages through simple manure management changes.

In this work we will describe the Anaerobic Biodegradation Model (ABM) (Dalby et al., 2021), which explicitly considers microbial growth for predicting methane emission from stored liquid manure. We validated the model using full-year in-house methane emission measurements from a pig house. Using the validated parameter set (Dalby et al., 2023) we will demonstrate how ABM can be used for predicting barn and outside storage methane emission from cattle and pig liquid manure at the farm level.

### Methodology

ABM is a flexible mechanistic model that includes multiple groups of methanogens, each with a specific temperature response. It is currently available as an R package. It tracks organic matter conversion to volatile fatty acids, which in turn is converted to methane by distinct methanogenic groups. In the latest developments, multiple ABM simulations were integrated to track organic matter and microbial population flows from the animal to barn to outside storage environment. Different manure management mitigation options were explored by "building" the desired farm management in a separate spreadsheet input template. At barn level, parameters such as excretion of organic matter from the animals, design and management of pen floors and slurry pits were included.

### Results and discussion

We explored mitigation options and found that temperature, manure removal frequency, residual slurry level, and application time of the slurry to the field was important for farm-scale methane emission. Methane emissions from storages was larger than from barn in both pig and cattle farms at Danish conditions, where farmers store the major part of the liquid manure in outside storages. Consequently, at pig farms methane emission could be reduced by more than 20% by reducing the amount of manure stored outside during the warm season with field application over the summer. At cattle farms, weather was more important because in-barn manure temperature was affected by the outside temperatures in the open ventilated barn. Hence during cold years ~15% less methane would be emitted from cattle manure at the farm level.

### Conclusion

Methane emission prediction and exploration of mitigation options is possible with a dynamic model that considers microbial growth and links organic matter flows between the different emission sources.

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## Relocate 10 billion livestock to reduce harmful nitrogen pollution exposure for 90% of China's population

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### Introduction

Livestock production in China is increasingly located near urban areas, exposing human populations to nitrogen pollution via air and water. Here we analyse livestock and human population data across 2,300 Chinese counties to project the impact of alternative livestock distributions on nitrogen emissions. The objectives of our study are: (1) to analyse the driving forces and impacts of spatial distributions of livestock production in China for the period 1990–2012; and (2) to explore the possible impacts of a spatially more even distribution of livestock production on nitrogen use and losses in 2050. We focus on nitrogen because of the severity of nitrogen pollution in China and for reasons of brevity. The NUtrient flows in Food chains, Environment and Resources use (NUFER) model was adjusted and a multicriteria-based livestock spatial planning concept was developed for the purpose of this study.

### Methodology

The NUFER model was used to quantify the environmental impacts of different spatial distributions of crop and livestock production at county level in China. NUFER includes data for 2,300 counties (out of 2,850 counties), which accounted for 94% of the total crop production and for 98% of the total livestock production in China in 2012.

### Results and discussion

The livestock population in China increased by 80% between 1990 and 2012, from 240 to 430 million standard livestock units (LU). A standard livestock unit equals a 500 kg dairy cow19. About 98% of the increase occurred to the right of the Huhuanyong Line (Hu Line). The main livestock production counties (that is, counties with more than 320,000 LU), contributed 9.2% to the total LU in 1990 and 55% in 2012. This has led to the high density of nitrogen losses, especially for ammonia emission which has exceeded UN guidelines. These regions also accounted for 60% of Chinese population. In major of these regions, ammonia emission was the main driving forces of high PM2.5 concentration, and hence, contributed greatly to air-quality related health problems. In addition, uneven distribution of livestock production also led to the spatial disconnection between crop and livestock production, and responsible for the substantial nutrient losses. We developed a new framework to relocate livestock production in China, to either recoupling crop-livestock or relocate livestock production to regions with less risk of high population exposure to high ammonia emission. Relocating 5 billion animals by 2050 according to crop–livestock integration criteria could reduce nitrogen emissions by two-thirds and halve the number of people exposed to high ammonia emissions. Relocating 10 billion animals away from southern and eastern China could reduce ammonia exposure for 90% of China's population. Spatial planning can therefore serve as a powerful policy instrument to tackle nitrogen pollution and exposure of humans to ammonia.

### Conclusion

Overall, China may have to relocate 5–10 billion animals to tackle nitrogen pollution of air and water caused by concentrations of livestock production. This is an enormous challenge, with huge economic and societal impacts, but will yield improved nitrogen pollution control as final result. Policy-makers need to carefully select the criteria for spatial planning of livestock production because the ultimate effects of spatial planning depend on the criteria prioritized.

### Acknowledgements

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## Scenarios for nutrient recovery from urban organic matter

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### Introduction

In our increasingly urban world, cities represent points of high nutrients concentration, as they import significant amounts of food to sustain a large population over a comparatively small area. In most cities o industrial countries, these nutrients end up as food residues in municipal waste and as excreta that is flushed to the sewers down to waste water treatment plants. In both cases, limited fractions of the nutrients are recovered, and their release in the environment causes significant pollution to the water and soil. The CAFE project provides methods and tools to evaluate the nutrient deposits generated by the population of a given territory. From these spatialized deposits, we can then evaluate collection and transformation methods to make fertilizer and amendmen that will be returned to agricultural parcels

### Methodology

In this presentation, we will show how to quantify the spatial distribution of organic matter and nutrients using open- source software[OrgMatt] and open data. To do this, we will discuss how to compute the eating and excreting population and its location over a given territory, as wel as how to estimate the amount and composition of organic matter that is generated. Using geospatial and network analysis [NNGT], we will then see how to account for the logistics necessary for the storage and collection of source-separated biowaste and excreta.These results will also be used to include logistics' impacts in the life-cycle analysis (LCA) of the bio-based fertilizers.

### Results and discussion

We will discuss several collection and treatment scenarios for different cities and territories in France and how the bio-based fertilizers may answer local agricultural demand today and in the future, depending on the evolution of food production and comsumption patterns. The environmental impacts of the new logisitics of organic matter management and fertilizer production computed by LCA methods will be compated to standard practices for fertilizer synthesis and waste (water) treatment.

### Conclusion

Through these tools and methods, we are able to provide a detailed spatial assessment of the main organic matter deposits in urban areas, together with the associated nitrogen, phosphorus, and potassium distribution. As they rely on open data for the territory of interest, these methods provide locally relevant information and can help determine which specific collection and transformation schemes are suited for a given area.

### Acknowledgements

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OrgMatt.

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## Session 1 - Soil Quality

### Has applying organic matter to land in Scotland increased the microplastic content of soils?

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### Introduction

Organic waste such as treated sewage sludge is regularly applied to land to recycle nutrients and increase soil organic matter, reducing the need for manufactured fertiliser and supporting development of a circular economy. However, microplastics, which are an emerging contaminant of concern in part due to their potential effects on human and animal health and effects on physical and chemical properties of soil (Hüffer et al., 2019), are present as a contaminant in sludge. This raises the question of whether spreading sludge on agricultural land is introducing microplastics into the soil (Mahon et al., 2017). The current study screened samples taken from farms in Scotland which have had organic waste applied, comparing fields which had been spread with those on the same farm which had not had organic waste applied.

### Methodology

The first stage of this study aimed to develop a method of microplastic analysis which was cost effective and provided results consistent enough to allow for comparison between fields. The final method settled upon for this used hydrogen peroxide to digest organic matter, followed by microplastic extraction with vegetable oil, and a two stage pouring off procedure. Nile Red dye was used to stain microplastic particles, which were then visually counted under a 40x microscope.

### Results and Discussion

As microplastics have been found in sewage sludge, this study has initially looked primarily at farms where sewage sludge had been spread to land. However, further work is planned to look at farms across Scotland which have been spread with other organic wastes, such as distillery waste, to compare the plastic loading in soils receiving different types of waste. Results from this study are still being analysed, although microplastic counts for most of the sewage sludge samples have been completed. Preliminary analysis of data suggests that plastic film and particles are elevated in fields with sewage sludge applications on some of the farms sampled, but plastic fibres show a less obvious difference in levels. Full results from the study will be presented at the conference in September.

### Conclusion

The results of this study will highlight whether microplastics are being introduced to agricultural soils through waste spreading to land and help to establish which wastes are responsible for this. To inform future regulatory needs, results from this study must be combined with those from future work on the impact of microplastics on soil health, the wider environment and crops and livestock, and with results from investigations of the transport behaviour of plastics in the soil environment. This should allow safe limits for microplastics in soil to be estimated and therefore enable us to establish regulation/guidance to reduce risk of unsafe accumulation of microplastics in soil associated with waste spreading to land.

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## Effects of Manure Land Application on Soil Health Indicators

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### Introduction

A state-wide incentive program in Missouri has been offered to encourage the adoption of cover crop to improve water quality and soil health. Manure application information has been requested along with the soil samples collected since 2016. This provides a unique opportunity to examine the overall effects of manure land application on soil characteristics, especially those that have more implications for soil health improvement. In order to better examine the effects of manure land application on soil characteristics under similar management and soil type, a set of research plots was set up at a university research farm as well. This abstract presents the correlations between manure application and soil health indicators, and crop yield.

### Methodology

The team collected, assembled, and analysed the data of soil health-related variables, crop rotation and yield, and manure application details of the samples sent in across Missouri. Critical land application of manure data being asked in the submission form included information such as manure type, tons/acre, and method applied. The manure-related information was collected since 2016, thus this data set does not include data prior. Key soil health indicators analysed are nitrogen, phosphorous, organic carbon, active carbon, exchangeable cations, bulk density, and water stable aggregates, and biological analysis, phospholipid fatty acid (PLFA). For the research plots, dimensions were 4.6mx9.2m, at a Research Farm of University of Missouri, near Columbia. The soil of the research plot is Mexico Silt Loam. The control plots included corn/soybean rotation that received chemical fertilizer following agronomic rate. The treatments included either a) Rotation: corn/soybean and corn/soybean/wheat; b) Cover crop: minus and plus cover crop; and c) Fertilizer: minus (using chemical fertilizer) and plus manure application. Each of the treatment had four replicated plots. Soil samples (15cm) were taken from each plot twice per year, to characterize the changes in soil health indicators.

### Results and discussion

A total of 8,490 soil samples were received from 96 counties across Missouri state from 2016 to 2019. Among the soil samples, 72.45% (n= 6,151) were treated with inorganic/chemical fertilizers, while 10.24% (n= 869) were from fields that received manure, and 1,470 samples (17.31%) were undefined due to lack of information in the submission form. A total of 5,405 samples (63.66%) were recorded with no cover crop practice history, and the cover crop practice group had 2,451 soil samples, or 28.87% of the total samples. The t-test results indicate that the manure application resulted in significantly higher amounts of nitrogen, phosphorous, active carbon and organic carbon content, while exchangeable cation was higher for inorganic fertilizer application. State-wide data also showed that except for organic carbon and bulk density, other soil health properties were significantly affected by cover crop practice. The nitrogen, phosphorous, and active carbon contents were higher in the cover crop practice group than in the non-cover crop group. For the research plot data, only crop yield data is available. Inorganic fertilizer application significantly increased the corn yield than observed for the plots with manure application. Interestingly, the application of manure significantly promoted the soybean yield compared to inorganic fertilizer application. On the other hand, soybean yield was significantly lower for cover crop practice compared to no cover crop practice. The cover crop and application of manure did not increase wheat yield significantly when compared with inorganic fertilizer application.

### Conclusion

The manure land application and cover crop practice are showing different impacts on soil health indicators and crop yields. More soil samples across the state are being collected and corresponding soil health analyses are being conducted, along with the field experiment at the university farm is being continued. Outreach activities include a poster presentation at the International Meeting of the professional society, and a webinar.

### Acknowledgements

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**The Manure and Organic Replacement Experiment (MORE) - effects on soil properties and crop production efficiency from different soil amendments.**

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## Introduction

The benefits of increasing soil organic matter for agronomic performance and soil physical and biological properties is well documented. The challenge for land managers in Eastern England is obtaining and applying sufficient organic material to build soil organic matter to levels that influence soil function. The Manure and Organic Replacement Experiment (MORE) is a long-term experiment (2011-present) examining the use of different sources of soil amendments on soil properties and crop performance. The fully factorial, three replicate experiments have received either a single dose (diminished, applied in year 1) or repeated doses (augmented, applied in year 1,4,7, and 10) of either turkey manure (TM, ca. 8 ha-1), green waste compost (GWC, ca. 35 ha-1) or paper crumble (PC, ca. 50 ha-1) compared to untreated. The soil is a sandy clay loam following the on-farm rotation of winter wheat, with sugar beet and combinable break crops including spring peas, winter oilseed rape, spring oats and spring barley.

## Methodology

Soil physical properties including soil bulk density, infiltration and visual evaluation of soil structure (VESS) are recorded annually. Soil chemical properties including P,K,Mg and soil organic matter are also monitored annually at the plot level. Annual plot level agronomic measurements include yield, grain N content, specific weight, head counts and plant counts. An extension study has also developed a novel methodology integrating nutrient budgeting with yield analysis to calculate nitrogen, phosphorus and potassium efficiency of food production in each system (Willoughby et al., 2022). Soil health metrics were then compared for each organic amendment management to describe system soil health and productivity.

## Results & Discussion

Across years results show that repeated application of soil amendments over a relatively short time span (10 years) can significantly decrease bulk density and increase soil organic matter content, infiltration rates, soil macroporosity and nitrogen supply, all of which were linked to increases in relative yield %. However, the scale of these effects is dependent on the amount and type of organic amendment used. Nutrient budgeting has shown that the TM and GWC play a key role in contributing to balance phosphorus management compared to paper crumble and untreated plots. The augmented use of amendments avoids an overall soil organic matter deficit. Amendment use has only shown small impacts on crop productivity to date however significant response to amendments have been recorded in individual years but not across the rotation as a whole.

## Conclusion

This work has demonstrated that soil physical properties can respond to repeated us of organic amendments relatively quickly and benefits to soil function can be achieved. The impact of these changes on crop productivity is small, however other long-term studies (NIAB, 2022) have demonstrated these effects might be obtained over longer time scales. A novel method integrating nutrient budgeting and yield analysis has also been demonstrated and can be of value to other studies monitoring soil health and crop productivity.

## Acknowledgements

The experiment is located at and supported by The Morley Agricultural Foundation (TMAF), Norfolk, England.

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## Impact of trace metal excess in cow diets on the agro-ecosystem: a preliminary study

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### Introduction

There is little information on whether current dairy production practices promote the accumulation of trace metals (TM) in the environment. A recent study (Duplessis et al. 2021) showed that 99% of cows in 100 Eastern Canadian dairy herds were fed diets higher than their Co and Mn requirements, and about 85% of them were fed diets higher than their Cu and Zn requirements according to the new guide of nutrient recommendations for dairy cows (NASEM, 2021). The aim of this preliminary study is to evaluate over a period of two years whether diets given to cows influence the content of TM in milk, feces, urine, manure, soils receiving manure as well as in sediments and water.

### Methodology

Samples of cow diets, milk, urine, feces from 100 cows, manure and soils, were collected from five Eastern Canadian dairy herds at different times during a period of two years to determine their TM content (Co, Cu, Mn, Zn, etc.) and other properties. Sediments and water from a stream adjacent to the field receiving the manure were also sampled. Samples of milk, diets, urine, feces and manure were digested for their total TM content following USEPA 3051 method (USEPA, 2007). Surface soil (0-20 cm) in the field and in the riparian strip as well as sediments samples were digested following USEPA 3050B (USEPA, 1996). The soil samples and sediments were additionally extracted with the Mehlich-3 (M3) solution (Ziadi and Tran 2007). All samples were analyzed with and ICP-OES.

### Results

Dairy diets from participating herds provided 72%, 31%, 84% and 11% more Co, Cu, Mn, and Zn than recommended, respectively, but there were also variations between farms. Spearman correlation coefficients between TM concentrations in diets and feces were between 0.50 and 0.55, which is strong suggesting that potentially high levels of TM will be applied to the soils through manure application.

Soils and sediments pH varied between 5.9 and 6.4 and between 7.1 and 7.9 respectively. In general, TM-M3 contents were higher in the soil compared to the riparian strip which is consistent with the fact that no manure is applied in this area. However, TM-M3 contents were higher in the sediments compared to the soil samples except for Cu. Results also confirmed that feces are a more important source of excretion of TM than urine.

### Conclusion

This project shows results over two years but it will be important to evaluate the impacts of feeding excess TM to cows over the long term in order to better understand and evaluate the negative impacts on the environment that may occur. This project also raises awareness on the importance of avoiding TM excess in dairy cow diets.

### Acknowledgements

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## Soil phosphorus after 20 years of high-dose application of different organic wastes

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### Introduction

Sourcing fertiliser phosphorus (P) from organic wastes (OW) produced in urban or agricultural environments represents a more sustainable strategy than fertilisation with mined mineral P. However, organic wastes contain diverse P forms and complex organic matrixes. Studies on long-term field experiments (LTFE) have looked into the effect of fertilisation strategies on soil P (distribution of P into fractions obtained with a sequential chemical fractionation (Moir & Tiessen, 2007), C:N:P ratios, P stored in the microbial biomass). Phosphorus fraction distribution was found to remain stable across gradients of fertilizer P inputs and fertilization strategies (Hu et al., 2022). However, in the Danish CRUCIAL LTFE, OW applications have provided yearly 100 kg N ha-1, resulting in P inputs in the range of 0-621 kg P ha-1 a-1. At the OW inputs of the CRUCIAL LTFE, we hypothesized that different OW treatments will result in differences in the P fraction distributions, and on the size of the soil microbial biomass and its ability to store P since no P limitation is foreseeable for microorganisms at the mentioned P inputs.

### Methodology

We have measured the P fraction distribution (P fractions (extractant): Resin-P (anion exchange resin), Microbial-P (anion exchange resin and hexanol), Organic-P (0.25M NaOH), Adsorbed-P (Inorganic P in 0.25M NaOH) and HCl-P (1M HCl) and total nutrient contents (C, N, P), of OW applied to the CRUCIAL LTFE in 2008, 2018-2021, and of the soils in the CRUCIAL LTFE in 2021 and 2022. The organic wastes and their corresponding soil treatments were compost, sewage sludge and cattle-derived slurry, manure, and deep litter.

### Results and discussion

The largest P-fraction in Compost and sewage sludges is Adsorbed-P, comprising more than 50% of total P. Cattle-derived OW have most P in the Resin-P fraction (20-50%). All studied OW contain significant amounts of Organic-P (20-30% of total P). However, in soils, we found no significant differences between the sizes of Organic-P and Microbial-P across treatments. All treatments accumulated P in the Resin-P and Adsorbed-P fraction, compared to control treatments with balanced P inputs vs. outputs. Moreover, we found both Resin-P and Adsorbed-P fractions to be strongly correlated (0.8 r2). This indicates that, the P fraction distribution in the OW had no effect in P fraction distribution in the soil. Total C, N and P of the soils are clearly differentiated across OW treatments, however, soil molar C:N ratios remained at 10:1, which has been described as a typical ratio in Danish sandy loams (Sørensen, 1983). The size and C:N ratio of the soil microbial biomass did not change across treatments.

### Conclusion

Despite P inputs that greatly exceed P offtakes, we could not find soil P in the CRUCIAL LTFE to resemble the P fraction distribution found in the applied OW, neither an impact on the size and P content of the soil microbial biomass.

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## Impacts of different management practices and site conditions on soil acidification rates in long-term experiments

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### Introduction

Excessive mineral nitrogen (N) fertilizer application in Southern China has accelerated soil acidification. This has resulted in a decrease in soil pH, with potential impacts on the yield of crops in non-calcareous soils when the pH drops below 5.5 (Zhu et al., 2020). Replacing mineral N fertilizers with manure is a solution because it adds buffering materials, which prevents acidification (Cai et al., 2021). However, using manure may also increase soil acidification through nitrogen mineralization. Additionally, the effects of mineral fertilizers and manure on soil acidification may differ depending on site conditions such as climate and soil properties. This study aimed to quantify impacts of different combinations of mineral fertilizers and manure and site conditions on soil acidification rates, based on data from long-term experimental sites.

### Methodology

Soil acidification rates were quantified based on inputs (atmospheric deposition, mineral fertilizer and manure), uptake (crop removal) and losses of major elements ($NH_4^+$, $NO_3^-$, $SO_4^{2-}$, $H_2PO_4^-$,$Ca^{2+}$, $Mg^{2+}$, $K^+$, $Na^+$, $Cl^-$, $HCO_3^-$, as well as the main driving factors of soil acidification being natural acidification due to $HCO_3^-$ leaching, N transformations (conversion of $NH_4^+$ to $NO_3^-$ followed by $NO_3^-$ leaching) and crop removal. Related data were collected from 13 long-term experimental sites in southern China.

### Results and discussion

Compared with mineral fertilizer treatment, low acidification rate was found under treatments with manure, regardless of soil type. The dominant driver of acid production varied with different fertilizer treatments and soil types. In general, N transformations was the main driver of acidification in all fertilizer-treated non-calcareous soils. In calcareous soils, $HCO_3^-$ leaching dominates under mineral fertilizer treatment, while N transformation is more important under manure treatment. Acid production by N transformation increases with soil N surplus and precipitation surplus, but decreases with higher soil organic carbon. Acid production by $HCO_3^-$ leaching showed a strong relation with land use (higher in paddy than in upland soils) and also increased with an increase in precipitation surplus.

### Conclusion

Manure application can indeed counteract soil acidification by adding base cations and $HCO_3^-$. Since the dominate acid production process and main factors varied with different fertilizer treatments and soil types, the optimal crop management must be determined according to specific site conditions to control soil acidity efficiently and improve fertilizer use efficiency.

### Acknowledgements

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## Ammonia emissions and nitrogen use efficiency of untreated and plasma treated digestate

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### Introduction

Ammonia losses from the storage and spreading of organic materials accounts for c.35% of ammonia emissions from UK agriculture. Ammonia emissions can be harmful to human health, contribute to acid rain, damage sensitive habitats, and represent a loss of crop available nitrogen. Digestate pH controls the chemical equilibrium between ammonium (NH4+) and ammonia (NH3). Reducing digestate pH reduces losses of ammonia by shifting this equilibrium towards a higher proportion of ammonium nitrogen, which is retained in solution. The N2 Applied plasma treatment is a new method for reducing ammonia emissions whilst simultaneously increasing the crop available nitrogen content.

### Methodology

A field experiment was set up on a sandy loam soil in Nottinghamshire in April 2020 to compare ammonia emissions and nitrogen use efficiency (NUE) of plasma treated and untreated digestate applied to a winter wheat crop. Digestate was bandspread to supply c.240 kg total N per hectare for the plasma treated digestate (20 m3 ha-1) and 214 kg total N per hectare (40 m3 ha-1) for the untreated digestate. Other treatments were nitrogen response plots (ammonium nitrate at 50, 100, 150, 200, 250 and 300 kg nitrogen per hectare) and a no nitrogen control. Each treatment was replicated four times. Ammonia emissions from the digestate treatments were measured for one week after application using one wind tunnel per plot, based on the design developed by Lockyer (1984). At harvest (August 2020) crop yield and grain/straw N concentrations were measured and used to calculate fertiliser replacement values (an indication of the amount of manufactured mineral N fertiliser saved when using digestate) and NUE of the applied digestates.

### Results and discussion

Ammonia emissions from the plasma treated digestate (21 kg ammonia N ha-1) were significantly lower than from the untreated digestate (102 kg ammonia N ha-1) ($P<0.01$). The emission factors (% of total N applied) were 8% for the plasma treated digestate and 49% for the untreated digestate ($P<0.01$). Most of the ammonia losses from the untreated digestate occurred in the first 24 (c.50% of total) to 48 hours after application (c.70% of total). In comparison, for the plasma treated digestate, there was no initial peak in ammonia emissions after application, which remained low throughout the duration of the 7-day monitoring period.

Plasma treated digestate numerically increased winter wheat yield by c.0.8 t ha-1 ($P=0.06$) compared with the untreated digestate. In addition, the grain nitrogen content of the plasma treated digestate (2.45 kg N ha-1) was higher than from the untreated digestate treatment (1.98 kg N ha-1), ($P<0.01$). Similarly, the straw nitrogen content of the plasma treated digestate (0.82 kg N ha-1) was higher than from the untreated digestate treatment (0.66 kg N ha-1), ($P<0.05$).

Winter wheat yield and nitrogen offtakes responded to manufactured fertiliser and NUE was calculated using both the yield and offtake methods. The NUE based on crop offtake of the plasma treated digestate (59%) was higher than the untreated digestate (21%) ($P<0.05$). Fertiliser replacement value (based on crop N offtake) of the plasma treated digestate was 146 kg ha-1 compared to 46 kg N ha-1 for the untreated digestate ($P<0.05$).

### Conclusion

Plasma treatment significantly reduced ammonia emissions (c.80%) from digestate so that more nitrogen was retained in the digestate and available for crop uptake. As a result, the fertiliser value of the digestate was increased (compared to the untreated digestate) which increased crop yield and grain nitrogen content and reduced the requirement for purchased N fertiliser applications to meet optimum crop demand.

### Acknowledgements

Funding of this work by N2 Applied is gratefully acknowledged.

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## Greenhouse gas fluxes from winter wheat fertilised with treated and untreated pig slurry

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### Introduction

Greenhouse gas (GHG) emissions from the agricultural sector are of increasing concern as they impact air quality and contribute to climate change. The storage and spreading of livestock waste contribute significantly to these emissions, and there is an urgent need to develop new processing technologies to treat slurry to improve nutrient utilisation and minimise environmental impacts. This study compares GHG emissions over 83 days from winter wheat plots fertilised with (i) inorganic fertiliser, (ii) pig slurry and (iii) nitrogen (N)-enriched pig slurry. It was hypothesised that GHG emissions would be greatest from the organic treatments, and highest from the N-enriched pig slurry.

### Methodology

A randomised block experiment (3 x 3) was established at the University of Leeds research farm. Each block consisted of a plot measuring 2 m x 0.5 m and an automated chamber of 0.5 m diameter, both planted with winter wheat in October 2021. The chambers measured CO2, CH4, and N2O fluxes every two hours continuously between March and June 2022. The fertiliser treatments were (i) inorganic fertiliser (IF), (ii) pig slurry (PS) and (iii) treated pig slurry (TPS) which was N-enriched via plasma induction. Fertiliser was applied across four applications and each plot and chamber received the same amount of available N (220 kg N ha-1). Over the growing season, vertical extensions were added to the chambers to accommodate the growing crop. At the end of the experiment, the crop was harvested from the plots and yield compared.

### Results and discussion

Total CO2-equivalent emissions were greatest from TPS, followed by PS and IF. N2O-N fluxes constituted the majority of GHG emissions for the TPS treatment, whereas for the PS treatment it was CH4. Cumulative N2O-N fluxes were significantly greater from TPS (1.38 g m2) compared to PS (0.3 g m2, P=<0.05) and IF (0.18 g m2, P=<0.05). Large peaks in N2O-N emissions were observed following TPS application and remained elevated for five days before returning to pre-fertilisation levels; N2O-N emissions also peaked following PS application but were lower in magnitude. Cumulative CH4-C fluxes were significantly greater from PS (0.28 g m2) compared to TPS (-0.14 g m2, P=<0.05) and IF (-0.05 g m2, P=<0.05). CH4-C fluxes peaked immediately after the application of PS and remained elevated for one day before returning to pre-fertilisation levels. CO2-C emissions were not influenced by the type of fertiliser and emissions from all treatments followed a strong diurnal pattern. There were no significant differences observed in yield (t ha-1) between the three treatments. The higher cumulative N2O-N emissions from TPS can be attributed to TPS having a higher proportion of fine solids and a higher N content than IF and PS, so its N is more accessible to soil microorganisms for transformation to N2O (Chadwick et al., 2000). During slurry storage, CH4 is first produced and dissolved into PS, then volatilised and emitted following application (Bastami et al., 2016). There was no CH4-C emission response from the IF and TPS treatments; IF contains no carbon source for CH4 production (Moreno-Garcia et al., 2020), and the plasma induction process used to produce TPS results in no CH4 production during storage, and subsequently no emissions at application.

### Conclusion

Our results provide a near continuous record of CO2-C, CH4-C, and N2O-N emissions from a winter wheat crop amended with organic and inorganic fertilisers over a three month period. The TPS treatment had the highest emission of N2O on application, which resulted in the greatest overall CO2-equivalent losses from the TPS treatment, followed by the PS and IF treatments; as there was no significant difference in yield between treatments, the TPS treatment therefore had the highest GHG emission intensity. Future work will consider a life cycle analysis approach to determine GHG emissions during both storage and application, to ascertain which the full climatic impact of fertiliser applications.

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## Does acidification of livestock slurry at land spreading increase greenhouse gas emissions?

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### Introduction

Agriculture is responsible for c.85% of UK ammonia (NH3) emissions with livestock slurry accounting for c.35% of losses. With targets to reduce NH3 emissions, slurry acidification has been identified as a potential abatement measure. Acidification reduces NH3 loss and conserves mineral nitrogen (N) in the soil, which may increase emissions of the greenhouse gas (GHG), nitrous oxide (N2O). The UK is committed to achieve net zero by 2050, therefore it is important that measures implemented to reduce NH3 emissions do not result in increased GHG losses.

### Methodology

Field experiments were carried out at two arable sites (central England, sandy loam soil & east England, clay soil) and two grassland sites (south-west England, clay soil & north Wales, sandy clay loam soil). At the arable sites in autumn (2019) and spring (2020), pig slurry was applied via trailing hose and surface broadcast methods. At the grassland sites in spring 2020 and summer 2021 following silage cuts, cattle slurry was applied to simulate band spread and surface broadcast methods. Nitrous oxide and methane (CH4) emissions were measured using the static chamber (3 chambers/plot; 5 replicate plots) technique. A control treatment was included where no nitrogen (N) was applied. Alongside GHG measurements, topsoil samples were taken to determine soil mineral N and moisture content.

### Results and discussion

Following both the autumn and spring application timings at the arable site in central England, pig slurry acidification reduced NH3 emissions by c.60-75%, which was reflected in the greater ammonium-N content of the topsoil from the acidified treatments than non-acidified. Although this conserved N risked increasing N2O emissions, there was a reduction ($P<0.05$) in N2O loss following acidification, suggesting it was not only soil mineral N availability driving emissions. Acidification is likely to have reduced the slurry soluble carbon content which will reduce the carbon available for denitrification and N2O production compared with the non-acidified slurry. Cumulative N2O emissions from non-acidified slurry applied in the autumn (0.55% total N applied) were about double those from acidified slurry (0.24% total N applied), but in the much drier spring, emission factors (EFs) ranged from only -0.07% to 0.03% total N applied.

At the east of England arable site there was no effect ($P>0.05$) of pig slurry acidification on N2O loss from both application timings, reflecting the lack of any clear treatment differences in topsoil mineral N (or slurry carbon). Emission factors ranged from 0.57-0.73% total N applied and a mean of 0.62% – similar to the new IPCC 2019 disaggregated organic material EF for wet climates of 0.6% total N applied. As observed at the central England site, N2O emissions were lower ($P<0.001$) in spring than autumn (0.15% vs 0.62% total N applied), reflecting differences in rainfall.

Following a May cattle slurry application at the south-west grassland site, there was a reduction ($P<0.05$) in N2O loss following acidification with losses from non-acidified slurry (0.26% total N applied) about twice those from acidified slurry (0.15% total N applied). However, following the later July application, N2O emissions on the acidified treatment (0.50% total N applied) were c.2-fold greater ($P<0.01$) on the non-acidified slurry, reflecting the topsoil nitrate-N content, which was higher on the acidified slurry than the non-acidified treatments. Following all three application timings (March, June & August), at the grassland site in North Wales, there was no effect ($P>0.05$) of acidification on N2O loss, likely due to very dry soil conditions with mean EFs of 0.08%, 0.17% and 0.07% total N applied.

At both arable sites on the day of application, acidification reduced ($P<0.05$) CH4 emissions to those from the control treatment reflecting inhibition of methanogenic activity. Similarly, at the grassland sites acidification reduced CH4 emissions, although after the August application in North Wales, there were signs of CH4 uptake from all treatments.

### Conclusion

This UK study shows that acidification of livestock slurry at land spreading on N2O emissions was inconsistent, with an increase, decrease or no effect of acidification, probably reflecting differences in slurry composition (especially readily available N and carbon content) and soil conditions around slurry application. Acidification consistently reduced CH4 emissions up to two days after slurry application.

### Acknowledgements

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## Mitigating ammonia emission from slurry digestate applied to winter wheat crops: effect of digestate composition, digestate treatment, and application technique

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### Introduction

Biogas from anaerobic digestion of a broad spectrum of waste feedstocks is a renewable energy source that can substitute fossil fuels. The effluent from the process (digestate) can be utilized as a fertilizer in agricultural crop production. Utilizing liquid animal manure (slurry) as a feedstock for biogas production reduces greenhouse gas emissions from the slurry considerably (Møller et al., 2022).

The digestion process changes the chemical and physical properties of the slurry considerably; therefore, the ammonia (NH3) emission potential of the digestate is different from the raw slurry entering the biogas reactor. Most data presented in the literature showed that digestion increased pH and lowered. These two changes would tend to counteract each other, resulting in similar emission for raw slurry and digestate. During the last decade, more recalcitrant high DM biomass, such as straw, has been utilized for biogas production in Denmark. This change in feedstock modifies digestate characteristics. The increased DM content of actual digestates has the potential to drastically increase the NH3 emissions after field application compared to past digestates with different feedstock.

Dry matter is known to have a large effect on emissions. However, it is hypothesized that it is not solely the DM content of the slurry or digestate that affects infiltration into the soil, and thereby NH3 emissions after field application, but also viscosity. While for cattle and pig slurry, DM and viscosity have been found to be linearly correlated (Thygesen et al., 2012), recent measurements from 23 Danish biogas plants show that this relationship is not strong and a large variation in these parameters exists (Romio et al., in preparation). How DM and viscosity individually and concurrently affect emissions is not known.

There is an urgent need to understand how digestate DM, viscosity, and pH affect the NH3 emissions after field application of digested slurry with different application technologies and how emission can be mitigated for high-DM digestates.

### Methodology

Nine experiments will be conducted during spring 2023 to evaluate how different digestate characteristics, treatments (mechanical treatments and acidification) and application techniques affect the emissions and which combination is most effective to reduce emissions. A new design of dynamic chambers enabling application of slurry or digestates both manually and by full-scale farm machinery will be used in combination with online measurements of NH3.

Four experiments will evaluate the effect of application with a novel trailing shoe design (Samson Agro A/S, Denmark) and the combination of the novel trailing shoe with covering of the soil with a tine. The reference application methods will be trailing hose and a commercial trailing shoe (Bomech, Bomech B. V., The Netherlands).

Five experiments will assess both different combinations of mechanical treatment and acidification of digestates from biogas plants with both high and low inputs of straw. In addition to NH3 emissions, exposed surface area after application, infiltration of the slurry, and slurry surface pH will be measured. Digestates will be selected from a wide range of biogas plants to cover a range of DM and viscosity combinations. Digestates from a total of nine plants will be investigated in these five experiments, and a total of 18 unique plant × treatment × acidification combinations will be assessed.

### Results and discussion

Anticipated results will give unique insight into the effects of DM and viscosity on infiltration and NH3 emissions from field applied digestates. Furthermore, knowledge of the effect of different mechanical treatments, acidification and application techniques will give valuable information to biogas plants and farmers on how to deal with digestates that have a high emission potential.

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**Mitigation of ammonia and global warming potential with slurry treatments during slurry storage and after landspreading in a North-Western Atlantic climate**

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## Introduction

Storage of cattle slurry and subsequent application to grassland leads to the release of pollutant gases (e.g., ammonia (NH3), methane (CH4) and nitrous oxide (N2O)) which undermine the sustainability of agricultural production. Irish agriculture accounts for 99% of NH3 emissions. Manure management and landspreading of slurry accounts for almost 80% of this total. Similarly, the agricultural sector in Ireland contributes the largest share (38%) of greenhouse gas (GHG) emissions with manure management and agricultural soils contributing almost 34% of this total. Treatment of cattle slurry by acidification and amendments has the potential to abate NH3 during slurry storage and application to soil and potentially increase slurry fertiliser value. However, there is limited information regarding the impact of these treatments on global warming potential (GWP) and grass yield in Ireland. The goal of this study was to assess the efficacy of slurry treatments on NH3 and GWP during storage and after landspreading of slurry.

## Methodology

Two experiments, namely slurry storage experiment and a landspreading experiment were conducted to achieve the goals of this study. The storage experiment was carried out at a pilot scale with 660 L of slurry in underground storage tanks to simulate Irish storage conditions. The storage experiment, which lasted for two months, was conducted as a completely randomised design with three replicates and four treatments namely: slurry, slurry + sulphuric acid, slurry + biochar and slurry + gypsum. Slurry pH was monitored throughout the storage period. NH3 was sampled using the dynamic chamber with the acid trap technique whereas GHG (CH4) was sampled using the static chamber technique. The landspreading experiment was a plot-scale trial carried out on a permanent grassland site at the Teagasc research centre in Johnstown Castle, Wexford and AFBI research centre in Loughgall, Co. Armagh. The landspreading experiment was conducted as a fully randomized block design with five blocks incorporating agronomy plots (4 m x 2 m) and microplots (1.5 m x 1.5 m) for NH3 (three blocks) and N2O (five blocks) measurements. The landspreading experiment used the same treatments as the storage experiment in addition to two other treatments, namely; protected urea (i.e., urea fertiliser treated with urease inhibitor N-(n-Butyl)thiophosphoric triamide (NBPT)) and control (without N fertilisation) to make up six treatments in total. Treatments were applied to agronomic and microplots on the same day at a rate of 40 kg N ha-1 per application in three split applications cross the two sites. Dry matter yield was measured after each of three harvests, N2O was measured frequently throughout the growing season with static chambers, whereas NH3 was measured within the first week after slurry application using dynamic chambers coupled with an INNOVA gas analyser.

## Results and discussion

Results from the storage experiment indicate NH3 reduction of 68, 39 and 28% for the sulphuric acid, gypsum and biochar amended slurries respectively relative to the untreated slurry. Methane from slurry storage was reduced by 42 and 32% in the sulphuric acid and gypsum treatments respectively relative to the untreated slurry. In contrast, biochar tended to increase (8 %) CH4 relative to the untreated slurry. Slurry acidification with sulphuric acid consistently reduced NH3 from slurry landspreading whereas the other slurry amendments (i.e., biochar and gypsum) showed variable results. N2O emission factors were in the order; slurry + sulphuric acid (0.23%) > slurry + gypsum (0.17%) > untreated slurry (0.11%) > slurry + biochar (0.09%) > urea + NBPT (0.04%). The GWP of slurry treatments during slurry storage and landspreading followed the order: slurry + sulphuric acid (14 T CO2-eq ha-1) < slurry + gypsum (16 T CO2-eq ha-1) < Slurry (23 T CO2-eq ha-1) < Slurry + Biochar (25 T CO2-eq ha-1). Grass yield ranged from 1.3 to 6.4 t ha-1 corresponding to the control and protected urea treatments respectively There were no significant differences between the treatments relative to yield.

## Conclusion

Overall, slurry acidification proved to be an effective strategy to mitigate NH3 and GWP during slurry storage and landspreading.

## Acknowledgements

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## Greenhouse gas fluxes from organic fertilisers in cereal production and their residual effects

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### Introduction

Anaerobic digestion for biogas production leaves behind a digestate that is a valuable source of nutrients and especially of nitrogen for new biomass production. It also contains some organic material that will be a potential carbon source for microorganisms in the soil. In agriculture, liquid digestates and slurry may be used in similar ways, and their application to soil is expected to increase microbial activity in general although properties may vary widely. With respect to greenhouse gas emissions, differences are likely, not only between slurry and digestates, but also among digestates based on different feedstocks. The aim of this study was therefore to determine greenhouse gas (GHG) emissions following the application of different liquid organic fertilisers, both in the field and under controlled conditions.

### Methodology

In a field experiment on a loamy soil in south-eastern Norway, cattle slurry and two biogas digestates, one based on food waste, and one based on a mixture of food-waste and sewage sludge, were compared to mineral fertiliser. During two field seasons, greenhouse gas emissions were measured using a static chamber method, taking gas samples from closed chambers at several time points during the season. In the first season, measurements started after the addition of the different fertilisers and sowing, whereas in the second season, measurements were also taken before spreading of the fertilisers, as well as during the growing season. After three years of addition of different organic fertilisers, an incubation study of the field soil was carried out, in which GHG fluxes were followed repeatedly over a period of eight weeks. In addition, the organic fertilisers were added to previously untreated loam from the field area and to a sandy soil, and incubated, all at 20 °C.

### Results and discussion

CO2 fluxes measured did not differ clearly between organic and mineral fertilisers. In the second season, there was a clear pattern of higher emissions from the organic fertiliser treatments throughout the season. The highest CO2 fluxes were recorded in the plots with cattle slurry, followed by the digestate based on food waste, whereas the digestate based on a combination of food waste and sewage sludge resulted in low emissions until late in the growing season. N2O fluxes were generally higher from organic fertiliser treatments. During the first, rather dry season, N2O emissions were generally low until heavier precipitation episodes in the autumn. N2O emissions then reflected amounts of plant-available nitrogen in the soil, with particularly high emissions for the mineral fertiliser and the food waste/sewage sludge-based digestate treatments.

In the soil samples that were incubated after three years of fertiliser additions in the field, overall CO2 fluxes were highest for the treatment that had received digestate based on food waste, whereas the digestate based on a mixture of food waste and sewage sludge showed lower CO2 fluxes, also compared to slurry. N2O fluxes were highest from the slurry treatment. With new addition of fertilisers for the incubation, similar patterns of emissions were found.

### Conclusion

The results suggest that qualitative differences in digestates depending on feedstock have an impact on microbial activity and thus GHG emissions. Additionally, other factors such as soil type must be considered.

### Acknowledgements

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Session 2 - FertiCycle

## Disclosing the P dynamics in soil treated with pH modified animal slurry; A rhizobox study

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### Introduction

Phosphorus (P) is an essential plant macronutrient involved in a plethora of biochemical reactions. Application of animal slurry to the soil is a bio-based alternative to mineral fertilisers and is considered a valuable source of P (Fangueiro et al., 2021). Slurry acidification with chemical additives can increase P solubility in slurry and consequently improve its fertiliser value. However, strong acids, such as sulfuric acid (H2SO4), are highly corrosive substances and therefore should be handled by specialized workers. On the other hand, slurry alkalinization with chemical additives has been proven to result in a sanitized material (Rodrigues et al., 2021). Agro-industrial by-products can serve as alternative additives and substitute or replace the use of chemical ones. The present study aims to assess the P dynamics in the soil-plant system after surface application of pig slurry treated with different products to modify its pH.

### Methodology

The impact of treated slurry on maize growth and root development was assessed by using rhizoboxes. The low P soil used was labelled with 33P to reach a final activity of 0.9 MBq kg-1 dry soil. Three strategies were used to modify the pH of pig slurry: 1) acidification to pH 5 with H2SO4 and Spent Acid1, 2) alkalinization to pH 9.5 with potassium hydroxide (KOH), 3) bio-acidification to pH 5 after sucrose addition (30g kg-1) to a pre-acidified slurry (H2SO4_pH6+Suc30). Raw and treated slurry were surface applied in each rhizobox at a rate of 40 mg P kg-1 soil. Fertilization with the inorganic fertilizer triple superphosphate (TSP) was used as a positive control, whereas a treatment without fertilizer application acted as a negative control (CNT). After harvesting, soil was analysed for acid phosphomonoesterase (ACP) and root colonization by Arbuscular mycorrhizal fungi (AMF). Analysis also involved P quantification deriving from the soil and fertiliser.

### Results and discussion

The highest P uptake from the fertiliser was achieved by TSP and H2SO4-treated slurry (51 and 45%, respectively), whereas raw slurry and KOH treatments showed the lowest (8 and 3%, respectively). This is in agreement with an increased P solubility (>70 % TP as water-extractable P) in all acidified materials that therefore facilitated P uptake by the plant. Nevertheless, the soil P uptake was similar in CNT, RS and KOH while it seemed to have decreased in Spent.A (3.3 mg P plant-1) and H2SO4_pH6+Suc30 (2.64 mg P plant-1) treatments. Below ground images taken during the growth of maize further support the low root dry weight of Spent.A and H2SO4_pH6+Suc30 (0.76 and 0.74 g, respectively). In addition, all treatments involving slurry acidification exhibited lower ACP values (<100 µg PNP g-1soil 75-1 min) than the CNT and TSP treatments, whereas ACP in the KOH treatment was high with >200 µg PNP g-1soil 75-1 min similar to that of the CNT. Despite that all treatments showed low root colonization (<20% total root length colonised) by AMF, the highest mycorrhiza colonization can be seen in CNT (approx. 16%) and the lowest in Spent.A (5.5 %).

### Conclusion

From all tested additives, slurry acidification with H2SO4 is the most promising treatment to increase the TP uptake by maize crop. The by-product Spent.A and H2SO4_pH6+Suc30 treatment appeared to have a negative effect on TP and soil P uptake, probably due to phytotoxicity phenomena close to the rhizosphere zone. Based on the results, slurry alkalinization is not recommended to increase P availability, however, is a practice that should be further explored.

### Acknowledgements

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1 Sodium-sulphate sulphuric acid solution used during the bleaching process of paper making

## Biowaste materials as possible peat replacement in organo-mineral fertilizers

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### Introduction

Organo-mineral fertilizers (OMFs) are made by combining an organic fraction with one or more mineral fertilizers (MF) into a unique fertilizer (Smith, Wilson and Pagliari, 2020). Despite a low organic C concentration if compared with organic fertilisers, OMFs – that have a minimum concentration of 7.5 % Corg, according to the RU legislation (EU, 2019), can increase nutrient use efficiency compared to MF alone (Florio et al., 2016), thanks to a slow nutrient release (Kominko et al., 2017) as a results of chemical, physical and microbiological processes. Currently, peat is commonly used in commercial OMFs in Europe. Replacing peat with bio-waste materials would add a circular value to the agronomic value of OMFs and reduce depletion of peat geological formations (Kern et al., 2017). The aim of this study was to test new prototypes of biowaste OMFs on tomato crop yield, N and P uptake and nutrient use efficiencies.

### Methodology

Peat (Corg = 21%), green compost (GC, Corg = 19%), vermicompost of composted manure (VC, Corg = 20 %), or municipal solid waste compost (MSWC, Corg = 24%) were mixed with urea (U), ammonium sulphate (AS), and triple super phosphate (TSP) to produce four different granular OMFs with a similar concentration (7.5 Corg-20 N-10 P2O5). A greenhouse pot experiment was conducted using tomato seedlings fertilized at 170 kg N/ha and 85 kg P2O5/ha with the four OMFs, or a mixture of U, AS and TSP as mineral control (Min), or no fertilisers as NOfert control. Each treatment was replicated four times in a completely randomised block design. Chlorophyll indices (SPAD-502 meter) and plant growth parameters were measured weekly. Shoot and fruit biomass, root biomass, tissue N concentration (elemental analysis; Unicube, Elementar), and P concentration (malachite green method; Ohno & Zibilske, 1991) were measured after 75 days of growing. A two-way ANOVA test, with treatment and block as factors, was used to analyse the data with R studio.

### Results and discussion

Vegetation indices and growth plant parameters highlighted a similar potential of all OMFs to promote tomato plant development. However, the SPAD index showed a higher chlorophyll concentration in GC (+20% of NOfert) compared to the other OMFs (+11% of NOfert). At harvest, no significant differences in below- and above-ground biomass yields were found among the four fertilized treatments. N and P tissue concentrations and uptakes were also similar among OMF treatments and respect to Min. Consequently, contrary to previous research (Fachini et al., 2022; Florio et al., 2016), no significant differences in NUE or PUE were observed among the OMFs treatments and Min.

### Conclusion

Biowaste materials can potentially replace peat in commercial OMFs without compromising crop yield and nutrient use efficiency. However, further research is necessary to fully evaluate the feasibility of biowaste materials as an economic, industrial sustainable alternative to peat in OMFs.

### Acknowledgements

This project has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Sklodowska-Curie grant agreement No.860127

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## Phosphorus and heavy metal release from (pre-treated) biochars and ashes in a rye grass experiment and 12-month incubation

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### Introduction

Biochars and ashes derived from P-rich wastes could be used as sustainable P fertilizers improving P recycling and P transportation out of nutrient-rich areas. However, their immediate P fertilizer value is often low, especially in alkaline soils (Jeffery et al., 2017). Further, heavy metals can be up-concentrated in biochars and ashes can become plant available when applied to the soil. Chemical pre-treatments, for example with sulphuric acid, can increase their P fertilizer value (Sica et al., 2023). However, the effect of different pre-treatments on different biochars and ashes has not been tested in different soils yet. Further, the nutrient release over time from ashes and biochars has not been investigated. The objective of this study was to determine and compare the P release and P fertilizer value as well as the heavy metal release of biochars and ashes and pre-treated biochars over time and under different soil pHs.

### Methodology

Two biochars, sewage sludge biochar (SS-C) and digestate solid biochar (DS-C), and two ashes, sewage sludge ash (SS-A) and poultry litter ash (PL-A) were selected. The materials were pre-treated with sulphuric acid, and the sludge biochar with NaOH as well, before soil application to increase the plant available P. The pre-treated and untreated materials were then tested in an incubation experiment with three different soils (loam, two sandy soils with contrasting pHs) and P release was measured as WEP and Olsen-P after 1 week, 6 months and 12 months. After 1 week and 12 months, heavy metal availability (Cd, Ni, Pb, Cu) was assessed using DGTs Further, a ryegrass experiment was conducted comparing the fertilizer value of freshly incorporated materials with materials after six month soil incubation in the low and high pH sandy soil.

### Results and discussion

In the incubation, the DS-C WEP increased after 6 months reaching the same level as the pre-treated DS-C in all three soils. Similarly, the WEP of the untreated PL-A increased over time. The pre-treatments increased WEP and Olsen-P, but differences were less pronounced after 6 months. The first DGT sampling, showed an increased heavy metal availability, especially Cd, in the sulphuric acid pre-treated sludge biochar and ash treatment. The NaOH pre-treatment decreased Cd availability. In the rye grass experiment, the biomass yield was generally lower in the low pH soil and the difference between untreated materials and pre-treated was smaller. The pre-incubation did not change the effect on shoot biomass for most of the materials, except for a minor decrease in the effect of the untreated SS-A. A lower soil pH resulted in a bigger effect of the untreated DS-C and PL-A on shoot biomass compared to the high pH soil. Overall, the SS-C was the least effective material with biomass yield as low as the negative control in all soils and with and without pre-incubation. The acidified poultry litter ash had the highest biomass yields in all soils among all materials followed by the acidified digestate biochar. Especially in the high pH soil, the pre-treated materials increased biomass significantly more than the untreated materials. The data on P uptake is expected to give even clearer differences between the treatments and the second DGT sampling insights on the heavy metal availability after 12 months.

### Conclusion

Digestate biochar and poultry litter ash can be effective P fertilizers and might not require a pre-treatment, especially in low pH soils. For sludge materials, soil pH only has a minor effect on P availability. The sludge materials, especially sludge biochar, had a very low fertilizer value that only marginally increased after 6 months of incubation even in a low pH soil. The data suggests that there is no major solubilizatio

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## Application of Fourier Transform Infrared Photoacoustic Spectroscopy as rapid tool for Quantification of Nutrient Contents and their Plant Availability in manure and digestate

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### Introduction

Bio-based materials contain essential macronutrients (N,P, K, S, Ca and Mg), plant-available forms of nitrogen and phosphorus (Nitrate (NO3-N) and NH4+-N, bicarbonate-extractable P) micronutrients (Na, Fe, and Zn). Although it is recognized that manure and digestate can increase crop yields, farmers are hesitant to rely solely on them due to concerns about the unknown nutrient composition. For that purpose, traditional laboratory methods for nutrient quantification are commonly used, however, these methods are slow, expensive and are therefore, inadequate for this purpose. This study aims to assess the feasibility of using Fourier Transform Infrared Photoacoustic (FTIR-PAS) to measure nutrient contents in manures and digestates. FTIR- PAS was used to predict macro-nutrients (N, P, K, S, Ca, Mg, NH4+−N, bicarbonate-extractable P) and micro-nutrients (Na, Fe, and Zn) in manures and digestates.

### Methodology

The 122 samples used in the current study, were collected from various farms in the Netherlands and Belgium, including cow, chicken, pig manure, and digestate. The samples were air-dried at 50°C for a week, finely milled, and analyzed for total nitrogen (TN), total phosphorus (TP), potassium (K), calcium (Ca), sodium (Na), iron (Fe), magnesium (Mg), zinc (Zn), and sulfur (S) using inductively coupled plasma optical emission spectrometry (ICP-OES). To determine plant-available forms of nitrogen, ammonium (NH4+−N) and nitrate (NO3−−N) were extracted using 1 M KCl and measured using flow injection analysis. Bicarbonate-extractable P was measured using a 0.5 M NaHCO3 solution.

### Results and discussion

The prediction results for TN, TP, Ca, S, Mg, Na, and Fe using FTIR-PAS show superior performance compared to NH4+-N and Bicarbonate-P. However, the prediction capability for K is not good due to its low sensitivity in FTIR range. The results for NH4+ are in an acceptable range as suggested by Saeys et al (2005). The prediction results for TP are classified as better performance. The results for Ca, Mg, Fe, Zn, Al, and Na fall within the excellent range of prediction. The results shows the potential of FTIR-PAS to be used as a rapid analysis technique, with promising results for all nutrients ($R2 > 0.91$ and $RP\ D > 2.5$) except for bicarbonate-extractable P, K, and NH4+−N ($0.8 < R2 < 0.9$ and $2 < RP\ D < 2.5$). The results for nitrogen and phosphorus were further evaluated using a novel error tolerance-based interval method to validate if FTIR-PAS in the current state could be used to meet the accuracy's required for application in agricultural practice. The results for TN evaluated using these methods show that the FTIR-PAS is an alternative method of nutrient quantification, however the prediction of TP needs to be improved in future using more advance machine learning techniques.

### Conclusion

The study demonstrated that FTIR-PAS is a quick and efficient analysis technique to measure the nutrient content in various bio-materials. The study also proposes a new error interval-based method to address the challenges associated with conventional assessment guidelines for nutrient prediction. The proposed method provides visual and quantitative measures of assessing prediction accuracy and is applied to nitrogen and phosphorus. The results indicate that FTIR-PAS combined with the PLS model is highly effective in predicting the concentration of nitrogen, phosphorus, and plant-available forms of these nutrients. However, further research is needed to improve the prediction accuracy for K, NH4+, and plant-availability of phosphorus.

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## Increased slurry acidification does not promote S and P bioavailability and uptake in maize

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### Introduction

Slurry acidification with H2SO4 is a cost-efficient technology for mitigating ammonia emissions (Beyers et al., 2022). In addition, acidification can increase plant-available forms of N and P (Pedersen et al., 2017; Schreiber et al., 2022), yet the effect on plant uptake of N, P, and S from acidified slurry, and nutrient cycling in soil remains poorly understood. We hypothesized that a low slurry pH would increase the uptake of N, P and S by plants as a result of increasing their availability in soil. Therefore, the objective of this study was to estimate the effect of slurry pH and H2SO4 addition on plant available N, P and S in the soil–plant system. This was achieved through a pot experiment where maize (Zea mays L.) was grown with dairy slurry labelled with the radio-isotopes, 33P and 35S, and the stable isotope, 15N.

### Methodology

Dairy slurry was collected from the reception pit of a commercial dairy farm. It was sieved to remove large pieces of straw and acidified using H2SO4, resulting in four pH treatments: non-acidified slurry (pH 7.4), slurry at pH 6.0, 5.5 and 4.5. Slurry was applied to a sieved (5 mm) sandy clay loam soil in 1.5 litre plant pots, between two equivalent depth soil layers. Four maize plants were sown in each pot and plants were grown under controlled conditions for 7 weeks. Prior to application, the slurry was labelled with 15NH4 (to achieve an atom percent enrichment of 20%) and either Na235SO4 (added with H2SO4), or H333PO4 (added directly to the slurry), both radioisotopes were added to achieve a level of 68 and 25 kBq/pot. Plant height and chlorophyll (SPAD) readings were measured weekly, and root and shoot biomass were measured at harvest. The activity of 35S and 33P were determined in shoot and root biomass, soil, and microbial biomass. One-way ANOVA followed by Tukey-Kramer HSD ($p \leq 0.05$) was performed separately on each set labelled with 35S or 33P.

### Results and discussion

Despite the increased SO4-S content with the acidification, the recovery of 35S in maize was significantly higher with the minimum H2SO4 addition (pH 6), accounting for 1.44 ± 0.14 and 1.13 ± 0.14 % recovery in the shoots and roots, respectively. In comparison, the rest of the acidification treatments had similar 35S recovery, suggesting a limited S use efficiency (Ma et al., 2021). Further, slurry acidification did not significantly increase the content of PO4-P in the soil and recovery of 33P in the plant. Nutrient recovery in the microbial biomass was not affected at any slurry pH level.

### Conclusion

Increased slurry acidification with H2SO4, does not increase the bioavailability of S and P in the first 7 weeks of maize growth.

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## Effect of bio-based fertilisers on cherry tomato productivity and trace element uptake: A greenhouse study

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### Introduction

The use of waste-derived fertilisers for the production of greenhouse vegetables can efficiently contribute to sustainability and circularity (Chiaraluce et al., 2021). They can be called bio-based fertilisers (BBFs). Based on their origin and treatment they have undergone, these substrates have different characteristics and are used as nutrient suppliers (fertilisers) or as organic amendments in relation with their organic matter content and stability. Intensive studies about the efficiency and safety of these BBFs are required. This study's objective is to examine the effect of combining BBFs either considered as fertiliser or as organic amendment, on cherry tomato productivity and trace element uptake.

### Methodology

A pot experiment was conducted in a greenhouse conditions. The experimental treatments included combination of green waste compost and food waste digestate (GWC-D), green waste compost and human urine (GWC-HU), green waste compost and synthetic fertiliser (GWC-SF), food waste compost and food waste digestate (FWC-D), food waste compost and human urine (FWC-HU), food waste compost and synthetic fertiliser (FWC-SF), cow manure and synthetic fertiliser (MAN-SF), synthetic fertiliser only (SF), commercial organic fertiliser (COF) and a control treatment without any application (Control). Each treatment was replicated four times. The fertilization was ensured at a total rate of 100 mg mineral nitrogen per kg dry soil corresponding to 200 kg mineral N ha-1 in the field. For the treatments with combinations, composts and manure were first applied at 2 g C kg-1 soil (equivalent to 4 t C ha-1 in the field), followed by the addition of either human urine or digestate or synthetic fertiliser to reach the total mineral N rate while considering the mineral nitrogen already present in the composts and manure.

### Results and discussion

Statistically similar growth was observed with all the fertilized treatments regarding the tomato fruits (ranging from 290 to 325 g), their number (from 50 to 59) and average fruit weight per plant (0.85 to 1.10g) with respect to the control treatment. These results are consistent since the application were made to supply the same mineral N rate. However the combinations' effect were not perceived. Following the application of BBFs, the nitrogen content in tomato fruit significantly increased with FWC-HU displaying the highest content whereas no significant variation was observed on P, K, Ca, Mg content. Trace element (Cd, Cu, Pb, Cr, Hg, Ni, Zn) content in the tomato fruits did not differ among treatments except for Cd which highest values were obtained with synthetic fertiliser treatments. Moreover, all the trace elements were below the threshold set by the European Commission, thus showed no risk for consumption. BBFs also positively affected the soluble sugar content as lowest value were obtained with SF applied alone. This result is also found by Bilalis et al. (2018).

### Conclusion

The positive impact of BBFs on tomato fruit yield associated with their innocuousness on tomato quality suggest they can be used for production and therefore contribute to cities sustainability.

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**Session 2 - Treatment & Processing Technologies**

## Study the Behaviour of biodegradable plastic bags in industrial Composting

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### Introduction

With the growing awareness of the adverse impact plastic can have on the environment, the trend of biodegradable plastic (BDP) bags for organic waste collection is picking up stream. These bags are certified (DIN 13432, 2020) as compostable. DIN 13432 defines a material as compostable if 90 wt.% of the material is disintegrated into particles < 2 mm with in twelve weeks of standardized composting. Since composting plants process biowaste into finished compost, they have great concern about insufficient biodegradability of BDP bags during composting operations which leads to residues of biodegradable material in finished compost. Many organic farmers reject municipal biowaste compost due to visible impurities in compost. To this end, this study aims to better understand this discrepancy and investigates the degradation behaviour of commercially available BDP bags for kitchen waste collection at Neumünster composting plant. The goal of the research is to determine whether the tested BDP bags really fulfil the certification requirements and to what extend the residues of BDP distributed in coarse and fine fraction in finished compost after industrial composting. Therefore, four different types of BDP bags were tested. After composting duration of 6 weeks, the degree of degradation of bags were determined based on remaining macro (>8 mm), meso (2-8 mm) and micro (<1 mm, 1-2 mm) particles in finished compost. The industrial scale tests were followed by laboratory investigations and degradation behaviour of bags in anaerobic environment and its characteristics were investigated. In addition, the current situation of biowaste collection in German municipalities was analysed to find out whether the application of BDP bags really improve biowaste collection system.

### Methodology

Certified biowaste collection bags from four different manufacturers were selected for this study and their disintegration under industrial conditions were investigated over a period of six weeks at Neumünster composting facility. Two types of starch blend and two PLA (polylactic acid) blend BDP bags were used in the experiments. Specifications of the bags like volume, thickness, area, mass and material composition was investigated. For industrial composting large number of these bags were filled with kitchen waste and biowaste and placed in nets. The remaining portion of nets was filled with biowaste. 32 nets were prepared, each nets contain 20 BDP bags. These nets were placed in rotting containers filled with waste from bio bins. Containers were connected to aeration system and temperature measurement. After two weeks of intensive rotting, the containers contents were dumped in the rotting hall for post rotting. Natural ventilated post rotting phase continued for four weeks. Temperature was measured weekly whereas surface temperature of rotting material was determined by thermal imaging camera. Composting conditions were monitored, and sampling was carried out after 2,3,4,5, and 6 weeks. At the end of the experiment macro particles were manually separated from nets content and weighted. Meso- and microparticles were analysed using representative samples. Area and mass of macro particles were determined directly, while masses of meso- and microparticle was determined indirectly by number of particles and their area.

Also, anaerobic degradation tests of selected BDK bags were carried out on laboratory scale following VDI 4630 guidelines. To this end, two series of experiments were carried out. In first experiment BDP bags material was used. Bags material was cut in pieces of size 6x6 and used as substrate. It was followed by second experiment where BDP bags filled food waste was used as substrate. The experiments were carried out in 1 L fermentation flask, at 37°C. The ratio of substrate to inoculum was set as 1:2 at natural pH. The experiments were terminated after 60 days.

### Results and discussion

Results of industrial composting of BDP bags showed maximum degradation of bags occurred in first three weeks. Starch blend bags showed faster and higher degradation than PLA blend. The degradation rate of most starch blend bags was above 90% after 4 to 6 weeks, hence certification standards have been fulfilled however PLA blend bags failed to meet the standards. Micro and meso- particles were detected in all batches at all sampling times whereas macro particles were also found in most of the samples. The rate of degradation was determined using minimum degradation rate of residual particle masses and maximum degradation rate of residual particle areas. The actual degradation rate lies in between. To improve the results, the study suggests a cleaning method for contaminated macro particles. The macroparticle masses were determined directly by weighing. However, contamination highly effect the results therefore a cleaning method was proposed to minimise inaccuracy in results. However, masses of meso- and microparticles were determined indirectly by particle numbers and their areas. These calculations were based on the thickness and densities of original bags which also contribute to uncertainties. To lessen these uncertainties a correction factor ought to be defined which is a part of our ongoing research. Besides the type of bag material, temperature, thickness of the bag and moisture content of surrounding rotting material plays an important role, zone of rotting material with water content less than 20% showed almost no biodegradation activity.

Laboratory investigations of anaerobic degradation experiment showed no signs of disintegration of PLA blend BDP bags whereas for starch blend bags only 15-21 % degradation rate was achieved. In second experiment it was examined that the food waste had no positive influence on the anaerobic degradability of bags. Therefor it was concluded that the tested PLA blend BDP

bags are not anaerobically degradable, yet starch blend bags are conditionally degradable. However, it cannot be taken as general statement for the degradability of BDP material types. There are many other governing factors which effects the degradability of material under anaerobic conditions, eg. Mesophilic and thermophilic environments, material composition which may vary even for bag of same basic material etc.

In Germany the biowaste collection regulations very regionally and are difficult to understand for a lay man regarding terminologies. A large part of kitchen waste is not collected separately so far. There is a great need to increase the quality and quantity of kitchen waste, some research projects indicates that better collection rates can be achieved by some collection utilities like BDP bags or presorting (INFA, 2022; Walk & Körner, 2022). However this study does not recommend the use of BDP bag for kitchen waste collection. Since it is an additional generation of waste. The production of these bags is associated with land consumption and additional emissions (Morão & de Bie 2019), also the complication in recycling needs extra cost and technical adjustments. The unclear effects of BAK residues in finished compost is another governing factor for its rejection.

## Conclusion

The study concludes that composting time, water content and temperature are the most significant composting parameters. Maximum degradation of bags occurred in the first three weeks, this phase should be given special attention in further investigations. Drying out of rotting material led to slower degradation rate, hence appropriate water content (≈50%) throughout the rotting material should be maintained. Typical temperature profile of composting systems was found to be compatible for degradation of bags, however extremely low temperature indicates desiccation. The results showed a large number of microparticles as compared to mesoparticles in samples of rotting material, no doubt for degradation rate calculations they are relatively insignificant, however it not only indicates the decay of material but also predicts significant number of small particles in finished compost. It will increase the chance of entrying into food chain. The outcome of the investigations reveals that all BDP bags certified as compostable may not necessarily degrade in a composting plant according to the certification requirements. Although this study does not encourage the use of BDP bags for kitchen waste collection however it does not means that these bags are generally not recommended. For many applications, in agriculture or in consumer sector they can be a sustainable option.

## Acknowledgements

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## Study of biodegradable plastics in anaerobic digestion

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### Introduction

According to EU recommendations, biowaste from household, public and private establishments should not be incinerated or landfilled anymore but separately collected and recycled in composting or anaerobic digestion (AD) (EEB.org). Consequently, the amount of biowaste treated in codigestion with manure in agricultural biogas plants will increase. In order to facilitate the biowaste collection process, biodegradable plastics are sometimes used as biowaste containers. Nevertheless, stakeholders from AD facilities report a partial degradation of these biodegradable plastics, still poorly described in literature. The aim of this study is to understand better the mechanisms of degradation of biodegradable plastics by making some links between material properties and the biological process in AD.

### Methodology

Biodegradable plastics selected for the study are those which are likely to be found in AD facilities namely two polyesters used in food packaging, the polylactic acid (PLA) and the poly(3-hydroxybutyrate-co-3-hydroxyvalerate (PHBV) containing or not different percentages of cellulose, and a composite bag based on starch and polyester, the Mater-bi® (Novamont® Italy). All experiments were set up by using the Biochemical Methane Potential test (BMP) as a technique to evaluate the biodegradability of a substrate in AD (Nachod et al., 2021). As a first step, the performance of 2 different inocula (one from agricultural biogas plant and one from an urban AD facility) was tested with the 3 biodegradable plastics in mesophilic and thermophilic conditions. The influence of the inoculum to substrate ratio (ISR) was also evaluated. Finally, the degradation of plastic pieces of PHBV and Mater-bi® was monitored by analyzing the material properties and the associated microbial communities at different stages of the biodegradation process. Methane production was monitored by pressure measures and gas chromatography. Microbial communities were characterized by high throughput 16S rDNA sequencing. Plastic degradation was assessed by Scanning electron microscopy (SEM), spectroscopy FT-IR, size exclusion chromatography, and nuclear magnetic resonance.

### Results & Discussion

The mesophilic agricultural inoculum exhibited the most repeatable methane production for cellulose and PHBV, both in mesophilic and thermophilic conditions, in accordance with values given in literature. The ISR tested ranged from one to four. As methane curves were quite similar between all ratios, an ISR of one was chosen for the following experiments. The BMP tests showed clear evidence of cellulose degradation, used as positive control for the inoculum, reaching 100% of biodegradation within 25 days. In comparison at the same time, PHBV reached 30 % of degradation while Mater-bi® and PLA displayed only 5% and 2% degradation respectively, which is in accordance with stakeholders observations. Incorporating cellulose into PHBV polymers improved their degradability since a PHBV-cellulose composite containing 20% of cellulose was degraded at 80% in 25 days. Analysis of the plastic pieces of PHBV and Mater-bi® submitted to BMP tests showed a reduction of their physical properties and molecular weights as biodegradation progressed. Characterization of the associated microbial communities is in progress and will be presented.

### Conclusion

Experimental optimization of the BMP test allowed defining the most relevant conditions to study biodegradable plastics degradation in anaerobic conditions. The incorporation of cellulose into PHBV material triggers a better degradation.

### Acknowledgements

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## Holistic study about the biochar addition into the manure composting piles for soil health

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### Introduction

Soil health is crucial for sustainable crop and animal production, and composting is a common method to improve soil health by converting organic waste into nutrient-rich soil amendments. However, composting can result in significant greenhouse gas emissions during the thermophilic phase, especially when using manure. Biochar has been shown to enhance composting and reduce greenhouse gas emissions while improving soil structure and nutrient retention. This study aimed to evaluate the effects of biochar addition to organic residues (manure, rice, apple) on the composting process and compost quality as organic amendment to enhance soil health.

### Methodology

The study monitored composting process of two manures (PM: poultry and CM: cattle) with and without biochar, using various physical, biochemical, chemical, and microbial parameters. Methane emissions were quantified during composting using chromatography, while the quality of the mature composts was assessed by monitoring different C pools. Enzymatic activities and levels of carbohydrate and hydrosoluble polyphenol were measured through a colorimetric method using a spectrophotometer. Lignin content was measured using the American standard method (Serramia et al., 2010), while C13-nuclear magnetic resonance (NMR) was utilized to identify the characteristics of different carbon groups in humic acid (HA) and fulvic acid (FA) derived from manure compost. The thermal stability of the samples was evaluated through thermal analyses. Finally, principal component analysis (PCA) and correlation matrix were employed to summarize the information content of the microbial, physical, chemical, and biochemical data.

### Results and discussion

Using biochar addition into the manure composting (PMB and CMB), the methane emission was significantly reduced during the composting process. This could be due to enhanced aeration and reduced anaerobic conditions by changing in bulk density. The polymerization ratio of (HA/FA was higher in PMB and CMB, indicating that biochar addition improved the humification process. The analysis of C13 NMR for humified carbon demonstrated that the proportion of aromatic groups, considered recalcitrant C groups, was increased by the addition of biochar. In terms of easily-degradable compounds, PM and CM had significantly higher levels of total dissolved carbon, carbohydrate, and water-soluble polyphenol than PMB and CMB throughout the composting process. Additionally, the higher levels of ATP, NH4-N content, and enzymatic activities of dehydrogenase, b-glucosidase, and alkaline phosphatase in PM and CM compared to PMB and CMB are strongly associated with the easily-degradable compounds that serve as substrates for microorganisms, inducing enzymatic activities. In PCA analysis, 92% of the variance can be explained by PC1 and PC2. The variables closely related to stability and recalcitrance, such as the aromatic index of HA and FA and thermal stability have large loadings that strongly influence the components. PMB and CMB had higher values for these variables, indicating that the biochar addition improved the recalcitrance and stability of the composted material.

### Conclusion

Biochar addition to organic residues during composting can significantly reduce methane emissions, improve the humification process, and enhance recalcitrant carbon groups. However, biochar addition may decrease easily-degradable compounds, affecting microbial activity. These findings demonstrate the potential for biochar to improve compost quality and promote soil health.

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## Application of compost extracts as a sustainable practice for the control of airborne fungal pathogens

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### Introduction

Compost extracts (CEs) are nowadays considered a remarkable alternative to agrochemicals due to their biopesticidal and fertilising properties. CEs contain bioactive concentrations of extractable compounds from composted materials and microorganisms that have a key role in the promotion of plant growth and protection against plant pathogens (Giménez et al., 2020). Biopotential of compost extracts to suppress plants diseases seems to lie in their biological component where the microbial community and its metabolites show a key role (Lie et al., 2020). However, these properties could be affected by the different variables of the extraction protocols and by the starting compost. The aim of this research was to evaluate the biological activity of a catalogue of compost extracts, obtained from different mature compost and by the application of different extraction protocols, to investigate their biopotential to suppress the fungal diseases caused by the air-borne pathogens, using Cucumis sativus as host plant.

### Methodology

Four types of compost were used: agro-Food waste (AFW), olive-oil mill waste (OMW), sewage sludge (SS) and vegetal wastes (VW). Four compost extraction protocols (CEP-1, CEP-2, CEP-3, CEP-4) were tested according to Lerma-Moliz et al., 2023. The biological activity of CEs were assessed by the quantification of the specific culturable microbiome (chitinolytic, glucanolytic, proteolytic, amylolytic, lipolytic and cellulolytic microorganisms) and functional enzyme activities related to the suppression of plant pathogens. Finally, in vivo trials were carried out to assess the suppressive effect of CEs on Botrytis cinerea and Alternaria alternata using cucumber plants. Plants were growth and CEs were twice applied before the artificial inoculation of the air-borne pathogens.

### Results and discussion

The four protocols assessed significantly affect the biological activity of the CEs, although the raw material of starting compost also seemed to affect their biological properties. CEP-3 extracts, based on the application of more aggressive temperatures, were characterized by a low biological activity. However, extracts obtained by protocols based on mild to moderate temperatures, during either brief or extended incubation periods (CEP-1, CEP-2, CEP-3 and CEP-4), showed similar microbial counts for most of the specific microbiome assayed, although different trends were observed depending on the starting compost used. Conversely, the application of protocols based on large period of incubation at mild temperatures (CEP-4) tended to produce extracts with the highest diversity of functional activity for all the starting composts. However, the raw material of compost also was a source of variation in the functional enzyme activity of CEs. In this view compost extracts obtained from OMW were characterized by a low enzyme activity in comparison with the other extracts. For this, CEs from AFW, SS and VW obtained under mild temperatures and extended incubation (CEP-4) were chose for the in vivo assay. The three tested extracts suppressed at different level the disease of cucumber plants caused by B. cinerea and A. alternata.

### Conclusion

The results obtained showed the chance of producing compost extracts with good and effective suppression against air-borne plant pathogen throughout the application of some extraction protocols. Further studies on the factors involved in plant pathogen inhibition could help to develop more robust protocols to obtain extracts effective against a wider range of plant pathogenic fungi.

### Acknowledgements

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## Reduction of GHG and ammonia emissions from stored pig slurry using a peroxide-based slurry additive, with consequent improvement in biogas potential post-storage

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### Introduction

Pig meat constitutes 34% of the global meat trade, with demand increasing. Despite being non-ruminants, pigs account for roughly one fifth of agricultural emissions, principally from their excreta (FAO, 2017) and include greenhouse gases as well as significant amounts of ammonia (NH3). These gases are detrimental to animal welfare, while also contributing to global warming and reduced air quality. Additionally, gaseous losses from manures lower the nitrogen and carbon content therein, so reducing both the N-fertiliser replacement value and the biogas potential. The agricultural sector is thus under increasing pressure to manage livestock more effectively in order to increase outputs while reducing emissions (Loyon, 2018). Treatment technologies in the form of slurry additives represent an under-utilised means of mitigating gaseous losses from stored manure (Petersen et al., 2013). To this end, a novel peroxide-based slurry additive, with previously demonstrable efficacy at laboratory-scale using dairy cattle slurry (Thorn et al., 2022), was assessed for its suitability in reducing emissions from large scale experimental units of stored pig slurry.

### Methodology

Trials were performed in 1m3 intermediate bulk containers (IBCs) fitted with heated jackets, to mimic the temperature of beneath-housing slurry storage, and filled with 700L of weaner slurry. The additive was applied at the start of the experiment (~ at 0.8g kg-1) via injection into the slurry. Air flow over the surface at 4L min-1 was provided & emissions (CH4, CO2, N2O and NH3) measured from the tank outlet using a photoacoustic multi-gas analyser (Gasera). A matched untreated control was also assessed. At the end of the 30 day trial, samples from treated and control units were analysed for biomethane potential (BMP).

### Results and discussion

Emissions from untreated controls increased steadily over the initial 14 days, peaking at 1 and 2 g hr-1 m-3 of CH4 and CO2 respectively, while at the same time treated tanks emitted only 0.2 and 0.8 g hr-1 m-3 of CH4 and CO2 respectively. Even lower emission rates were seen earlier in the trial. Throughout the trial, N2O emissions were approximately 50% lower in the tank receiving the additive. Ammonia emissions were slightly elevated in the initial 4 days post treatment application, and then fell below that of the untreated for the remainder of the experiment. A single dose of the additive significantly dampened emissions for ~25 days, after which both CO2 and CH4 began to increase. BMP assays on day 30 samples demonstrated an increase of 34% to 56% in biogas potential from treated slurry vs the untreated controls.

### Conclusion

A single dose of a novel slurry additive was highly effective in reducing GHG and NH3 emissions from stored swine slurry over a 30 day storage trial. The lower CH4 and CO2 emissions resulted in retention of biogas potential as demonstrated by BMP assays. This increases the biogas output which can be used to off-set costs associated with acquiring such an additive. This peroxide-based additive therefore represents an innovative means of retaining the resource value of stored animal manure for its efficient onward use, for example as a biogas feedstock.

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## Animal slurry sanitization for a safe use in industrial horticulture: a field study using tomato

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### Introduction

Agronomic valorization of animal slurry (AS) for industrial horticulture is a win-win strategy for both livestock and horticultural producers. Indeed, it will increase the soil area for AS application and create a new market for AS, while offering a new alternative to the use of expensive mineral fertilizers, promoting a sustainable production system. However, the application of AS as fertilizer in horticulture requires caution, as crops, soil, and water resources can be contaminated with pathogens. In the present study, an efficient and cost-effective AS sanitization treatment by pH adjustment (acidification or alkalinisation) has been developed, including the use of a biofilter to reduce NH3, N2O, CO2 and CH4 emissions during the AS alkalinization process. The safe use of sanitized AS as fertilizer has then been tested in a field experiment to assess its agronomic value and potential environmental impacts to air and soil.

### Methodology

AS sanitization was first optimized by testing different pH targets and additives (Rodrigues et al., 2021). A mixture of tomato waste and rice husk was tested as biofilter media, to reduce NH3, N2O, CO2, and CH4 emissions during the alkalinisation step of AS sanitization (Pereira et al., 2022). A field-scale experiment with tomato plants was established, in a clay loam soil, to evaluate the effect of top-dressing application of sanitized pig slurry (PS) by pH adjustment on: (i) soil fertility, (ii) N2O, CO2, and CH4 emissions, and (iii) quality and yield of tomatoes. Six treatments with different fertilization approaches (n=3) to supply 180 kg N ha-1 were tested in a field experiment with 1 × 2 m2 plots: (i) raw PS, (ii) acidified PS [pH =5.0] with H2SO4, (iii) alkalinized PS [pH=9.5] with KOH, (iv) alkalinized/neutralized PS [pH=7.0], (v) mineral fertilizer (NH4NO3) and (vi) a control (without fertilizer application).

### Results and discussion

Acidification of PS reduced efficiently the concentration of Escherichia coli below the legal limit of 1000 colony-forming units per gram of fresh PS. Sanitization of PS by alkalinization was achieved at a pH of 9.5 using similar doses of KOH or NaOH, but KOH was selected as it enriches PS in K. The remaining additives tested, Ca(OH)2, urea (CH4N2O) and ammonia (NH3), were not as efficient and/or had operative constraints. The biofiltering media, composed of tomato waste and rice husk, had the potential to retain NH3 and greenhouse gases (GHG) produced during slurry sanitization by the increase of pH. The higher tomato yield was obtained with raw slurry (35.61 ton ha-1) against 19.94 and 24.24 ton ha-1 in acidified and alkalinized PS, respectively. Such decrease might be associated to a lower nutrients availability induced by pH modifications. No pathogen contamination of the tomatoes was observed in any of the treatments. The quality parameters of the tomatoes (pH, fenol, ascorbic acid and citric acid concentration) were not affected using treated or non-treated PS. The use of raw, alkalinized, and neutralized PS led to a significant increase of N2O emissions, compared to NH4NO3 application, while no significant differences were observed between acidified slurry and NH4NO3.

### Conclusion

Slurry sanitization by pH adjustment can be a simple and cost-effective solution that allows the safe use of PS for the fertilization of horticultural crops, without generating new residues. Nevertheless, this study evidenced a low risk of tomato contamination with pathogenic microorganisms, even when using raw PS in top-dressing application.

### Acknowledgements

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## Wednesday 13th September

### Plenary Session 2 – Air and Water Quality

### Reducing greenhouse gas emissions from manure management in Ireland

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#### Introduction

The management of animal manures in Ireland is important from a nutrient cycling and nutrient efficiency perspective but it results in emissions of greenhouse gases such as methane/nitrous oxide and can result in pollution of waters. In Ireland agriculture accounts for 98% and 34% of ammonia and greenhouse gas emissions. There has been considerable focus on mitigation of ammonia losses from manure management but there is still relatively little information on greenhouse gas emissions with 4 to 5 countries accounting for 86% and 79% of all N2O and NH3 data in DATAMAN (Beltran et al. 2021). This paper reviews our recent manure related research on refining emission factors, improving activity data, assessment of mitigation options and we highlight our key research findings including avoiding pollutant trade-offs.

#### Methodology

This review paper highlights the recent research findings from Ireland and case studies of emission factor refinement and abatement measure evaluation. Our research to date has focused on 1. Manure inventory refinement 2. Low emission slurry spreading 3. The use of amendments to reduce emissions from storage and land-spreading 4. The use of nitrification inhibitors to reduce nitrous oxide emissions. The studies reported here used a range of methods including static chamber measurements, simulated manure storage, pilot manure storage, field-scale horizontal flux gradient/ eddy covariance.

#### Results & Discussion

Improving national agricultural inventories is important to ensure they best match the actual losses and that potential mitigation measures can be incorporated into them. Research in Ireland has found that the slurry, dung and urine emission factors are considerably lower than the IPCC default value ranging from 0.5% to 0.67% for liquid manures and highlighted that the indirect emissions are almost equivalent to the direct emissions. Manure additives have been widely researched and acidifying compounds such as alum, ferric chloride or polyaluminium chloride can reduce NH3 and CH4 losses during storage by over 80% but can reduce the potential use of manure for anaerobic digestion (AD) (Kavanagh et al 2019) . Hydrogen peroxide was recently shown to reduce CH4 losses from manure storage by over 60% while avoiding the trade-off of increasing NH3 losses (Connolly et al. 2023) and could be used to increase biogas yields from AD. Nitrification inhibitors have been found to reduce N2O emissions by 47-88% from manure spreading when animals fed with DCD (Cahalan et al. 2015; Minet et al. 2018). Slurry spreading method and the impact of slurry acidification on direct N2O emissions is currently being researched due to contrasting results in the literature (Cahalan et al. 2015).

#### Conclusion

Manure related landspreading N2O emissions were considerably lower than the IPCC default value and the effects of manure treatment on the full greenhouse gas balances are needed. Slurry additives can dramatically reduce emissions but trade-offs and impacts for manure processing need to be considered. Nitrification inhibitors are very effective at reducing direct N2O but effects on NH3 need to be considered. Animal manures are an important source of nutrients and carbon and they will play an increasingly important role as agriculture strives to achieve climate neutrality 2050.

#### Acknowledgements

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## Plenary Session 2 – Treatment and Processing Technologies

### Developments in manure processing technologies

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### Introduction

After WWII, European economic growth can be characterized as a linear economy in which natural finite resources are used to produce food and feed. Agricultural production is highly dependent on the availability of (fresh) water, macronutrients including N, phosphorus (P) and potassium (K) and healthy soil. Phosphorus is a vital, irreplaceable element and fossil P reserves are limited (USGS, 2022). Since Europe has no significant phosphate mines, it relies heavily on imports of phosphate rock for P fertiliser production (De Ridder et al., 2012). In addition, large quantities of P-rich animal feed are imported to the EU to feed intensive livestock production, which accumulates as manure in the soil. Finally, large amounts of fossil fuels are used to produce mineral N fertilisers (EFMA, 2004).

Current European policy focuses heavily on the transition from a linear economy to a circular economy (EC, 2015). The main goal is "economically sustainable growth by keeping the value of products, materials and raw materials in the economy for as long as possible. The three main strategies are (a) minimize waste, (b) promote reuse and recycling of materials and products, and (c) create value: from waste to valuable resource. As a result, there is a special focus on recycling waste materials and by-products as fertiliser (Ehlert and Schoumans, 2015). Furthermore, there is a European initiative to increase the stock of soil organic carbon by 4 per mille (the so called '4 promille initiative'[1]).

### Methodology

Based on the outcome of several studies, the status of current manure treatment and nutrient recovery out of manure is evaluated in terms of technical and economic feasibility. Furthermore, additional attention will be given on new innovative developments in processing technologies.

### Results & Discussion

Organic biomass such as manure, digestate and compost and, in some countries, also sewage sludge, is used as a source of organic matter to maintain soil organic matter levels and to apply macro (N, P and K), secondary (Ca, Mg and S) and micro (B, Cu, Fe, Mn, Mo, Zn, ...) nutrients. In extensive agricultural areas, most organic matter can be applied locally, taking into account soil-crop recommendations and, if necessary, the legal aspects of, for example, the Nitrates Directive (1990) on Nitrate Vulnerable Zones (170 kg ha-1 N). However, there is a trend to create more value from organic biomass waste streams, such as the production of biogas to replace natural gas and the application of biomass separation technologies to concentrate parts of the nutrients and eventually by recovering nutrients from the biomass to replace industrially produced mineral fertilisers (Schoumans et al., 2021). Biogas production became important during the energy shortages of World War II and during the 1970 oil crisis and is still increasing (Grando et al., 2017; Brémond et al., 2021; Gustafsson and Anderberg, 2022). Moreover, there is longstanding experience with the use of separation technologies to concentrate organic matter and phosphates mainly in the separated solid fraction and ammonium and potassium in the separated liquid fractions, which provides better opportunities to apply appropriate amounts of organic matter and nutrients to agriculture. Depending on the type of manure/digestate and separation technologies (e.g., screw press, centrifuge, belt press) with and without flocculants/polymers, the separation efficiency of the solid fraction with respect to dry matter, total N, N-NH4, P and K varies remarkably (Aguirre-Villegas et al., 2019; Guilayn et al., 2019; Grell et al., 2023).

Composting and drying and pelleting of the solid fraction are well-known common technologies to create a more transportable and marketable products with higher value. In areas with manure surpluses, the emphasis in recent decades has been increasingly on nitrogen and phosphate recovery (Schoumans et al., 2015; Camilleri-Rumbau et al., 2021; Dadrasnia et al., 2021; Palakodeti et al., 2021; Pandey and Chen, 2021; Witek-Krowiak et al., 2022; Rizzioli et al., 2023). Ammonia is stripped from solutions under alkaline conditions and at higher temperatures and then washed with an acid solution (mainly sulfuric acid, nitric acid) to ammonium sulphate or ammonium nitrate. In addition, reverse osmosis technologies are used to extract water from the liquid fraction to make a more concentrated nitrogen and potassium solution, called mineral concentrate. However, according to the Nitrates Directive, all nitrogen products recovered from processed manure are still considered manure and cannot yet be used to replace synthetic mineral fertilisers. Phosphate recovery focuses primarily on precipitating ortho-phosphate from the liquid fraction into struvite through the addition of magnesium-based agents. Since manure is a complex substrate for nutrient recovery, the technologies are often high-tech and relatively expensive. However, in intensive livestock production areas with high costs of transporting excess of manure or digestate, these technologies are already feasible. In addition, the development of new innovative technologies is increasing rapidly, especially with regard to new membrane technologies to recover nitrogen and treatment of the solid fraction, which contains the most phosphate, to recover phosphate. This creates a palette of new processing and treatment technologies with lower costs and opportunities to tailor fertilisers that increase agronomic nutrient efficiency and reduce nutrient losses to the environment.

## Acknowledgements

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## Parallel session 3 – Air and Water Quality

### Effects of feeding tannin-rich diets to dairy cows on ammonia emissions in a naturally ventilated housing

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#### Introduction

Dairy farming is an important source of ammonia (NH3) emissions. Feeding condensed tannins (CT) is a promising strategy to mitigate N excretion and consequently reduce NH3 emissions. The tanniferous legume sainfoin (Onobrychis viciifolia) and the CT extract from the wood of Acacia mearnsii showed potential to reduce urinary N excretion at the individual animal level (Lazzari et al. 2023). However, this result awaits confirmation on a practical scale at herd level. Therefore, we performed an experiment with two dairy herds in a naturally ventilated dairy housing to study the effect of feeding silage-based diets containing CT compared to a grass silage-based diet on NH3 emissions.

#### Methodology

The experiment was conducted during summer 2020 in a naturally ventilated dairy housing with cubicles and solid floors. Two separate compartments, each for 20 cows, enabled comparable measurements in parallel. Ammonia emissions were quantified using a dual tracer ratio method (Mohn et al., 2018). In one compartment, a group of 20 lactating cows was fed, in succession, a grass silage-based diet, a sainfoin-rich diet, a sainfoin-rich diet supplemented with 20 g of A. mearnsii extract per kg dietary dry matter, and again a grass silage-based diet. Each feeding period lasted four days. In parallel, a second group, housed in the other compartment, was offered the same grass silage-based diet during the four periods. Then the treatments were exchanged while the two herds remained in their respective compartments, following a cross over design. The diets fed were isonitrogenous. Milk yield of each cow was recorded at each milking, and milk and spot urine samples were collected on the last day of each feeding period.

#### Results and discussion

The baseline of NH3 emissions was (mean ± SD) 38.3 g LU-1 d-1, which is in the range of values reported in other studies that measured NH3 emissions in summer (Poteko et al., 2019). The NH3 emissions were reduced by 19% and 33% with feeding of sainfoin and sainfoin + Acacia, respectively, compared to feeding of grass silage. The same was true for the milk urea concentration which was 41% and 49% lower, respectively, and the urinary urea concentration which was 30% and 57% lower, respectively. Concomitantly, the feeding of sainfoin and sainfoin + Acacia reduced the energy corrected milk yield of the cows by 11% and 20%, respectively, compared to feeding of grass silage. The NH3 emissions were enhanced by air temperature. This resulted in a daily pattern, namely with higher emissions during the warmer hours of the day, and also on a longer-term course when temperature increased in summer.

#### Conclusion

In conclusion, feeding of sainfoin silage alone and in combination with the A. mearnsii extract were highly effective in reducing NH3 under practical husbandry conditions. However, the mitigation effect might be accompanied by a decrease in animal productivity (e.g. lower milk yield), which requires careful evaluation before implementation of CT-rich diets on dairy farming.

#### Acknowledgements

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**Dietary supplementation of benzoic acid at 0.5% reduces ammonia emission and improve zootechnical performances of growing fattening pigs.**

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## Introduction

Gaseous pollution due to ammonia (NH3) generated by pig farms leads to environmental problems affecting air quality, the health of humans and animals and the neighbourhood. Nutritional strategies, such as low protein and/or high fiber diets, are widely researched to reduce the gas emissions. Additionally, dietary inclusion of feed additives such as benzoic acid (BA), which lowers urinary pH helping to retain ammoniacal nitrogen in the slurry and consequently avoiding ammonia volatilization, has been recognised as one of the best available technique to reduce NH3 emissions from pig (IRPP, 2017). However, the data generated about NH3 emissions using BA at 1% were run more than 10 years ago, when crude protein (CP) levels were higher (17-18% and 15-16% in grower and finisher phase, respectively) than the current levels used by pig producers. Moreover, most of the fatteners pig diets also include feed enzymes, such as carbohydrases (CH) which reduce digestive viscosity and improve nutrient utilization which may affect the availability of certain compounds for microbial fermentation, subsequently leading to reduce harmful gas emissions from the host (O'Connell et al., 2006). Thus, the objective of this study was to evaluate the dietary supplementation of BA at 0.5% in a commercial diet with 14 and 12% CP (grower and finisher diets, respectively) on growth performances and NH3 emissions.

## Methodology

Two successive batches of growing finishing pigs from january to october 2022 were allocated in two rooms in the experimental station of Crecom (France). In each room, 72 pigs, from 31 kg to 121 kg live body weight, were group housed in 12 pens. The pigs in the control room were fed with two-phase feeding strategy: grower feed included 0.9 g LYSd/ MJ NE and finisher feed with 0.8 g LYSd/MJ NE. In test room, the animals were fed the same control diets supplemented with 0.5% of benzoic acid. Gas concentrations of NH3, CO2 and water were measured continuously in the room area and outside with an infrared photoacoustic monitor (INNOVA 1412) during each batch period (93 days on average). Air flows were estimated with CO2 balance to calculate gaseous emissions. The pigs were weighed individually to measure the average daily gain (ADG). Feed intake was measured by pen, which made it possible to calculate feed conversion ratio (FCR) and daily feed intake (DFI) by pen.

## Results and discussion

At the end of the two batches, pigs in test room showed better ADG than the control room on fattening (975 vs 936 g/d; $p<0.001$). FCR was also improved (2.52 vs 2.61; $p<0.001$) allowing an equivalent feed cost per kilo of growth between the two groups around 1.15 €/ kg. Results on NH3 emissions showed a 18% and a 22% reduction in the test room compared to the control room for each batch, respectively. The efficiency on ammonia reduction with an incorporation of 0.5% of BA is superior to that retained from the IRPP, which shows a reduction in ammonia emissions in between 3.6 and 5% with a diet to 0.5% BA.

## Conclusions

The results of this study confirm that dietary inclusion of BA at 0.5% reduces NH3 emissions by up to 22% in the current low protein commercial diets including CH while improve animals growth performances. Further investigation is needed to evaluate the synergistic effect between BA and CH to consider this practice to reduce ammonia emissions within the framework of the IED directive.

## Acknowledgements

Authors want to thank the technicians of the experimental pig farm of Crecom for their implications in the project.

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## Comparison of ammonia and methane emissions from perforated and solid floors in dairy housings

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### Introduction

In the current discussion on ammonia (NH3) reduction measures, perforated floors are often mentioned as a mitigation option. However, simultaneous emission measurements of perforated versus solid floors in naturally ventilated dairy housings are rare. The aim of this study was to quantify methane (CH4) and NH3 emissions from perforated and solid floors on a practical scale in order to improve the data basis for emissions from dairy housing systems.

### Methodology

The investigations were carried out in the experimental dairy housing for emission measurements, Agroscope Tänikon (Switzerland). The housing consists of two experimental compartments - each for 20 lactating cows - and a centre section for milking, analytics and office. The two spatial separated housing compartments enable comparable measurement conditions (e.g. climatic conditions) on a practical scale. In one compartment feeding aisles, cubicle access area and outdoor exercise area were equipped with perforated floors and manure was removed with a robot. The other compartment had solid floors. The aisles were cleaned with stationary scrapers. To determine emissions under naturally ventilated conditions, a dual tracer-ratio method using sulfurhexafluoride (SF6) and trifluoromethylsulfur pentafluoride (SF5CF3) as tracer gases was applied (Mohn et al. 2018). Integrative air samples from both experimental compartments were extracted sequentially, using a selector switch and analysed for NH3 and CH4 by cavity ring down spectroscopy (CRDS, Picarro Inc.) and for SF6 and SF5CF3 by gas chromatography (GC-ECD, Agilent Technologies). To describe each measurement situation, relevant accompanying parameters like climate data, animal and feed data, soiling of the floors etc. were recorded. Measurements over three seasons (summer, transition season, winter) covered climatic variations in the course of the year.

### Results & Discussion

NH3 emissions showed seasonal effects regardless of the floor design: Emissions were highest in summer and decreased over autumn to winter. In summer and winter, NH3 emissions were higher with perforated floors compared to solid floors. In autumn, NH3 emissions with perforated and solid floors were at the same level. Our results confirm the findings of a recent meta-analysis of emission data, indicating no significant differences in NH3 emissions between perforated and solid floors (Poteko et al., 2019).

In contrast to NH3, no clear seasonal variations in CH4 emission level within one floor design variant were observed. However, individual daily averages of CH4 emissions in the compartment equipped with perforated floors were up to 45% higher than in the compartment with solid floors. The higher CH4 emissions with perforated floors indicate that the slurry stored in the channels underneath the perforated floors, can contribute substantially to the total CH4 emissions.

### Conclusion

Our results clearly show, that perforated floors cannot be considered as a NH3 reduction measure. Furthermore, perforated floors cause increased CH4 emissions, and therefore display a negative climate impact.

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## Strategies for greenhouse gas and ammonia emissions mitigation in dairy houses

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### Introduction

Dairy cattle housing systems are one of the most important livestock sources of gaseous emissions. Enteric methane (CH4) production represents an environmental issue and a loss of energy for the animals (Benaouda et al., 2020), also manure on the barn floor surface represents a direct source of ammonia (NH3) and nitrous oxide (N2O) emissions due to its aerobic and anaerobic conditions (Owen et al., 2015). In this context, the European project LIFE CLINMED-FARM aims to demonstrate innovative slurry management approaches for climate change mitigation in Mediterranean agricultural systems at farm-scale. Within the project, the aim of this study was the evaluation of frequent slurry removal and the use of feed additives in the cow diet as mitigation strategies to reduce ammonia and GHG emissions.

### Methodology

Two naturally ventilated dairy barns located in Candiolo (Turin – Italy) were compared considering slurry removal frequencies of 4 and 12 times per day, performed in both cases by automatic scrapers. The sampling strategy consisted of five sampling points inside and one outside each barn, according to VERA protocol (Vera-verification, 2018). Ammonia and GHG concentrations were measured using a quartz-enhanced photoacoustic spectroscopy (QEPAS) analyser (ETG 6900), coupled with a multipoint sampler, and gaseous emissions were estimated through the carbon dioxide (CO2) mass balance method (Pedersen et al., 2008). The evaluation of the effectiveness of two commercial feed additives (a garlic-based product and a hydrolysed yeast product) has been performed during in vitro fermentation trials, consisting in the incubation of 1 g of a dried dairy cow ration (DM) with 3 increasing dosages of the two additives and 150 mL of rumen fluid. The tested dosages of the additives were: 0.05 g g DM-1 (1), 0.1 g g DM-1 (2) and 0.2 g g DM-1 (3). An automatic system (Ankom RF Gas Production System) consisting of 24 modules (250 mL glass bottles) equipped with temperature and pressure sensors, monitored the amount of gas pressure produced during the fermentation process. Methane concentrations were measured with gas chromatography technique.

### Results and discussion

The removal frequency of 12 times per day led to significative ($p<0.05$) reductions in NH3, and N2O emissions of 27 and 69%, respectively. Average CH4 emissions were also reduced (-15%), even though this reduction was not significative. The average CH4 production (28.38 mL g DM-1) data were in line with those presented in other studies (Rivero et al., 2020). The trials results showed no significant ($p>0.05$) difference among treatments and control on potential enteric CH4 production. However, only garlic additive tested ad dosage 3 led to reductions in CH4 production compared to control (-15%).

### Conclusion

Two mitigation strategies have been evaluated in order to reduce ammonia and GHG emissions from dairy housing systems. Frequent slurry removal from the animal building's floor has shown to be an effective technique to mitigate NH3 and GHG emissions from the livestock activity. The two additives did not significantly influence the methanogenesis process. Further trials need be performed in order to improve the effectiveness of feed additives and find effective solutions to mitigate enteric CH4 emissions.

### Acknowledgements

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## Ammonia and odour emissions from fattening pig housings with outdoor yard in Germany

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### Introduction

The social and political demand for more animal welfare in fattening pig farming requires designing housing systems that include outdoor yards. However, an important question is how to evaluate the environmental impact of these systems in terms of ammonia and odour emissions. To address this issue, the project "Determination of emission data for the assessment of the environmental impacts of livestock farming" (EmiDaT), was launched to determine emission data for ammonia and odour of fattening pig housings with outdoor yards across different regions of Germany.

### Methodology

Measurements were carried out at 8 locations on practice farms over at least six measurement periods to map weather variability throughout a year. We selected two types of pig housings with outdoor yard at 4 locations, respectively: (1) pig housings with solid littered floor in the yard; (2) pig housings with slatted floor and slurry channels in the yard. To determine the ventilation rates and emission rates of the pig housings with outdoor yards, the tracer gas ratio method with an artificial tracer (SF6) according to VERA (2018) was used. SF6 was added into the yard floor area at a constant volume flow, and SF6 concentrations in the air were measured by GC-ECD. Ammonia concentrations in the air were measured simultaneously and at the same location using FTIR. Odour samples were collected from the same line, placed in bags, and later analyzed in the laboratory.

### Results and discussion

The ammonia emission rates for the 8 pig housings with outdoor yard ranged from 0.9 to 4.2 kg NH3-N animal place$^{-1}$ a$^{-1}$, with high variability observed among the measurements. Consequently, no significant differences between the types of pig housings were detected. The calculated average ammonia emission rate for the 8 measured housings was 2.6 kg $NH_3$- N animal place$^{-1}$ a$^{-1}$ (mean live weight over the fattening period: 67 kg). Notably, this mean annual ammonia emission rate was lower than the current emission factor of 3.0 kg NH3-N animal place$^{-1}$ a$^{-1}$ applied for closed, forced-ventilated barns with fully slatted floors in Germany (VDI 2011). As animals typically confine their defecation to specific areas of the outdoor yard, these housings systems have a limited emission potential even with larger outdoor yards. The odour emission rates ranged from 9 to 83 European odour units (ouE) s$^{-1}$ livestock unit$^{-1}$. Given the limited number of measurements, no annual emission rate was calculated for odour. On farm level, we observed that management practices, such as the amount of straw used for littering in the yard and the cleaning frequency of the yard, had a considerable impact on the ammonia emission rates, which could explain the differences between farms. However, the large variation observed in odour emission rates could not be accounted for.

### Conclusion

Through the EmiDaT project, we established a standardized measurement and evaluation approach to collect data on ammonia emission rates from pig housings. These data serve as a basis for assessing different rearing systems, including those with outdoor yards for fattening pigs. The calculated average annual ammonia emission rate allows to compare these systems with closed, forced-ventilated pig housings, and the results indicate that they are generally not worse in terms of ammonia emissions. However, further investigations are necessary to assess the odour emissions from these systems.

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## Particulate matter ($PM_{10}$) concentrations and emissions at a commercial manure-belt laying hen house

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### Introduction

Commercial egg production facilities are emission sources of multiple aerial pollutants, including particulate matter (PM). Qualities and characteristics of these emissions depend on many factors, such as building design and manure handling. Long-term (e.g., ≥ 6 months) and continuous (or high frequency) monitoring is needed because considerable diel and seasonal variations in pollutant concentrations exist at these facilities. However, long-term and high-quality PM emission data from manure belt layer houses are scarce.

### Methodology

This study was conducted in a layer house of a commercial egg farm in Midwestern USA, where measurements of PM10 concentrations and emissions were conducted for half a year. A mobile lab, equipped with PM monitors, various sensors, and a computer data acquisition and control system, was set up 10 m from the house. A weather station was set up 30 m from the house on the rooftop of a building.

The $PM_{10}$ concentrations were measured with three Tapered Element Oscillating Microbalance (TEOM) monitors (model 1400a Ambient Particulate Monitor, Thermo Fisher Scientific, Waltham, MA, USA). The sensor units of two of the TEOMs (TEOM-N and TEOM-S) were installed side-by-side (1 m apart) at the inlet of a minimum ventilation fan for continuous exhaust PM10 concentration measurement. The sensor unit of the third TEOM was set up at the top of the mobile lab for ambient $PM_{10}$ measurement. The control units of all three TEOMs were installed in the mobile lab.

l 46 wall ventilation fans in the house were individually and continuously monitored with Hall Effect sensors for their rotational speeds. Static pressures across the walls were also continuously monitored. A portable Wall Fan Tester (WFT) was designed and developed in this study to determine the on-site fan ventilation rates at different fan rotational speeds and under different static pressures. A fan ventilation model was developed based on the WFT measurement data and was used to calculate the measured rotational speeds and wall static pressures to ventilation rates for all individual fans.

### Results and discussion

conditions that were largely spring and summer with minimum and maximum hourly outdoor temperatures of -6.2 °C and 34.2 °C, respectively. The data completeness of hourly mean and daily mean PM10 emission rates was 98.7% and 98.4%, respectively. The hourly mean house ventilation rates, which included all 46 fans, ranged from 1342 to 22,436 m3 min-1. The average daily mean (ADM) house ventilation rate was 10,803±5906 (mean ± standard deviation) m3 min-1. The ADM ventilation per bird was 0.078 m3 min-1. Daily mean PM10 concentrations showed 244±173 and 219±143 μg $m^{-3}$ at TEOM-N and TEOM-S, respectively. Although the responses of the two TEOMs to PM10 concentrations were linearly correlated (R2 = 0.963), the ADM concentration for TEOM-S was 10.2% lower than TEOM-N. Using the mean concentrations from the two TEOMs, the PM10 emissions from the house per AU (500 kg live weight) and per bird were 35.6±31.1 kg $d^{-1}$ $AU^{-1}$ and 19.2±16.1 mg $d^{-1}$ $bird^{-1}$, respectively.

### Conclusions

**1.** High level quality assurance and quality control for the field monitoring ensured high data completeness rates.

**2.** Although the in-house PM10 concentrations measured with the two side-by-side TEOMs at the exhaust fan correlated very well, the difference between the two TEOMs demonstrated variations between individual instruments.

**3**. The ADM PM10 emission rate was within the range reported in five other manure belt layer houses using similar instruments and measurement protocol in the literature, which was between 12.4±19.3 and 25.2±33.3 mg d-1 bird-1. Bird molting appeared to have impact on PM10 emission rates.

### Acknowledgements

The project proposal, monitoring design, and Quality Assurance Project Plan were prepared by Dr. Albert Heber. Mr. Claude Diehl participated in measurement system setup and emission monitoring during the entire study. Supports by the egg farm to this project are greatly appreciated.

Session 3 - Nutrient Utilisation

## The effects of wastewater recovered struvite on growth and phosphorus acquisition in chickpea and wheat

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### Introduction

Phosphorus (P) is an essential element for all living organisms. Overcoming P limitation will play a key role in the productivity of agriculture in the coming decades in order to maintain food production at required levels (Edixhoven et al., 2014). The primary source of P, phosphate rock reserves, is expected to be exhausted in the next few centuries (Fixen et al., 2012). Therefore, sustainable sources of P are urgently needed to increase food production in the face of an increasing global population (Cordell et al., 2009). Struvite is a crystal of ammonium magnesium phosphate which is recovered from wastewater treatment plants via precipitation. Struvite contains a significant amount of P, has low solubility (<1–5%) in water, but is highly soluble in the presence of organic acids. Hence, struvite has great potential as an alternative sustainable source of P (Krishnamoorthy et al., 2021). This study aimed to investigate the effects of struvite, a slow-release P fertiliser, on plant growth, yield and P acquisition of chickpea and wheat.

### Methodology

Chickpea and wheat were grown in pots filled with a mixture of field soil and river sand (in 3:7 ratio) with low P availability, in a temperature-controlled glasshouse. Four treatments were established including no additional P, and 90 µg P g-1 dry soil as struvite (ST; 12.5% P), mono ammonium phosphate (MAP; 22.8% P) or Super SR Extra (SSRE; 9.5% P). Half of the plants were harvested at 58 days after sowing. Shoot dry weight (DW), root morphological traits, rhizosheath carboxylates and plant nutrient acquisition (P and magnesium) were determined. The remaining plants were harvested at physiological maturity to determine grain yield.

### Results and discussion

At the early growth stage, the shoot and root dry weight of chickpea under ST and SSRE was similar, which was ~5-fold higher than under MAP. Shoot DW of wheat under ST was lower than under MAP and SSRE while root DW was highest under SSRE, followed by that under ST and MAP which was similar. For chickpea, shoot P content under ST and SSRE was similar, which was 2.5-fold greater than that under MAP. In wheat, shoot P content under ST was 4.1-fold and 3.0-fold lower than that under MAP and SSRE, respectively. Shoot Mg content in chickpea was greatest under ST, followed by reduction of 1.6- and 7.2-fold under SSRE and MAP, respectively. Shoot Mg content in wheat was greatest under MAP and SSRE, which was 2-fold greater than under ST. ST increased the rhizosheath carboxylate amount in chickpea by 6.4- and 1.6-fold compared to MAP and SSRE, but in wheat it showed the opposite trend. Chickpea grain yield increased by 88% and 19% under ST relative to MAP and SSRE, respectively; while wheat grain yield was similar under ST and SSRE, which was 58% lower than under MAP. The higher growth and grain yield of chickpea under ST might be associated with increased rhizosheath carboxylates.

### Conclusion

Wastewater-recovered slow-release struvite showed a strong ability to supply P to support growth of both crop species, especially chickpea. Further research is required to fully understand the benefits of ST and to identify more crops which can acquire P efficiently from ST.

### Acknowledgements

The authors thank the Department of Agriculture, Water and the Environment, Australia for providing financial support for the research and to Water Corporation WA for proving struvite samples. MS is also partially supported by the Tim Healy Scholarship – from the AW Howard Memorial Trust Inc and the ARC Training Centre for the Transformation of Australia's Biosolids Resource.

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## Let's improve ammonia emission models for field-applied manure

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### Introduction

Ammonia (NH3) emission has increased exponentially since mid-19th century (Stevens et al. 2020). During this period ammonium in rain shifted from low to high at the Rothamsted research station and high to low in London (Russell & Richards, 1919, Uwizeye et al. 2020) reflecting a shift in the source of NH3 from coal burning to agriculture. Presently most of this NH3 is derived from animal manure (Uwizeye et al. 2020). The high concentrations of atmospheric NH3 and related pollutants are detrimental to human health and environment. Furthermore, loss of fertilizer N by emission also affects farmers' economy (Sutton et al. 2020; Sommer and Knudsen 2021).

The European Union has focused on reducing NH3 emission, but some European farmers have pushed back against demands for reducing NH3 emission from manure management. Dutch farmers argue that the measured emissions and emission calculations are inaccurate. The calculations indeed are simple, because detailed information about manure composition, soil properties, management practices etc. are not available, and could hence not sufficiently be included in calculation algorithms and models. Therefore, emission factors are used. These are means of very variable data, have large coefficients of variation, and do not always reflect regional or national environmental conditions or manure management.

In contrast, emission models can incorporate effects of local environment and management and have the potential to improve inventory estimates and even support farm management by incorporation into decision support tools. But this requires accurate and trusted models. To reach this aim accurate and robust process algorithm and access to driving variables and factors are required. In this contribution we will present our opinions on how emission models can be improved through an in-depth understanding of the processes of NH3 release from manure applied in the field.

### Methodology

We summarized results from selected articles that used measurement or modelling approaches to identify, weight and clarify processes controlling NH3 loss from field-applied slurry. These works, to the best of our knowledge, represent the state of art and latest developments within the topic area.

### Results and discussion

A common understanding in most studies is that emission of NH3 from a surface is driven by the concentration gradient between the NH3 (g) in the air immediately adjacent to the surface and that in the ambient atmosphere. One significant challenge is to understand and calculate the concentration of NH3 (g) at the slurry surface or develop simple approaches that capture the essential controlling processes. At the time of writing our focus is on pH buffers, slurry dry matter and viscosity, weather variables (wind, rain, surface temperature), slurry chemistry (ionic strength, equilibrium constants), and slurry and soil physics. We intend to show how emission models might be improved by better representation of these processes. Actually, available process knowledge and data to improve models are highlighted for 'next generation' emission calculators.

### Conclusion

The important feature of the next generation of emission models is to reflect site-specific environment and management effects. We propose that in this process focus should be on models that relate emission to the controlling chemical and physical processes most likely through simplified algorithms or model structures derived from more complex models. It is acknowledged that this must be balanced with the availability on environmental (soil, weather etc.) and management data (application technologies, application timing etc.).

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**Quantifying subregional nutrient flows as a benchmark for more circular food systems.**

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Contemporary studies on circular food systems often lack quantitative understanding of the current situation as well as local context. This information is needed to come to feasible and practical options towards improving circularity. Our objective was to quantify how subregional variations in soil type, agricultural specialization and population density affect nutrient flows and losses in the entire agri-food-waste system.

Farm-level data and municipality level statistics data were combined to quantify nitrogen (N) and phosphorus (P) flows in the export-oriented Northern region of the Netherlands (NN). Subregional variation was assessed by comparing nutrient flows, losses, nutrient use efficiency and nutrient cycling in 30 constituent areas varying in dominant soil type, agricultural specialization and population density. The food system encompassed the subsystems agriculture, food and feed processing, consumption and consumer waste processing.

We found that nutrient flows in the NN food system were highly linear, with low nutrient use efficiency and recycling, but large losses to the environment. The nutrient use efficiency of the food system was 0.25 for N and 0.75 for P. System losses were 276 kg N ha-1 y-1 and 11 kg P ha-1 y-1. Nutrient cycling was neglectable and the system strongly depended on external inputs, especially of artificial fertilizer and imported feed. Of all subsystems consumer waste(water) treatment had the lowest nutrient use efficiency (0.05 for N; 0.04 for P), as nutrient recovery from waste is currently very limited. However, 91% of food system losses were from agriculture, owing to the low population density and high production in the region. Food processing had little losses, but also a low conversion rate of raw agricultural products into food products, as much of the raw product ended up in exported non-food flows.

Nutrient use efficiency and nutrient losses varied strongly with dominant soil type, agricultural specialization and population density of a subregion. In areas with drained peat soils N losses from agriculture were as high as 465 kg N ha-1 y-1, as the additional inputs provided by decomposing peat were largely lost to the environment. By contrast, losses from agriculture on sandy soils were as low as 169 kg N ha-1 y-1. Livestock production was associated with larger losses and lower nutrient use efficiencies than arable farming, due to losses during feed production and low conversion efficiencies of feed into food products. Phosphorus losses per hectare were larger in more densely populated areas, as only 4% of P is recovered from human waste, whilst the use efficiency in agriculture is 70%. In contrast to P, N losses were larger in areas of production, due to the large losses from agriculture.

We conclude that there is substantial variation in nutrient balances at the subregional level, that needs to be considered when steering towards a more circular nutrient use. Circularity cannot be achieved by merely increased re-use of current residual flows, but will require a more transformative change of the current system. Important action points for improved circularity in the NN region are: rewetting of peat soils to reduce losses, limiting feed production and import and thus animal production, improving the conversion rate of agricultural products into food products during processing and increasing the recovery of nutrients from consumer waste. Improvement of circularity in the food system requires locally specific redesign of agriculture for which this study provides a benchmark. We are currently developing adapted farming systems aimed at improving circularity at the food systems level.

## The Transition to Sustainable Fertilisers for Achieving Nutrient Autonomy and Sustainable Food Production: Investigating Recycled Materials and Phosphorus Use Efficient Traits in Crops.

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### Introduction

Achieving food security for our growing global population while accelerating food access in developing economies places strains on planetary boundaries. Australia aims to deliver an ambitious goal of increasing the value of its agricultural industry by 25% (£11 billion) by 2030, which may conflict with Australia's commitments to the Sustainable Development Goals and Paris Climate Agreement. Australia's agricultural industry currently contributes 13% of total national emissions which is forecast to reach 20% by 2035 (DCCEEW, 2022a, 2022b). Without intervention, increasing agricultural outputs will place further strains on Australia's environments, such as the Great Barrier Reef which is already threated by climate change and agriculture (Hughes, Day, & Brodie, 2015). Furthermore, the fragility of Australia's fertiliser industry was exposed by Covid-19 and recent geopolitical decisions that caused supply chain disruptions and price hikes (Walsh et al., submitted manuscript, 2023). The transition to sustainable fertilisers is critical for achieving nutrient autonomy and sustainable food production, and contributing to Sustainable Development Goals and environmental targets.

### Methodology

1) A broad lifecycle analysis of the current geopolitical, economic, environmental, and social issues caused by conventional phosphorus fertiliser production and farmland application, 2) A series of glasshouse experiments analysing the agronomic efficiencies of different recycled materials, including the agronomic effect of phosphorus use efficient (PUE) crop genotypes compared to commercial types, and 3) The use of two novel technologies (FT-ICR-MS and microdialysis) to compare and identify PUE exudation profiles when grown with different phosphorus substrates.

### Results and discussion

1) We investigated alternatives to synthetic fertilisers for crop production. These include traditional recycled organics, novel valorised inorganic materials, and combinations of both to create organo-mineral fertilisers. Focusing on phosphorus, we report on our research findings that show how recycled inorganic materials, in the right combination, can replace conventional phosphorus fertiliser. Combining recycled organic and inorganic materials as fertilisers has many benefits, as is pairing PUE crops with recycled materials, and 2) A pilot study was conducted to compare exudation profiles between sorghum genotypes and found metabolomic differences may be a contributing factor to PUE. Our ongoing experiment now expands into other PUE characteristics, such as root architecture to help provide a broader understanding of PUE crops and respective relationship with recycled materials.

### Conclusion

Nutrient security can be achieved through the adopting of recycling and valorisation technologies. This will take addition efforts in developing economies, where foreign aid aligned with the Sustainable Developments Goals can help the financial and infrastructure barriers. Further understanding PUE traits can help pair specific crop genotypes with different environments and recycled materials, such as legacy mining in phosphorus rich soils, or greater nutrient acquisition characteristics in nutrient poor soils. These results contribute to broader effort to minimise synthetic fertiliser use, improve nutrient use efficiencies, boost soil fertility, and improve food security.

### Acknowledgements

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## Comparing the performance of P Olsen and P saturation degree in predicting crop yields and P leaching risks using long-term P fertilization experiments

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### Introduction

The fate of P, in terms of crop uptake, soil P accumulation and P losses to water, in response to P fertilization is strongly affected by the P pool size and whether the P in soil is available in soil solution, weakly or strongly adsorbed to the soil matrix. The P pool size and its distribution over the P forms are in turn affected by past P management (Sharpley et al., 2013). However, the dynamics in P pools in response to P addition are often quantified under controlled lab conditions, limiting our understanding of how the P supply and availability can be altered under field conditions. In addition, field P management practices are often based on single agronomic soil P tests, such as POLSEN, ignoring differences in P buffer capacity. Recent studies suggest that the P saturation degree (PSD) is a high-potential agri-environmental soil P test as it measures the current pool of reversibly sorbed while it also gives insight in the maximum soil P sorption capacity (Schoumans & Chardon., 2015). We thus evaluated and compared the response of POLSEN and PSD to P fertilization and their performance in explaining crop yield and potential P leaching risk using long-term field experiments in Qiyang, a Chinese county characterized by huge agronomic and environmental challenges for sustainable P use.

### Methodology

A long-term (29 years) field experiment was used to explore soil P dynamics under long-term excessive P application. Changes in four soil P pools (extracted with CaCl2, NaHCO3, $(NH4)^2C^2O^4$ and HClO4-H2SO4 and named PCACL2, POLSEN, POX and PTOTAL, respectively) and crop yield responses to various P fertilization rates (and P sources) were examined. In addition, the concentrations of Al and Fe were determined allowing the calculation of PSD, defined as the ratio of Pox over a*(Al+Fe)ox. The performance of POLSEN and PSD in predicting crop response and environmental risks was also assessed.

### Results and discussion

The accumulation of P surplus (P input minus P uptake) over the soil P pools varied with P accumulation. POLSEN and POX increased linearly with continuous P application and reached maximum values at a P accumulation near 3200 kg P ha-1. Continuing P application above that threshold only caused a gradual increase in PTOTAL and a linear increase in PCACL2, implying an increased leaching risk. The majority of the surplus P accumulated in POX before saturation. The variation in crop yield and potential P leaching losses is better explained by PSD (R2= 0.95 for crop yield and 0.95 for enhanced P leaching risk) than POLSEN (R2= 0.93 for crop yield and no significant relationship with enhanced P leaching risk). The critical PSD level for enhanced P leaching risk (0.20) was near the target level for crop yields when using a cut-off point at 80% of the maximum yield(0.22)

### Conclusion

Soil-reactive P pools (POX & POLSEN) will become saturated at high P input levels, which occurred in our experiment around an accumulated P surplus of 3200 kg P ha-1. Added P accumulated in more available P forms before the reactive P pools were saturated, whereas additional P inputs accumulated in more stable P forms once the soil was saturated. We showed that the PSD can be used to optimize both crop yields and potential leaching risks. In addition to the theoretical advantages of PSD, this index can guide sustainable P management. Regional fine-tuning can be applied by a values reflecting specific conditions for pedogenetic factors like climate and soil texture.

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### Acknowledgments

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## Soil Health Improvement, Nitrogen Loss and Use Efficiency through Combined Application of Organic and Inorganic Fertilizers in Paddy Cultivation

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### Introduction

Rice is the third major cereal crop in the world and a vital staple food in Asia. Production of rice ensures food security of the ever burgeoning population. Intensive rice cultivation depending on inorganic fertilizers with a lesser quantity of organic fertilizers results depletion of organic matter (OM), low nitrogen use efficiency (NUE) and degradation of soil health (Rahman et al., 2022). But, OM is vital to maintain soil health, ensure ecological integrity and agricultural sustainability (Obalum et al., 2017). Therefore, the objective of the study is to assess the efficacy of cowdung, poultry manure, rice straw, biochar etc. with inorganic fertilizers on water stable soil aggregates (WSA), NUE, carbon sequestration index (CSI) and nutrient losses.

### Methodology

Two experiments were conducted in wetland paddy soil of Bangladesh. The test rice crops were boro (dry season with full irrigation) and transplanted aman (T. aman) (wet season with supplemented irrigation). The experiment 1 consisted of five treatments viz., control (no fertilizers), poultry manure (PM), cowdung (CD), rice straw (RS) and recommended doses of fertilizers conducted in ten consecutive seasons. A fixed carbon (C) rate of 2 t ha-1 was ensured from organic amendments in each seasons. Inorganic fertilizers were not required for CD and PM treatments as these materials supplied required amounts of nutrients for rice, while in the RS treatment, 132 and 60 kg N with 2 and 0 kg P ha-1 were applied in boro and T. aman seasons, respectively in the first year only. The experiment 2 comprised of seven treatments viz., zero N (control), recommended dose of N (RDN), 125% of RDN (RDN125), 75% of RDN (RDN75), cowdung 2 t ha-1 + supplemented N (CDSupN), biochar 2 t ha-1 + RDN (BRDN), and deep placement of urea supper granules (USG) in four consecutive seasons of boro and T. aman. Prilled urea (PU) was used in all the N treatments except the USG.

### Results and discussion

Organic amendments increased WSA, labile C, CSI, and biomass C and N in soils. WSA in PM, CD and RS treatments were 37.1, 33.8 and 34.3%, respectively. Labile C was found significantly higher in RS treatment (7.16 g kg-1) than that of other treatments. The CSI of PM, CD and RS were 0.25, 0.22 and 0.21, respectively which can be used to predict soil C sequestration. Biomass C and N in PM treatment were 579 and 54 mg kg-1, respectively, while in the control the values were 243 and 23 mg kg-1, respectively. Compared to RDN, biochar and USG treatments reduced N leaching by 48% and 30% in boro season, respectively, while in aman season values were 49% and 40%, respectively. NH3-N emission was found the lowest in the USG followed by biochar and cowdung treatments in both boro and aman seasons. The highest agronomic (28 kg grain kg-1 N applied), physiological (46 kg grain kg-1 N uptake) and recovery efficiencies (62%) of N were found in USG followed by biochar and cowdung treatment in boro season. In aman season, the highest recovery efficiencies of N (61%) were found in biochar treatment, and agronomic (24 kg grain kg-1 N applied) and physiological (43 kg grain kg-1 N uptake) efficiencies were found in the USG treatment. USG and biochar reduced NH3 volatilization and nutrient leaching, while increased NUE. The variations in biomass C and N occurred in soils under different treatments is due to differences in characteristics and supply patterns of nutrients of different organic substrates. OM contributes to rapid multiplication of microbes in soils which attributes to increased biomass C and N. OM binds surrounding soil particles to form well aggregated soils and thereby increases WSA. Labile C was found significantly lower in PM treatment which endorsed the higher CSI in this treatment. Biochar may adsorb NH4+ and inhibits nitrification process, and USG applied at the root zone which slowly release N and maximizes plant uptake, and thus increases NUE.

Conclusion

PM contributed to maximum WSA, CSI, and biomass C and N compared to other organic treatments. USG and biochar were found promising in reducing NH3 volatilization and nutrient leaching, while increasing NUE. Therefore, use of organic fertilizers are recommended as an efficient option to improve soil health and NUE for sustainable agriculture.

### Conclusion

PM contributed to maximum WSA, CSI, and biomass C and N compared to other organic treatments. USG and biochar were found promising in reducing NH3 volatilization and nutrient leaching, while increasing NUE. Therefore, use of organic fertilizers are recommended as an efficient option to improve soil health and NUE for sustainable agriculture.

### Acknowledgements

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Session 3 - Treatment & Processing Technologies

## Performance evaluation of a large scale two stages agricultural biogas plant, coupling fermentation and anaerobic digestion

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### Introduction

Two-stage anaerobic digestion (AD) processes have a real advantage because they combine a separate fermentation reactor, upstream of the digester, with recirculation of liquid digestate (Holl et al, 2022). The fermentation reactor is the key point of the anaerobic digestion unit, allowing (i) the use of substrates with high dry matter content, and (ii) to optimize the process by increasing stability of the process and overall methane yield. However, the application of two-stage AD process in agricultural sector is uncommon due to the lack of knowledge on process stability and to the difficulties to evaluate the optimal operational parameters. This study aims to evaluate the performance of a two-step process at the field scale over several months.

### Methodology

Monitoring was carried out on an agricultural biogas plant (BP) which is a two-stage plant, constituted of a fermentation reactor, a digester and a post-digester. The fermentation reactor is fed with different substrates (60 t/d): mainly solid and liquid cattle manure, and to a lesser extent, slaughterhouse sludge and whey permeate. The recirculation of the digestate from the post-digester to the fermentation reactor allows to dilute solid substrates used as input. The volume of biogas from the fermentation reactor and the digester was registered automatically. Substrates, fermentation reactor output, digestates and post-digestates were collected when the process was stabilized. The hydraulic, mass and energy balances were carried out over 4.5 months with daily measurements to monitor the overall performance of the BP, and over four days with hourly samples of hydrolysate to monitor the physicochemical characteristics of the effluent at the outlet of the fermentation reactor (pH, volatiles solids (VS), volatiles fatty acids (VFA) and nitrogen contents). The Biochemical Methane Potential (BMP) analyses of the substrates were compared the real methane production recorded on the BP during 4.5 months. Moreover, our study focused on the gas flow rate of the fermentation reactor, especially on H2 production.

### Results & Discussion

Total VFA reached 15 g/L in the fermentation reactor. The most abundant acids were acetic (6.8 g/L) and butyric (5.6 g/L). Kinetics of the VFA show the progress of the hydrolysis/acidogenesis reactions in the fermentation reactor after the introduction of the organic matter. The pH in the fermentation reactor was close to 6.0. Under steady state condition, the hydraulic retention time (HRT) of 2.3 days was obtained in the fermentation reactor. The fermentation reactor and the digestate recirculation allowed to decrease the HRT of the digester close to 14 days. The overall organic matter balance was not recovered. Indeed, the BP transforms more than 56% of total VS due to biogas production (methane and carbon dioxide). The nitrogen balance is maintained as no significant difference between input and output was observed. The N-NH4 increases of 42%, highlighting the mineralization of N in the digesters. The measured methane production on the BP (3342 Nm3/d) was higher than the estimated value (measured by the BMP of the substrates) which was 2933 Nm3/d. Methane production was thus increased by 14% compared to the estimated value. Moreover, the fermentation reactor produced 3 Nm3 of H2 per hour, in average.

### Conclusion

The hydraulic balance has confirmed that the two stage process reduces the residence times, which are generally longer for classical agricultural BP. Energy balance highlights that the presence of the fermentation reactor improves the methane production in the digester. This two-step AD can help to reduce investment costs which is one limit for the development of the agricultural AD sector.

### Acknowledgements

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## Effects of trace elements supplementation in two-step anaerobic digestion of cattle manure and wheat straw/grass

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### Introduction

Trace elements (e.g., Fe, Ni, Cu, Cd, Zn) are essential to the growth and metabolism of microorganisms in anaerobic digestion (AD), with observed mitigation in the accumulation of volatile fatty acids (VFAs), contributing to higher biogas and methane yields (Rehman et al., 2019). In that sense, using tailor-made commercial additives containing essential micronutrients has been a common approach in biogas plants, and some authors state that multi-element supplementation can be more beneficial to the process (Choong et al., 2016). However, concentrations of these elements might vary according to the feedstock composition and operational parameters, in which the addition of key trace elements might contribute to higher biogas yields compared to the use of diverse micronutrients by attenuating the risk of the inhibition of the process. Therefore, this research aims to compare the effects of Cu and Zn supplementation to similar dosages of these elements in a commercial mixture of micronutrients on biogas production in a two-step anaerobic digestion of cattle manure and grass. Attention to these elements in AD has gained importance in the last years since they are involved in cell growth and methanogenesis process, besides many metabolic reactions in crops, promoting the use of the derived digestates as organic fertilisers.

### Methodology

A micronutrient-poor substrate, derived from a thermophilic co-digestion of manure and a mixture of straw and grass and separation process from the Biogas plant at Aarhus University, Research Centre Foulum (Viborg, Denmark) was chosen as feedstock in this study. The experiments were conducted in 0.3 L batch reactors through a four-level-factorial design in triplicate. First, different Cu and Zn concentrations (0, 0.1, 1, and 2 mg L-1) were tested in thermophilic digestion, in which an extra treatment of these elements (5 mg L-1) was also included, resulting in 22 treatments in triplicate. Then, a commercial mixture of micronutrients (i.e., Cu, Zn, Mn, Co, Ni, Mo, Se, Fe, and B) was applied to 5 treatments according to the aforementioned fixed concentrations of Cu and Zn, in which the inhibitory effects of NH4+ (1-2 mg L-1) and S (0.2 mg L-1) were also tested. The volumes of biogas were measured on days 3, 5, 7, 10, 15, 20, 25, and 30 through a water displacement system and normalized to the conditions of Standard Temperature and Pressure (STP), in NL Kg VS-1. In parallel, samples of 15 L mixed batch reactors were weekly collected to measure the pH, VFAs, and N-NH4+ when upscaling the aforementioned supplementation of the commercial mixture. The biogas composition was determined through micro-gas chromatography (μ-GC, Agilent 7890A, CA 95051, USA) equipped with Alltech® CTR 1 double-column (Grace, MD 21044, USA), a thermal conductivity detector and Helium as carrier gas. The normality of the data was tested using the Shapiro-Wilk test ($p < 0.05$), in which the differences between the treatments comparing the effects of the additives, and their interaction were examined using two-way analysis ($p \leq 0.05$) and Scott-Knott test as post-hoc analysis ($p= 0.05$).

### Results and discussion

The biogas production was higher for the Cu and Zn treatments, in which the highest accumulated volumes were 211 NL.Kg VS-1, 210 NL.Kg VS-1, and 202 NL.Kg VS-1 for 2 mg L-1, 5 mg L-1, and 0.1 mg L-1 of Cu and Zn , representing increment 14.1%, 13.9%, and 10.4% compared to the control, respectively. The lowest dosage of the commercial mixture containing 0.1 mg L-1 of Cu and Zn resulted in a 10.7% increase in biogas production, whereas its highest dosage (2 mg L-1 of Cu and Zn) inhibited the AD process, in which the accumulated volume was 35% lower compared to the control. In general, the biogas production of reactors containing Cu and Zn were significantly higher compared to the control and the highest dosages of the commercial mixture ( = 0.05), resulting in more beneficial use of these elements to the AD of this feedstock, particularly when combined dosages of these elements were applied to the process.

### Acknowledgements

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## Effects of pre-treatment techniques and two-step anaerobic digestion on the nitrogen fertiliser value by injection or surface banding to cereal crops

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### Introduction

Biogas production from anaerobic digestion (AD) of biowastes is limited by the recalcitrant nature of many substrates, which may also reduce the fertiliser value of the produced digestate. The degradability of substrates can potentially be enhanced by physico-chemical pre-treatment techniques before AD, and/or the degradation can be increased by extending digestion time in the reactors. In this study, we evaluated the effects of electrokinetic and ultrasonication pre-treatments of biowastes in a two-step AD process on nitrogen fertiliser replacement value (NFRV) of digestates obtained from two biogas plants with contrasting hydraulic retention time (HRT) in the primary AD step.

### Methodology

Pre-digested biowastes from two biogas plants with contrasting HRT and different substrates consisting mainly of cattle slurry and grass-silage mixtures were utilised. Reactor 1 runs at an HRT of 14 days and Reactor 2 at an HRT of 60 days, with both running at thermophilic conditions (51 °C). The two pre-digested biowastes from the primary AD step were treated by either an electrokinetic or ultrasonication device at 4.37 kWh/tons and 2.88 kWh/tons intensities, respectively. Treated or untreated digestates were further digested in a secondary AD step with six continuously stirred tank reactors (CSTR) with a working volume of 15 L for 30 days. After 30 days, digestates were sampled and freezed at -18 °C until used in field and soil incubation experiments.

Digestates were mixed with a small amount of highly enriched $(NH_4)_2SO_4$ to achieve around 1 atom % excess 15N in the ammonium-N immediately before application to framed field micro-plots in spring. The digestates were applied to established winter wheat in micro-plots by surface-banding or applied by injection before sowing a spring barley crop at rates of 150 kg total N ha-1. Dry matter yields and crop N uptakes were compared to plots receiving increasing rates of mineral N fertiliser. In addition, parallel soil incubation experiments were set up to study the effects of the two-step AD on N turnover in soil during 80 days and soil carbon sequestration estimated from fitting measured $CO_2$ evolution during 212 days to a carbon pool model.

### Results and discussion

The electrokinetic pre-treatment significantly increased the $NH_4^+$-N/N ratio in biowastes, but the effect was offset after the secondary AD step. Applying pre-treated digestates to winter and spring barley tended to increase NFRV, mineral fertiliser equivalent of ammonium-N and 15N recoveries from digestates. The two-step AD significantly ($p < 0.001$) increased 15N recoveries and mineral fertiliser equivalence of labelled $NH_4^+$-N in winter wheat and reduced ammonia losses, with a significant effect ($p < 0.001$) observed in digestates sourced from a shorter HRT biogas reactor (Nyang'au et al. 2023). The positive fertilising effect could be attributed to enhanced nutrient solubilisation during the AD process and changes in biochemical properties, i.e. dry matter and viscosity, which enhance better digestate infiltration.

After 80 days of soil incubation, the net inorganic N release from digestates obtained from a secondary AD step increased by 9-17% (% of the N input) compared to corresponding digestates obtained from a primary AD step, while the long-term soil C retention related to the C present before digestion was similar for one- and two-step AD at 12-16 % (Nyang'au et al. 2022). The increase in net inorganic N release was attributed to the enhanced mineralisation of organic N.

### Conclusion

Incorporating a pre-treatment step prior to a second step AD showed no clear effects on the N fertiliser value of digestates applied to cereals by injection or surface-banding. By extending the digestion time in a second AD step, the net release of mineral N in soil was increased, and the N fertiliser value tended to increase, thus potentially replacing more mineral fertilisers without affecting soil carbon sequestration, alongside with increasing biogas production.

### Acknowledgements

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## Impact of several food waste overloads on the microbial community structure of a pig slurry mesophilic anaerobic digester

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### Introduction

Many farmers introduce food waste into their anaerobic digester to increase biogas production. Since this waste hydrolyses quickly in the digesters, it can lead to process overload and eventually biogas production collapse. The aim of this study was thus to investigate the impact of several food waste overloads on the microbial community structure of an anaerobic digester treating different substrates in co-digestion with pig slurry.

### Methodology

A 35L working volume continuously stirred anaerobic reactor was run for about one year at 38 °C. The reactor was fed once a day with a feed prepared every week and kept at 4 °C. The base substrate was pig slurry supplemented with horse feed residues to ensure liquid digestion conditions and provide nutrients. Then 9 experiments of 4 to 7 weeks were carried out by successively adding to the reactor feed: crushed apples as Fruit Waste; butter as Food Fat; restaurant food waste; overload of fruit waste; a mixture of crushed apples and casein (Protein Waste) and a mixture of crushed apples and butter. Substrate additions resulted in increasing organic load rates varying between 0.8 and 5.2 kgCOD.m-3.d-1 provoking 2 overloads with fruit waste, 2 others with food fat and one with protein waste. In two experiments, the digester could not recover and was emptied and inoculated again with a new pig slurry. The digester hydraulic retention time varied between 20 and 29 days. Methane production yields, physical-chemical characteristics of the digestate (pH, COD, TKN, VFA, LCFA, NH4+), microbial groups concentrations (real time PCR) and composition (high throughput 16S rDNA sequencing) were determined every week to assess the performance of the system. A total of 61 samples was analysed.

### Results and discussion

After process stabilisation with pig slurry and horse feed, the addition of apples up to 2.6 kgCOD.m-3.d-1 did not show any inhibition and allowed biogas production to increase. Further addition of butter led to a load of 5.2 kgCOD.m-3.d-1 and rapidly provoked LCFA and VFA accumulation (up to respectively 2200 and 13 500 mg.L-1), acidosis (pH 6.4) and biogas collapse. After 7 days of starvation, restaurant food waste was added to the digester feed (3.9 kgCOD.m-3.d-1) allowing biogas production to recover. Five other experiments were then performed leading to biogas production failures related to overloads with crushed apples (3.0 and 4.1 kgCOD.m-3.d-1), stirring defect, casein (3.8 kgCOD.m-3.d-1) or butter addition (3.4 kgCOD.m-3.d-1) and allowing the recording of process parameters and microbial community dynamics.

The recorded data show different patterns according to the different induced failures. During stable process operation, the microbial concentration was stable at about 1010-1011 bacteria.g-1 and 109 archaea.g-1 of digestate. The average archaeal percent fluctuated between 9.1% and 0.5% of total microorganisms with a mean around 3.1%. Both experiments of apple waste overload induced a digestate acidosis (pH 5.5) and biogas production decrease. However, the concentrations of bacteria and archaea in the process did not change. The experiments with stirring defect and casein addition showed VFA accumulation up to respectively 3964 and 13548 mg.L-1 and NH4+ accumulation at 4000 mg.L-1 with casein, provoking a reduced biogas production and a one log reduction of the archaeal concentration. The bacterial concentration was not affected. The two experiments with butter addition resulted in acidosis and biogas production reduction with different microbial scenarios. In the first experiment, only the archaeal concentration dropped of about one log in the process. In the second experiment, both bacterial and archaeal concentrations dropped of about one log.

High throughput DNA sequencing showed the bacterial community was represented by hundreds of genera while the archaeal community was dominated by either the acetoclastic methanogen Methanosaeta or the hydrogenotrophic methanogen Methanobacterium. Interestingly, process failures correlated with different methanogenic metabolic pathways. Apple waste and butter overloads conducted to a shift from acetoclastic to hydrogenotrophic methanogenesis and the concomitant increase in H2 producing syntrophic bacteria. Process failures related to stirring defect or casein addition remained with a dominant acetotrophic methanogenic pathway. Finally, transition states of process instability showed the regular increase in members of the Methanosarcina genera able to produce methane from acetoclastic, hydrogenotrophic or methylotrophic pathways.

### Conclusion

Observing similar operating parameters for overloaded processes hides a consistent diversity of microbial community.

### Acknowledgements

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## Impact of post-treatments on the sanitary quality of digestates from three agricultural biogas plants

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### Introduction

The development of the anaerobic digestion (AD) sector has been stimulated by the increasing demand for green energy. Agricultural AD uses livestock manure and vegetable material as feedstock to produces biogas and digestate. The latter can contain pathogens originating from the manure. As a result, the spreading of digestate on agricultural land could have a potential impact on the safety of human, animal and environmental health, within the "One Health" concept. The effect of AD on pathogens is poorly documented, and most of the studies focus on levels of faecal indicator bacteria (FIB) and prevalence of pathogens between the inlet and outlet of the digester. Only few studies have quantified the reduction of FIB and pathogens throughout the AD process and the post-treatment of digestate (Orzi et al., 2015, Chiapetta et al., 2019). At the end of 2021, on-farm biogas plants (BP) represented 68 % (n= 889) of the total AD units in France. Most of them were anaerobic mesophilic digesters. However, the pathogen inactivation efficiency of these processes is lower than that of thermophilic AD (Liu et al., 2021). In this context, one of the objectives of the "PathoGaz" project was to study the fate of FIB and pathogenic bacteria throughout three full-scale mesophilic biogas plants over a one-year period.

### Methodology

Raw and post-treated digestate samples were collected six times during a one year period in three French biogas plants (BP) fed with pig manure (BP1) or with dairy manure, and to a lesser extent with poultry manure (BP2 and BP6).All received vegetable material as co-substrate. The matrices, collected at each sampling date in triplicate, were: raw digestate (BP1, BP2, BP6), post-digestate (BP2, BP6), compost of the solid fraction of digestate after mechanical separation (BP1), stored liquid and solid fractions of digestate after mechanical separation (BP6). The sample flasks (liquid matrices) and bags (solid matrices) were transported at room temperature to the laboratory and analysed on the same day. Samples were assayed for three FIB (E. coli, enterococci, Clostridium perfringens) and for five pathogenic bacteria (Campylobacter spp., Salmonella spp., Listeria monocytogenes, Clostridium botulinum and Clostridioides difficile).

### Results and discussion

The concentrations of the FIB in the digestates of the three BP ranged from 10 to 9.6 103 cfu.g-1 (E. coli), 3 102 to 4.4 104 cfu.g-1 (enterococci) and 103 to 5.2 105 cfu.g-1 (C. perfringens). Although these bacteria were still present, their levels were significantly lower in the post-treated digestates. Post-digestion and storage of the solid phase in a heap were less effective than composting. Campylobacter, never quantified, was detected only in the digestate of BP1. The other pathogens were present in the digestates of the three BP at a frequency of detection ranging between 50 and 100%, and at concentrations ranging from 1.6 to 75 MPN g-1 (Salmonella), 1.6 to 75 MPN g-1 (L. monocytogenes), 1.6 to 8.1 MPN g-1 (C. botulinum), and 1.2 to 29 MPN g-1 (C. difficile). Except for Salmonella, post-digestion and storage of the solid and liquid fractions had little or no impact on their frequency of detection and on their concentrations. Composting of the solid fraction decreased the occurrence of all targeted pathogenic bacteria, confirming the sanitary effect of this post-treatment.

### Conclusion

The impact of post-treatments depends on the type of treatment used as well as on bacterial intrinsic factors. Composting is the most effective form of post-treatment. The survival rates of bacteria over the course of the post-treatments are in the following order: Campylobacter, Salmonella and E. coli < enterococci and L. monocytogenes < Clostridia. Each post-treatment improves the overall sanitary quality of the digestate but does not eliminate the risk of dissemination of pathogens, especially spore forming bacteria.

### Acknowledgements

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## Acidification of livestock slurry and digestate, the role of their chemical-physical composition to predict the acid required and pH trends over time

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### Introduction

Acidification is a treatment that reduces NH3 emissions from livestock slurries by reducing their pH while maintaining their fertilizing potentiality. The amount of acid required for the process varies based both on the type of acid used and the buffer system of the slurries (Sommer and Husted 1995). Many studies are available in the literature which show a high variability in the quantity of acid required and in its effect over time, but often they are focused on a limited number of samples. Therefore, to evaluate the applicability of the acidification technique in a wide context of livestock farms, the aim of the study was to investigate its application on a larger sample set among slurry and digestate, finally identifying the chemical-physical parameters correlated with the added acid and with pH at one- and two-weeks. Furthermore, starting from slurry composition we developed models to predict the amount of acid to add and the pH over time.

### Methodology

A total of 54 samples including 19 pig slurries 18 cattle slurries and 17 digestates were collected in Lombardy-Italy. Each sample was analysed for the content of total solids (TS), volatile solids (VS), ash, total Kjeldahl nitrogen (TKN), total ammoniacal nitrogen (TAN), total alkalinity (ALK), pH, electrical conductivity (EC), phosphorus (P), potassium (K), copper (Cu), zinc (Zn), total organic carbon (TOC) and volatile fatty acids (VFA). Acidification was conducted by adding H2SO4 (98%w/w) to adjust pH at 5.5 of a slurry sample of 0.75 l. The samples were kept at 15°C for two weeks, measuring the pH daily. The relationships among the parameter were defined by an analysis of variance (ANOVA) and a Pearson correlation analysis were carried out. To predict the amount of acid necessary and the pH after one- and two-week based on slurry composition, regression trees (RTs) and random forests (RFs) were used (Cutler et al. 2007).

### Results and discussion

The amount of added acid to reduce the pH of slurries up to 5.5 ranged between 0.8-11.7 ml kg-1. Digestate differed significantly from dairy cattle and pig slurry, requiring more acid to be acidified ($p<0.001$). The pig slurry had significantly higher pH growth rates than the other two slurries ($p<0.01$), exceeding the neutrality threshold 2 weeks after the addition of the acid, in line with Regueiro et al. (2016). Correlations showed that added acid was mainly correlated with ALK (Sommer and Husted 1995), while the pH trend over time was correlated with TOC and VS. The RT models accurately predict the added acid ($r2=0.881$) by the alkalinity and the initial pH of the slurry; the pH at 1 week ($r2=0.728$) and pH at 2 weeks ($r2=0.667$) were accurately predicted by using the TOC and VS.

### Conclusion

This study represents comprehensive research on the parameters that affect the acidification process of livestock slurries and digestates. The prediction models were accurate and independent from the type of slurry, thus widely adoptable. The importance of solids content to maintain acidifying effect require further investigation, deepening the role that the finest solids could have in this process. The diffusion of the acidification treatment could be helped by identifying solutions that allow to reduce the need for acid and prolonging its effect, thus reducing the costs and the risk for the workers.

### Acknowledgements

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Session 4 - Air & Water Quality

## Contrasting high-frequency open path spectroscopy with Integrated Horizontal Flux ammonia ($NH_3$) measurements to compare the efficacy of Low Emission Slurry Spreading on cool temperate grasslands

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### Introduction

On the island of Ireland, over a third of all ammonia (NH3) emissions arise from the landspreading of cattle slurry (Bourdin et al. 2014), in part due to cattle densities being higher here than in many other countries. Traditionally, a splashplate attachment on a towed tank is used to broadcast-spread slurry, generating a wide surface area for NH3 to volatilise from. Whilst landspreading is necessary as slurry is the main fertiliser source for the grasslands which feed the cattle, the gaseous NH3 that is generated contributes to poor human and environmental health (Wyre et al. 2022). Low Emission Slurry Spreading (LESS) technologies, which reduce the surface area of the slurry and spread lower to the ground to minimise contact with ambient air, have been shown to reduce NH3 emissions from slurry spreading in a number of other countries (Nyameasem et al. 2022). However, there is uncertainty about the extent each of them reduces NH3 emissions from slurry spreading under Irish conditions. NH3 emissions are typically measured with Integrated Horizontal Flux (IHF) method, which can be labour-intensive. Therefore, the aim of this study was to investigate whether NH3 emissions measured by high-frequency open path Fourier-Transform Infrared (FTIR) spectroscopy were comparable to IHF measurements by investigating the efficacy of different LESS techniques on Irish grasslands.

### Methodology

Cow slurry was spread over six 50 m x 50 m plots at each of two permanent grassland sites, one in AFBI Loughgall (LG) in Northern Ireland and one in Teagasc Johnstown Castle (JC) in Ireland, representing two soil types, sandy clay loam at LG and loam at JC. At both sites, two plots were spread by splashplate and two by trailing shoe. At LG, the other two plots were spread by trailing hose (dribble-bar) whilst open slot injection was used at JC. Spreading occurred three times per year during the growing seasons of 2021 and 2022. Immediately following each spreading event, NH3 emissions were monitored using two methods: FTIR spectroscopy on three plots (one of each treatment) and IHF on all six plots. FTIR concentration data was modelled using Windtrax to enable comparison between the two methods.

### Results and discussion

Both IHF and FTIR measurement methods demonstrated that NH3 concentrations tended to peak on the day of spreading, rapidly returning to background concentrations within five days, although damp days could result in brief increases in concentrations later in the week. Spreading by splashplate tended to produce the highest NH3 emissions (up to 4.4 kg ha-1 d-1), except on one hot and dry occasion where this technique produced lower emissions than any LESS technique (1.7 cf. 3.3 kg ha-1 d-1). Usually trailing shoe produced the lowest NH3 emissions (as low as 0.3 kg ha-1 d-1), followed by open slot injection and trailing hose, although NH3 emissions were very variable between trials. The relationship between NH3 emissions and environmental variables will be explored, as will the comparability of the two measurement methods.

### Conclusion

The IHF and FTIR methods produced comparable results, meaning one could be substituted for the other. LESS techniques tend to lower NH3 emissions arising from Irish grassland. However, the efficacy of the LESS techniques was variable and therefore further investigation in spreading under certain weather conditions is recommended.

### Acknowledgements

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## Novel system to measure emission rates of $NH_3$ and $CH_4$ from open farm-scale agricultural sources

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### Introduction

Most emission factors estimating national emission inventories from agriculture have a large uncertainty. These emission factors are mainly based on small-scale studies with intrusive measurements methods (such as dynamic chamber and wind tunnels), which cannot reflect appropriate temporal and spatial emission distribution (reference). In addition, spot samples measurements that do not resolve the high variation in emissions potentially introduce a large bias in the estimation of emissions from a source (Kupper et al., 2020). Despite the mandatory emissions inventories and high agreement for incorporating mitigation techniques into agricultural policies for emission reduction, there are still limited numbers of reliable measurement methods for farm-scale emissions.

### Methodology

This work presents the validation and implementation of a novel system for measuring ammonia (NH3) and methane (CH4) emissions from farm-scale agricultural sources, which has been validated in eight controlled release experiments (Lemes et al., 2023) and implemented to measure emissions from slurry storage tanks (Lemes et al., 2022) and manure stockpiles (Lemes et al., 2022). This novel measuring system uses line-average concentration measurements with a closed path analyzer (CP), specifically a cavity ring-down spectroscopy (CRDS). By utilizing the well-established inverse dispersion method, the backward Lagrangian Stochastic model (bLS), emissions rates can be estimated in half hour intervals (Flesch et al., 2004, 1995).

### Results and discussion

In eight controlled release experiments, the recovery of CH4 based on closed path measurements and IDM (CP-IDM) was 98 ± 3%. Furthermore, under optimal conditions, a recovery of approximately 90% can be achieved for NH3 using CP-IDM, provided that deposition is accounted for.

### Conclusion

CP-IDM can be used to measure emissions of CH4 and NH3 from farm-scale agriculture sources with a relatively high data coverage that enables important insights into temporal variation and allows for evaluating emission factors and effects of mitigation strategies on emissions.

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## Comparison of methods for measuring ammonia volatilization from field-applied slurry

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### Introduction

Ammonia (NH3) is an air pollutant and the agricultural sector accounts for more than 81% of global NH3 emissions. NH3 emissions vary over time and space, making accurate quantification challenging. Different methods are used to determine concentrations and emissions from field-applied slurry. Differences among these methodologies may contribute to variability in the results. Furthermore, NH3 emission is affected by local soil properties and application method. The aim of this work was to compare different measurement methods and assess measurement biases. In the present work, three different research institutions measured NH3 emissions in parallel from the same field source, which eliminated variation due to weather conditions, soil properties, and application method.

### Methodology

Experiments were conducted at Aarhus University (AU), Denmark and Wageningen University and Research (WUR), the Netherlands. Both experiments included the backwards Lagrangian model (bLS) (Kamp et al., 2021) and wind tunnels (Pedersen et al., 2020), both with high time resolution concentration measurements conducted by AU. The Dräger Tube Method (DTM) (Pacholski et al. 2006) and ALPHA samplers with bLS (Tang et al., 2001) were included in the AU experiment by Thünen Institute, Germany. The experiment at WUR included the Integrated Horizontal Flux (IHF) method (Goedhart et al., 2020) and off-site flux chamber both with impingers conducted by WUR. Emissions were also estimated with the ALFAM2 model (Hafner et al., 2019) based on measured slurry properties and weather variables.

### Results and discussion

There was a tendency for methods with low time resolution (DTM, bLS-ALPHA, and impingers with IHF) to provide lower emissions compared to high time resolution methods. These differences reflect measurement biases and were partially caused by lower detection limits of some methods. Temperature and application method contributed to a large difference in emissions between the two experiments. Some of the difference could be explained with the ALFAM2 model. However, it was evident that performance of the slurry application and specific soil properties influenced the area covered with slurry, which is not accounted for in the ALFAM model. Accurate measures of this area are difficult to obtain but may need to explain emission differences between institutions.

### Conclusion

Differences among measurement methods likely contribute to high variability in reported emission estimates, but repeated comparisons will be needed to determine if consistent biases are to blame. More comparative measurements are needed to allow for more complete assessment of different methods. To maximize their value, NH3 emission measurements should be complimented by as many explanatory parameters as possible including soil type, slurry covered surface area, and climatic conditions. Higher time resolution of measurements provides more information on emission dynamics and along with quantification of explanatory parameters this can increase the understanding of the interactions that control NH3 emission after slurry application.

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## A wireless sensor network for low-cost monitoring of emissions

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### Introduction

The barn climate plays a crucial role for animal welfare and emission management. Besides temperature and humidity, the monitoring greenhouse gases like methane (CH4) or carbon dioxide (CO2), and environmental relevant gases like ammonia (NH3) is of great importance to assess their emissions and to optimize and monitor management strategies towards their mitigation. In dairy farming, the measurement of CH4, CO2, and NH3 emissions requires the use of expensive gas analyzers and sampling devices. Thus, measurements are often limited to few scientific focus barns and not suitable for a broad application, resulting in rather limited, often not representative databases. To overcome this gap, we developed a low-cost wireless sensor network (LC-WSN) for the measurement of levels of air pollutants and emissions from livestock housing systems.

### Methodology

The LC-WSN is equipped with a wireless sensor network, which consists of multiple nodes, spatially distributed inside the barn. Each node is equipped with low-cost sensors for CH4, NH3, and CO2 and the climate variables temperature, relative humidity, pressure, and lux. The low acquisition costs and the modular design allow an uncomplicated up-scaling of the system for parallel investigations of a large number of barns.

In this study, the sensors for CH4, CO2, and NH3 were investigated for their ability to accurately measure gas concentrations as the prerequisite for emission estimation. This was done first in the lab under controlled conditions with test gases for NH3 and CH4 under varied concentration levels. After that, the sensor network was installed in a naturally ventilated dairy barn in Germany. Gas concentrations for the estimation of emissions were measured in parallel with the low-cost sensor nodes and a reference method with a Fourier-Transform Infrared spectroscopy (FTIR) gas analyzer. The measurements were carried out continuously for a duration of 12 days. The reference measurements were used to assess and validate the sensor network. The LC-SNW stayed in the barn for further measurements to assess long-term stability and potential drifts.

### Results and discussion

For the averaged concentration levels over the measurement period, the low-cost sensors agreed well with the reference system. Relative deviations lower than 7% for all three gases, with maximum peak deviations up to 32 % for CO2, 67 % for NH3, and 65 % for CH4, with strong Spearman correlations for CO2 and NH3 (pCO2=0.8, pNH3=0.68), and a rather weak correlation for CH4 withpCH4=0.24, were measured. Long-term measurements are ongoing; the results for long term stability will be presented at the conference.

### Conclusion

The LC-WSN was found to be suitable for (relative) trend monitoring of CO2 and NH3 concentrations and emission levels, and usable for the estimation of absolute values for air change assessments. Further investigation will be needed on the calibration for the CH4 sensor for lower concentration values and on potential interference with humidity and temperature.

### Acknowledgements

The presented research was carried out and is further investigated in the framework of several projects. It was supported by the German Federal Ministry of Food and Agriculture (BMEL) through the Federal Office for Agriculture and Food (BLE) under the "MilKey" project (grant number 2819ERA08A), funded under the Joint Call 2018 ERA-GAS, SusAn and ICT-AGRI 2, and the "DairyMix" project (grant number 2822ERA15A), funded under the Joint Call 2021 ERA-GAS, SusCrop, SusAn and ICT-AGRI-FOOD. It is further investigated in the "ECONUTRI" project, which is funded by the European Union's Horizon Programme (HORIZON-CL6-2022-ZEROPOLLUTION-01) under grant agreement No 101081858.

## Experimental set-up to derive reductions of ammonia losses from field-applied manures and fertilisers

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### Introduction

Within the discussions to mitigate ammonia (NH3) losses, new application methods, processed manures or fertilisers are introduced from which the NH3 losses need to be derived. The Integrated Horizontal Flux (IHF) method is commonly used to estimate the NH3 emission from field-applied manure. Due to the large variation between field experiments, due to weather conditions, manure characteristics, soil type and grass height, a large number of experiments is required to estimate the mean or modelled emission factor (EF) for any particular application technique. This also holds for assessing the effect on the NH3 emission of for instance diluting or acidifying manure, or when processed manure is directly compared with un-processed manure in pairwise field experiments. Moreover, the IHF method has a large workload with limited possibilities for many replications within a single year, requires large field sizes when comparing different plots and requires that measurements on different plots start at approximately the same time such that weather conditions are comparable. Therefore, a new fast comparative small scale experimental setup was developed to compare the NH3 emission of alternative application methods and/or processed manure with standard methods for which an EF is available. Such experiments result in an estimated quotient of the NH3 emission (emission reduction factor) of a new method with respect to the standard method. The EF of a new method can then be estimated by multiplying the EF of the standard method by the quotient. The new measuring technique can also be used to compare the NH3 emission after manure or fertiliser application for different soil types, different irrigation strategies, different fertilizers and different urine and dung patches.

### Methodology

The base set up is flow chambers as described by Ruijter et al. (2010). Buckets (content circa 10 l, diameter 0.26 m) are filled with a soil or undisturbed grass sod layer of 0.14 m, up to 0.07 m from the top. The bucket is air tide placed within a cylinder which is covered by a perforated lid to let air enter the created headspace. Air is withdrawn from a central hole in the lid by a pump and washed by a NH3 trap. Air replacement rate of the headspace of once per minute. A measured amount of manure, urine or fertiliser is applied to the soil or grass sod after which the lid is placed on the cylinder and air is passing within the headspace. Measurements continue for 10 days, during which traps are replaced at certain time intervals. Measurements were done for up to eight objects in fourfold at the same time, including two blank measurements (no manure or fertiliser). One of the objects is the reference: in most cases shallow injection with dairy manure. The experimental set up is located outside under a cover to meet local weather conditions (temperature and relative humidity). Experiments are repeated over time to meet different temperature en humidity conditions.

### Results and discussion

When buckets are prepared, the start of an experiment can be conducted quickly (within a half hour) to meet comparable conditions. In the first few trials, air flow rate was adjusted to meet a common emission factor for shallow injection. The experimental set up revealed satisfactory results; repetitions of the measurements within an experiment helped to deal with variations in emissions. The set up was employed to compare artificial fertilisers or urine patches with shallow injection of dairy manure. It was shown that covering the open slot of shallow injection may mitigate emissions. Urea fertiliser had a comparable emission as shallow injection of dairy manure. Different N concentrations within urine were also compared with shallow injection.

### Conclusion

The new comparative experimental setup showed to be a fast method to investigate NH3 emissions from field applied manure, fertilisers or urine. The method could be used to compare different effects on the emission like soil type or irrigation management. Results may be used to derive the effects of different emission events by using the reduction potential compared to a given emission factor in inventories.

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## In situ quantification of methane leaks from 15 biogas facilities in France using an Optical Gas Imaging camera and a "flow-estimator" model.

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### Introduction

Minimizing methane leaks in biogas plants is essential in terms of GHGs as well as to limit loss of income. The quantification of such leakages remains a challenge. Some global or local methods are available, however they are often complicated to apply.

After a first project, Trackyleaks[1], which made it possible to develop a quantification method with an OGI Camera and its application to an agricultural biogas plant, the FELeaks project aimed to improve the method and investigate into representative biogas facilities of the French context.

### Methodology

Initially, laboratory work was carried out to improve the flow-estimator in its velocity and accuracy. Secondly, the method has been extended to a wider application by adapting it to another OGI camera currently in use.

Then, this method was applied to 15 biogas plants representative of French facilities. Among these sites, there were different kind of facilities (wastewater treatment plant, industrial digestion plant, biogas facilities on farms), of treatment (liquid and solid digestion), and of recovery (injection and cogeneration).

Quantifications were carried out on these installations, 5 with 2 OGI cameras (FLIR GF320, and EyeCGas), and 10 only with the EyeCGas camera.

### Results and discussion

OGI camera are typically used to pinpoint locations of gaseous emissions. The added value of this project was to make possible the quantification of methane, and to test the technology for different types of leaks and under different conditions (weather, distance, accessibility to the leak).

Three plant out of the 15, showed no measurable emissions with OGI camera. On the other sites, 30 non-controlled gaseous emissions were quantified. The leaks quantification results give around 60% of leaks lower than 1 m3 CH4.day-1 and around 7.5% of leaks higher than 100 m3 CH4.day-1.

These results provide initial French datas on a panel of biogas facilities, which makes it possible to measure the impact of leaks on the GHG of these sites.

### Conclusion

In order to assess fugitive emissions detection with the help of OGI cameras completed with a flow-estimator method was applied on different biogas facilities. These measurements allowed to evaluate the fugitive losses of methane. The emission factors for the facilities will be calculated.

If the method help to provide datas on fugitive emissions, it cannot be applied on diffuse emissions as storage of inputs or storage of digestate which should be considered.

### Acknowledgements

We are very grateful to ADEME for its support and funding for this project.

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Session 4 - Policy & Regulation

## The use of public data to target additional spatialized measures to reduce nitrate pollution of surface water: the case of Brittany (France)

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### Introduction

In Brittany (France) measures have been applied to reduce high nitrate concentrations in the surface water due to intensive agriculture for more than 30 years. Substantial improvements have been observed, but since five years, the regional mean concentration in nitrate seems to have reached a plateau (around 36 mg/l) but with diverse situations among the region. Some catchments display a limited reduction or an augmentation of the nitrate concentration of surface water. Additional measures are still needed in Brittany to tackle some specific water issues (algal blooms, drinking water directive, nitrate directive, European Water Framework Directive). The public stakeholders are thinking about spatialized actions according to the characteristics of each catchment (nitrogen and cultural pressure, hydrological characteristics, nitrate concentration in surface water). In the case of Brittany, hydro-biological models are generally used to assess the efficiency of the actions to reduce nitrate in the surface water, which find their limits mainly in the data access and the execution time. To work around this problem, one approach is the statistical analysis of the public data concerning the long-time monitoring of nitrate concentration in surface water and the anthropogenic pressures.

### Methodology

Our study aims to identify additional spatialized measures to reduce the nitrate concentration in the surface water of sixty catchments in Brittany. The additional spatialized measures are identified by the exploitation (geomatics and statistical analysis) of the public data of (i) nitrogen and cultural pressures, hydro-pedo-geomorphological parameters, climatic parameters, and (ii) the pattern of the nitrate concentration in the surface water since the year 2000 (Statitsical analysis by Hierarchical ascendant classification based on principal components, non-parametric regression). The nitrogen pressure is assess with the data of Nitrogen Flow Declaration (DFA) imposed under the Nitrates Directive by public services since 2014 for all the farmers in Brittany.

### Results and discussion

The results allow us to estimate the pattern of the nitrate concentration since 2000. The sixty catchments show a decrease. However, the statistical analysis points out 4 clusters of catchments dissimilar by the nitrate concentration and the nitrate concentration reduction since 2000. The first cluster comprises 26 catchments with a mean decrease of 0.4 mg NO3/l/an, the second cluster of 29 catchments is characterized by a mean reduction of 0.8 mg NO3/l/an, and the third cluster of 11 catchments with a mean decrease of 1.5 mg NO3/l/an. This third cluster contains four catchments displaying higher periodic nitrate concentrations than the other catchments (cluster 4). A second statistical analysis allowed us to identify the most explanatory factors (nitrate levels in groundwater, nitrogen pressure, climate conditions,…) (i) of the pattern of nitrate concentrations since 2000, (ii) the most characterizing factors of the four clusters of catchments. Based on the diversity of pressures (nitrogen and farming practices) between catchments and between the 4 clusters, additional spatialized measures are then proposed for the catchments targeted by the public stakeholder due to specific water issues.

### Conclusion

In order to reduce the nitrate levels in river, this statistical approach allows us to highlights indicators on which it is possible to intervene directly (nitrogen pressure, etc.) and contextual indicators on which it is impossible or difficult to intervene, such as the average temperature or the nitrate content of groundwater. this statistical approach makes it then possible to take spatial differences into account when proposing additional measures to reduce the pressures responsible for nitrate levels.

## Improving process and regulation: sustainable application of organic materials to land in Scotland

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### Introduction

Recycling organic materials to land is a well-established part of the circular economy which allows beneficial nutrient re-use and can help to increase soil organic matter content, while high fertilizer costs make it attractive to farmers. However, there is a risk that this approach puts further pressure on soils and the wider environment, for example by increasing contaminant loads. Joined-up thinking and increased use of new technologies can help us to regulate organic material spreading to land in a safer, fairer way, with benefits to industry, people and the environment.

ially, laboratory work was carried out to improve the flow-estimator in its velocity and accuracy. Secondly, the method has been extended to a wider application by adapting it to another OGI camera currently in use.

Then, this method was applied to 15 biogas plants representative of French facilities. Among these sites, there were different kind of facilities (wastewater treatment plant, industrial digestion plant, biogas facilities on farms), of treatment (liquid and solid digestion), and of recovery (injection and cogeneration).

Quantifications were carried out on these installations, 5 with 2 OGI cameras (FLIR GF320, and EyeCGas), and 10 only with the EyeCGas camera.

### Discussion

Over 13 million tonnes of organic materials are spread on farmland in Scotland each year. Materials spread in large amounts include manures and slurries, anaerobic digestates, sewage sludges and distillery wastes. The land bank, to which organic materials are spread, is often regarded as "endless". Although there is currently theoretically sufficient land bank available in Scotland to spread all organic materials, the uneven distribution of production and suitable land means that this is not true on a local or regional scale (Crooks & Litterick 2020).

Currently, regulatory regimes controlling organic waste spreading to land in Scotland (The Sludge (Use in Agriculture) Regulations 1989 and the Waste Management Licensing Regulations 2011) are outdated and piecemeal, reflecting knowledge and materials in use at the time they were established. In addition, despite similar risks and benefits being associated with most waste materials spread to land, the legal requirements of these pieces of legislation differ.

Notifications for waste spreading to land are currently processed on a case-by-case basis. Although information is received "electronically", it is often presented in Word or pdf documents. There are no consistent approaches to data returns or an overarching data system to allow SEPA to rapidly check for problems with waste to land activities.

SEPA aim to achieve improved sustainability of application of organic materials to land and more efficient processes for managing this activity through:

Working with waste operators within current regulatory regimes: SEPA are developing a new process to allow operators to rapidly assess risks and benefits from waste materials spread to agricultural land. We also audit operator soil/waste sampling activities and data to identify possible problems and make recommendations for improvements.

New and extended regulation: Scotland is currently moving to an Integrated Authorization Framework that will allow SEPA to regulate the application of waste to land in a more flexible and targeted way. This will consolidate waste spreading activities under a single regulatory regime. A consultation for the new framework is planned for spring 2023. SEPA also has new powers to allow the implementation of Fixed Monetary Penalties that could be used in this area.

New technologies: SEPA is building a new IS system fit for the challenges of the 21st century. Digital waste tracking will allow SEPA to track waste movements in real time and AI could help us to discover patterns in large datasets.

Collaborative research and development: SEPA are working with waste operators to explore alternative options for recycling/reuse of waste materials to spreading to land. We also commission research into issues associated with organic material spreading to land in Scotland. For example, Stutt et al. (2019) investigated risks to the environment and human health from organic contaminants in commonly spread materials. This leads us on to work with waste operators to develop methods to reduce the presence of harmful substances in materials that are spread to land.

### Conclusion

It is envisaged that a combination of more targeted and flexible regulation, improved data management and analysis, engagement with industry and research will improve the sustainability of organic material spreading to land in Scotland.

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## Future nutrient pollution and coastal eutrophication in Europe under global change

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### Introduction

Rapid agricultural development and high urbanization have resulted in increased nutrient losses in Europe (Grizzetti et al., 2017; Strokal et al., 2021; Sutton et al., 2011). High nutrient exports by European rivers end up in seas causing coastal eutrophication and harmful algal blooms (Billen et al., 2011; Garnier et al., 2010). This study aims at assessing the future river export of nitrogen (N) and phosphorus (P) and explore options to reduce associated coastal eutrophication in Europe under global change by focusing on agriculture and sewer systems.

### Methodology

First, we model the river exports of N and P for 2050 based on a baseline scenario combining Shared Socio-economic Pathways and Representative Concentration Pathways (SSP5-RCP8.5) by the MARINA-Nutrients (Model to Assess River Inputs of Nutrients to seAs) model (Strokal et al., 2016; Wang et al., 2020) in Europe. Second, we quantify environmental targets for N and P for most polluted basins at the river mouth. An index for coastal eutrophication potential (ICEP) is used to assess the impacts of excess nutrients on coastal waters (Billen & Garnier, 2007). ICEP above zero is considered as an indicator for high risk of coastal eutrophication (Billen et al., 2007). Third, the required reductions are calculated based on the environmental targets. We discuss the potential alternative options (e.g., Green Deal, Farm to Folk Strategy) to reduce future coastal eutrophication and reach the environmental targets.

### Results and discussion

Model results show that coastal eutrophication in Europe increases over time under the global change. River export of N and P to seas is projected to increase by 21% and 31%, respectively, between today and 2050. These increases are calculated for a scenario with intensive agriculture and high urbanization rates. Agriculture is expected to be responsible for most of N and sewage systems are mainly for P in seas. Required reductions for nutrients in seas in the future differ among basins and range from 1% up to 100%. These reductions are needed to avoid coastal eutrophication in the year 2050. The potentials to reach those reductions are the implementation of the European environmental policies (needed for N and P), replacement of chemical fertilizers with bio-based alternatives derived by organic wastes (largely needed for N) and the improved wastewater treatment in cities (mostly needed for P).

### Conclusion

The risk of coastal eutrophication increases in the future coupled with global change including socio-economic development and climate change. We conclude that recycling and/or upcycling nutrients in agriculture is urgently needed in Europe to reduce the nutrient pollution in surface waters as well as to close the nutrient cycles. Our results can contribute the formulation of effective environmental management strategies to avoid coastal eutrophication and to increase resource efficiency in agricultural production system in Europe.

### Acknowledgements

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## Exploring the Adoption Path of Bio-based Fertilisers: A Combined Approach of Theory of Planned Behavior and Van Westendorp Price Sensitivity Meter among Farmers in the EU

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### Introduction

Bio-based fertilisers form a new, rapidly developing market, with great prospect but also with high uncertainty. Marketing of new fertiliser products is an arduous task as multifaceted nature of farming as well as its multitude of stakeholders make it impossible to develop a marketing strategy encompassing everything at once. Therefore, a deeper understanding of adoption processes among farmers is needed to create marketing strategies accounting for differences in markets and marketed products. Yet, very little is known about psychological processes affecting eventual farmer's decision to start using bio-based fertilisers. In this context Theory of Planned Behavior (TPB) can be a useful tool that explores the potential adoption path by analysing potential psychological constructs affecting the eventual intention to adopt bio-based fertilisers. In the existing literature TPB has not been widely used for the bio-based fertilisers, moreover TPB studies rarely go beyond regular construct of 'Intentions', which provides only limited value for development of marketing strategies. As proposed by Dorce et al. (2021) TPB can be expanded by the 'Perceived price' construct which serves as a moderating variable between Intention and Behavior. In this study we aim to incorporate similar construct reflecting willingness-to-pay and assess how it affects/interacts with general 'Intentions' construct and willingness-to-buy for a set of specific fertilisers. Therefore, in this study we explore how TPB and general construct of 'Intentions' in particular interact with the willingness-to-buy and willingness-to-pay for a set of specific bio-based fertilisers and how these interactions are different depending on the region and demographics.

### Methodology

In this study we ran an EU-wide survey of farmers and utilised two separate techniques: (1) Theory of Planned Behaviour (TPB), and (2) Van Westendorp Price Sensitivity Meter (PSM). We used TPB to explore the adoption path of bio-based fertilisers using such psychological constructs as: Attitude, Subjective Norms, Perceived Behavioral Control and Intentions. PSM technique on the other hand implies showing the respondent a summary information about the bio-based fertiliser and then asking respondents questions to elicit four different psychological price levels for the product: (1) suspiciously too cheap price; (2) cheap or good price; (3) expensive, but acceptable price; (4) too expensive – unacceptable price. For this methodology, we selected 5 bio-based fertilisers commonly available or soon-to-be available in the EU, among those are: Ammonium Nitrate, Ammonium Sulfate, Struvite, Ash-based fertiliser and Biochar-based fertiliser. In addition to four regular questions of PSM we asked respondents how likely would they buy each of the presented products, thus allowing us to learn what is their willingness-to-buy for each analysed bio-based fertiliser.

### Results and discussion

The work is ongoing and we expect to uncover the insights before September. We expect that combining both TPB and PSM it will be possible to explore how TPB variables affect the willingness-to-buy for each analysed products. Four psychological price levels from PSM can expand the analysis and provide an extra layer of insights about farmers' perception of bio-based fertilisers. We aim to carefully explore the relationship between willingness-to-pay and willingness-to-buy, since counterintuitively depending on the region, demographic as well as the product in question this relationship may switch from positive to negative. The resulting analyses aim to provide the input to the understanding of farmers behavior and perception regarding bio-based fertilisers, moreover the comparison between the different regions would provide necessary data for tailor-made marketing strategies for bio-based fertilisers.

### Acknowledgements

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## Opportunities and challenges organo-mineral fertilisers can play in tackling food security – a Perspective

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### Introduction

Whilst mineral fertilisers are essential to meet nearly 50% of global crop production, its production is energy intensive and causes close to 2% of global greenhouse gas emissions1. With the price of mineral fertilisers increasing and the state of soil health decreasing, innovative solutions are needed to meet crop nutrient demands whilst ensuring that sufficient soil organic matter (OM) is conserved. One of such solution can be in the form of organo-mineral fertiliser (OMF). OMFs are a new concept that take organic waste products such as food waste and other wastes and combines them with mineral fertilisers to produce a more desirable nutrient content. The mixture is then dried and pelleted to make it easily storable and transportable. There has been pioneering work2,3,4 on OMF using biosolids as feedstock. This recycling of organic waste promotes a circular economy and provides a sustainable source of nutrients that will both feed the crops and act as a tool for the re-introduction of organic matter into agricultural soils.

The aim of this Perspective is to present an outlook on how OMFs can be considered as part of the toolbox to tackling some of the challenges and what will the opportunities and challenges pose in implementing sustainable agriculture.

### Methodology

The approach of this Perspective is in the form of a framework for a Strength Weakness Opportunities and Threat (SWOT) analysis. The SWOT analysis will critique how OMFs can play a role in implementing sustainable agriculture whilst tackling food security.

### Results and discussion

The strengths of using OMF shows potential to influence SOM and increasing water holding capacity. There has been evidence to reduce soil compaction and the carbon content of the feedstocks used to formulate OMFs can be important for improving soil health and contributing to residual nutrient for subsequent seasons. The carbon sources of OMF feedstock can also potentially contribute to carbon sequestration, albeit being slow thus addressing the climate agenda. The weaknesses of using OMF can be related to traceability due to variability of feedstocks used to formulate it. Gathering evidence on how to quantify the variability of nutrient content will provide confidence on OMF applications. There is on-going work on in-field technology using near and mid-infrared sensors that can be developed to determine nutrient content of organic feedstocks. Some work is in progress using high energy sub-atomic particles such as neutron and muon to quantify variability within OMF. There is also a need to ensure that contaminants of feedstocks are controlled so that the final product can be suitably applied in agriculture. The opportunities for using OMF can be capitalised by increasing innovations such as carbon capture, plasma, super critical oxidation technologies amongst some of them to valorise organic amendments. Each of these technologies has its advantages and disadvantages and needs to be used where suitable to optimise use of organic amendments. Technologies such as artificial intelligence, remote sensing and Internet of Things (IoT) can be very valuable in collating data on soil health and crop productivity associated with application of OMFs. The threats related to use of OMF can be associated to competition from other amendments such as compost, digestate, animal manure, crop residues and biosolids which are widely used and have more credibility in the agricultural sector. When using new products such as OMF, there is also a need to assess the willingness to pay for it, due to uncertainty on its efficacy. Using new products such as OMF will also be subject to regulatory restrictions to ensure that it is not classed as a waste and requires End-of-Waste status.

### Conclusion

OMF needs to be considered as part the solution to reduce reliance on mineral fertiliser requirements. The SWOT analysis will provide a critique and set the perspective on future directions to consider OMF as one of the options in the toolbox to address food security, soil health whilst tackling climate change and implementing a circular economy approach.

### Acknowledgements

Funding from Innovate UK, EPSRC, EU Framework 7 programme and industry are gratefully acknowledged.

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## Manure Management Under the Industrial Emission Directive: Impact on Ammonia Emissions

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### Introduction

While increasing nutrient availability as well as soil carbon stock and sequestration, manure N is linked to high Ammonia (NH3) emissions from its management and application (Jian et al., 2018; Köninger et al., 2021). These emissions negatively affect ecosystem health through acidification and eutrophication but also impact human health through their contribution to PM2.5 formation (Leip et al., 2015; Wyer et al., 2022). With an increasing number of livestock found on larger farms, introducing emission reduction requirements for such installations offers a way to reduce these impacts. The revised EU Industrial Emission Directive (IED), to be implemented by 2027, aims to do so by extending the previous coverage of large poultry and pig farms to cattle farms and reducing the threshold to already include farms of 150 livestock units and more (European Commission, 2022). To evaluate the impact of this revision on national as well as EU-27 NH3 emissions, we implemented the measures imposed by the revised IED in the GAINS model (Klimont et al., 2022).

### Methodology

We simulated implementation of the revised IED in the GAINS model by gradually increasing the adoption of most efficient NH3 removal technologies by all farms above the threshold from 2027 to 2050. The selected technologies are assumed to represent the best available technologies (BAT) and include e.g. a combination of low nitrogen feed provided to animals, tightly covered manure storage, and efficient application of manures on land. While in 2030 farms start implementing NH3 removal technology, full implementation of the most efficient technologies is expected by 2050 assuming it will be more complex in implementation hence demanding more resources to be fully set-up. The share of IED farms is estimated as the share of animals on farms with 150 or more LSU for each EU-27 country. Future farm size developments are extrapolated from past trends taken from the EUROSTAT farm structure survey (EUROSTAT, 2023).

### Results and discussion

Our results show that the implementation of the revised IED would lead to total NH3 emission reductions of about 2% (1-6%) in 2030 and about 12% (3-21%) in 2050 in the EU-27. The ranges represent the variation between countries as reductions highly depend on current implementation and technical applicability of mitigation measures as well as structural changes in the agricultural system reflected in farm sizes. While for Spain, where NH3 emission mitigation technologies can be improved in efficiency and implemented to a greater extent, a reduction of over 20% could be achieved by 2050, in the Netherlands a reduction of only 3% is projected for 2050 due to an already high implementation of such technologies and a highly industrialized livestock sector with mainly large farms. However, also the NH3 emission structure influences reduction potentials. As emissions from mineral fertilizer application in Bulgaria constitute almost 50% of total NH3 emissions, the overall impact of IED revision on the total NH3 emission remains small (1% in 2030 and 7% in 2050).

### Conclusion

The revision of the IED will lead to a NH3 emission reduction of about 2% (1-6%) in 2030 and about 12% (3-21%) in 2050 in the EU-27, with the extent of reductions depending on country-specific conditions like current production intensity and adoption of technologies as well as NH3 emission structure.

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Session 4 - Treatment & Processing Technologies

## Co-recovery of phosphorus and proteins from swine manure using fruit wastes

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### Introduction

A new approach for recovering nutrients and value-added products from waste is to search for a synergistic effect by combining two or more wastes. This work improved the recovery of phosphorus and proteins/amino acids abundant in swine manure by adding a second waste – fruit waste - rich in sugars. The second waste rich in sugars acted as a natural acid generator that replaced the use of purchased acids and lowered the overall recovery cost.

### Methodology

A new approach was developed to separate and recover concentrated phosphorus and proteins from animal waste (Vanotti and Szogi, 2019). It was improved by adding a second waste or product containing sugars, such as molasses and fruit waste (Vanotti et al., 2020). They could be used as a natural acid precursor that replaces the use of purchased acids and lowers the overall cost of phosphorus and protein recovery. In this study, the two model wastes were swine manure solids (source of extractable phosphorus and proteins) and peach waste (source of acid precursors).

### Results & Discussion

On a dry-weight basis, the swine manure solids contained high amounts of proteins (15.2%) and phosphorus (2.9%) available for extraction. It was shown that waste peaches, an abundant waste in SE USA with no cost, contain about 8% total sugars and can be used as an acid precursor to effectively extract phosphorus and proteins from swine manure (waste peaches were peaches that were too soft, had bad spots, or did otherwise not meet the grade at the Processing Plant for sale as fresh fruit). The waste peaches (Brix 7.7 deg) were added to the manure, and the combo received rapid fermentation (24-h) after adding an inoculum. Adding fruit waste to the manure and rapid fermentation produced abundant natural acids - lactic acid, citric acid, and malic acid – that effectively solubilized the phosphorus in the manure. Further, the peach fermentation did not adversely affect the protein recovery from the manure. A pH of about five or less is a valuable target to optimize the phosphorus and protein recovery from manure. The target was successfully met using a variety of natural acid precursors (fructose, molasses, and peaches). The phosphorus was precipitated with calcium or magnesium compounds, obtaining concentrated phosphate products with > 90% plant-available phosphorus. The proteins/amino acids in the manure were quantitatively recovered. It is appreciated that peaches are not the sole fruit or food waste product (i.e., vegetables) that contains significant amounts of sugar. It is contemplated that other sugar-containing agricultural by-products, such as other fruits and vegetables or lactose waste, could be used in this process for the same purpose with minor adjustments for amounts depending on the sugar concentration and initial pH of the fruit or vegetable.

### Conclusion

The synergistic combination of two wastes to enhance the recovery of phosphorus and protein products could be a potential new revenue stream from waste. The co-recovery of phosphorus and proteins from two wastes could be advantageous to offset treatment and storage costs and lessen land application's environmental impacts. The recovered proteins can produce amino acids, and the recovered phosphorus can be used as a recycled material that replaces commercial phosphate fertilizers.

### Acknowledgments

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## Phosphorous removal and recovery from cattle slurry using electrocoagulation

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### Introduction

Recent legislative developments in the United Kingdom (UK) could further restrict the land application of cattle slurry. The new Farming Rules for Water legislation restricts the volume of slurry that can be applied to soils relative to the soils existing phosphorous content (DEFRA, 2018). Applying cattle slurry to high phosphorous containing soils can lead to increased eutrophication of watercourses (Qin et al., 2020). Removal and recovery of phosphorus from cattle slurry for further valorisation is one method that could treat slurry on-farm to reduce its phosphorous content. The treated slurry could then be applied to soil to supply nutrients for crop growth, without breaching this new legislation. This research has been undertaken to test a novel electrocoagulation (EC) process developed by Elentec Ltd. Electrocoagulation is a physio-chemical process that dispenses ions into a solution and coagulates charged particles together and precipitates them from suspension for subsequent removal. The aim of this research was to test and demonstrate the efficacy of Elentec's pilot-scale EC process for the removal and recovery of phosphorous from cattle slurry. The separated, EC recovered phosphorous could be sold off-farm as a product for further valorisation, whilst the resulting EC-treated cattle slurry with lower levels of phosphorous could be applied to land for crop nutrient uptake.

### Methodology

Elentec's Ltd novel EC pilot-scale plant was installed on the Harper Adams University 450-head dairy unit. Slurry was screened through a commercial slurry separator and processed through the EC unit. The EC unit generates two separate fractions; the phosphorous-rich fraction and the phosphorous-deficient fraction. The raw, separated and EC-treated slurry fractions were analysed for dry matter, organic matter, total nitrogen, ammonium, phosphate and a range of elemental analyses, including phosphorous and potassium, using the respective standard analytical methods.

### Results and discussion

A range of cattle slurries have been tested through the pilot-scale EC unit and have demonstrated effective removal and recovery of phosphorous, along with other crop nutrient components. The recovered EC phosphorous-rich fraction had a dry matter content increase from 4.7% (raw slurry) to 7% and removed 98% of the phosphorous and 89% of the phosphates from the separated slurry. Through this slurry processing method, the volume of raw slurry requiring storage is also reduced. By separating the raw slurry, there is a (conservative) 15% volume reduction, with a further 35% volume reduction following EC treatment as the phosphorous-rich fraction is removed. If this EC phosphorus-rich fraction can be valorised for crop nutrient utilisation, this processing method could lead to an overall slurry volume storage reduction of 46% compared to raw slurry. This would present a significant opportunity for farmers to reduce the volume of slurry to store and spread, and aid future compliance with the Clean Air Strategy to cover open-topped slurry stores (DEFRA, 2019).

### Conclusion

Elentec's Ltd novel EC process is 98% effective at removing and recovering phosphorous from cattle slurry at on-farm pilot-scale operation. Further research will be undertaken to determine the bioavailability of these recovered nutrients for use by crops as a fertiliser-type nutrient product.

### Acknowledgements

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## A pilot plant for nitrogen recovery from animal slurries by a simplified ammonia stripping process

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### Introduction

Livestock manure is an important source of nutrients for crops, but in high livestock intensive areas it can cause environmental pollution phenomena. A nitrogen (N) recovery process could be beneficial to produce a mineral fertiliser that is easy to transport and use on crops. Among the possible processes, ammonia (NH3) stripping can be used to recover the N surplus in manures as mineral fertiliser, but it is currently expensive and difficult to manage. However, a simplification of the stripping process is possible moving towards to a slow-release system (Provolo et al., 2017). The aim of this study was the development of a pilot plant to demonstrate the feasibility of introducing a simplified NH3 stripping process in livestock farms.

### Methodology

e process was based on a slow-rate NH3 volatilisation promoted in a closed reactor and then removed by an air stream through the reactor headspace. The pilot plant has four reactors of 7.5 m3 each, mechanically mixed and heated by hot water circulation at a temperature of 40°C. Each reactor had a surface-to-volume ratio of 10 cm2 dm-3 and was half filled with slurry that was treated for 15-32 days. The air in the headspace flowed in a closed loop including a scrubber, where NH3 reacted with sulfuric acid (H2SO4 50% w/w) to form ammonium sulphate. The plant was controlled and monitored by an industrial pc which recorded the pH, temperature and level of the reactors, as well as the pH of the scrubber. Seven tests were overall carried out, two on pig slurry, three on dairy cattle slurry and two on digestate. At the beginning and end of each test, samples from each reactor were analysed for pH, total solids (TS), total Kjeldahl nitrogen (TKN) and total ammoniacal nitrogen (TAN) and from the scrubber to analyse pH, TS and TAN. Every 3-4 days a sample was taken from each reactor and scrubber to monitor the progress of TAN removal and recovery. The electrical and acid consumption was further monitored to determine the treatment cost.

### Results and discussion

The tests lasted between 15 and 32 days, resulting in recovery efficiencies of 42-72% of TKN and 35-79% of TAN. Comparable results were reported by Pandey and Chen (2021) and Provolo et al. (2017). A volume reduction of the treated slurries between 3-23% also occurred, due to the water evaporation from the reactors and its condensation into the scrubber. The ammonium sulphate solution obtained had average N concentration of 32.1 kg m-3, with the highest value reached of 66.5 kg m-3 resulting from the tests with less volume reduction of the reactors, which occurred in hot periods. The electrical consumption, acid consumption and treatment cost, expected on an optimized full-scale system, was around 2.5 kWh kg-1N recovered, 4 kg pure acid kg-1N recovered and 3 € kg-1N recovered, respectively.

### Conclusion

The plant was easily manageable and modulated in relation to nitrogen removal needs. Pilot plant tests have shown that about 45% of TAN can be recovered in 15 days of treatment. The treatment can be optimized by recovering the excess heat of a biogas plant and reducing slurry dilution in the livestock. The duration of the treatment can be reduced by introducing technical solutions which increase the surface-to-volume ratio. At the current cost of nitrogen, stripping would make it possible to obtain a highly efficient fertiliser from livestock slurries with significant environmental benefits.

### Acknowledgements

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## An advanced treatment system for nutrient recovery from digested slurry

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### Introduction

Livestock farming in the Wipptal Region of Alta Valle Isarco (South Tyrol, northeast Italy) generate approximately 250000 tons of manure per year. The well-managed application of animal manures to land enables their nutrient and organic matter content to meet crop nutrient requirements, and to maintain soil quality. However, land applied manures can also be a major potential source of diffuse pollution of water (Chambers et al., 2000). Runoff and subsurface drainage water from manured soils and livestock production facilities contain an appreciable total nitrogen (N) load, and nitrate (NO3−) leaching to aquifers that supply drinking water has important consequences for public health (Rasouli et al., 2014). To cope with these problems, a new digestate treatment system (DTS) has been developed and installed at a 1 MWel. centralised anaerobic digestion plant having 67 livestock farms as members suppling animal manure.

### Methodology

The installed DTS is made up of: a screw press separator and vibrating screen in cascading configuration; an innovative, fouling-resistant, membrane filtration vibrating system, in combination with spiral-wound reverse osmosis membrane technology; and a section for drying and pelletizing the solid fraction. Through this system, three types of products are produced: 1) a solid one, obtained by separating the solid fraction of the digestate, that is dried using the waste heat from the biogas cogeneration power unit, and subsequently turned into pellets; 2) a nutrient-rich concentrate, obtained from the ultrafiltration and reverse osmosis process; 3) dischargeable water (permeate). The performances of the installed DST were evaluated using a mass balance approach. Samples of the input and output materials were collected at each stage of the DTS during two sampling campaigns, and analysed to investigate their chemical characteristics and fertilizer value.

### Results and discussion

On average, 47.5% of the digestate mass entering the DTS was separated into the mixed (i.e., screw press + vibrating screen) solid fraction. The concentrate material and dischargeable water accounted on average for 33.9% and 18.6% respectively. The recovery of digestate total nitrogen (TN), total phosphorus (TP) and potassium (K) into the mixed solid fraction and into the concentrate was, on average, of 51.0% and 49.0%, of 57.3% and 42.7%, and of 43.4% and 56.6%, respectively. The concentration of total solids (TS), TN, TP and K in the pellet material (approximately the 8% of the total digestate mass input) resulted, respectively, 895.6 g/kg, 16.5 g/kg, 6.4 g/kg and 23.2 g/kg. The permeate showed an average TS content lower than 0.01 g/kg. None of the analysed permeate samples exceeded the concentration limits of ammonium nitrogen and heavy metals (e.g., copper - Cu, zinc - Zn, chromium - Cr, cadmium - Cd, nickel - Ni, manganese - Mn, lead - Pb) as recommended by National and European Union environmental laws for waste water discharge. Electric and thermal energy requirement averaged, respectively, approximately 30 kWhel and 130 kWhth per ton of treated digestate.

### Conclusion

The installed DTS produced high quality fertilizers suitable for partial or total substitution of mineral fertilizers. The concentrate material can be used as such for fertilising crops or added to the pellets in order to produce a "new fertilizer" with nutrient concentrations and proportions according to the requirements of the fertilized crops. Trial results proved the effectiveness and stability of the system at the operating conditions.

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## Biochar action on nitrogen cycle along composting: a key to reduce nitrogen emissions

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### Introduction

In a context where the use of bioresources and the circular economy appear to be key solutions to meet energy and climate challenges, anaerobic digestion is experiencing significant development. However, this development leads to a significant production of digestate, the recovery of which must ensure the sustainability of the entire sector. Composting is an interesting way of recovering solid digestate. Nevertheless, the losses of nitrogen during composting limit the agronomic value of the compost obtained and the environmental benefit (Zeng et al., 2016). Over the past ten years, studies in the literature have suggested that the use of biochar in mixtures of waste to be composted makes it possible to reduce these emissions (Manu et al., 2021). The objective of this work was thus to test the supplementation of a waste by different type of biochar, to study how it changes the nitrogen emissions and to understand through which mecanisms it acts.

### Methodology

To investigate the above questions, two biochars with differentiate chemical and physical characteristics (BC450 and BCC) were composted with an agricultural digestate (AW) at a 5% ratio (wet weight) using a 300l composting pilot with forced aeration. An experiment without biochar was used as a control. The experiments were performed for approximately 85 days. The reactors outlet gases were analysed for O2, NH3 and N2O and samples of the composted mixtures were collected all along the experiments. The samples were chemically characterised for the main nitrogen species (e.g. TKN, N-NH4+ and oxidised nitrogen) and microbiologically characterised for denitrification/nitrification genes (e.g. amoA, nirs, nosZ) and total bacteria, archaea and fungi. In the specific case of the experiment with BC450, biochar granules were removed from the mixture samples and analysed on their own.

### Results and discussion

The results show that biochars had different effects on the nitrogen cycle. BC450 reduced NH3 emissions by 29.6%, increased the proportion of initial nitrogen (TNi) transformed in organic nitrogen (Norg) and nitric nitrogen (N-NOx) but also increased N2O emissions compared to the control. Contrastingly, BCC increased NH3 emissions by approximately 30% and decreased N2O emissions by 22% compared to control. BC450 was characterized by the presence of acid functions on its surface, which are able to trap ammonia nitrogen, explaining the effect on NH3 emissions. However, when looking at the composted granules of BC450, it appears that only N-Nox was detected whereas N-NH4+ was expected. Microbiological results shown that the N-NH4+ initially adsorbed in the BC450 structure was transformed in N-NOX by nitrifying microorganisms: a higher number of amoA gene copies was found in the biochar granules compared to the compost. It led to a higher concentration in N-Nox that could explain the increase in N2O emissions. On the other hand, BCC was characterised by a high porous surface but rather no chemical functions. This absence of acid functions on the surface of the biochar led to a low capacity of ammonia nitrogen, which confirms that the biochar capacity to reduce ammonia emissions is ruled more by chemical than physical properties.

### Conclusion

This study clearly shows that biochars affect the composting nitrogen cycle differently depending on their chemical characteristics. It means that further researches have to be led in order to determine which parameters of the biochar should be promoted to minimize the nitrogen emissions. Moreover, the contradictory effect observed on ammonia emissions and nitrous oxide emissions has to be better studied to maximise the environmental profit of a composting process supplemented with biochar.

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## Changes in the concentrations of macroelements in the soil during fertilization with granular organic and organic mineral fertilizers

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### Introduction

The world's increasing demand and consumption of poultry meat generates a large amount of poultry manure. Application of raw manure to the field is complicated, also raw manure has a high content of ammonia nitrogen. This leads to nitrogen losses via leaching into the groundwaters or ammonia emissions. So sustainably produced fertilizers are very important for the possibility to reducing use of mineral fertilizers and lowering the ammonia emissions. Granulated organic and granulated organo-mineral fertilizers can be spread on field using conventional mineral fertilizer equipment. The aim of this work was to engineer a pilot scale process to produce granulated organic (OGF) and organo-mineral fertilizers (OMF) from poultry manure and to and compare their performance in potatoes and rapeseed yields to obtain descriptors of using these recycled nutrient sources towards cleaner agricultural production due to their slow-release properties. We determined the molecular and morphological structures of complex OGFs and OMFs obtained from poultry manure and mineral additives, such as diammonium phosphate (DAP) and potassium chloride (KCl). Collectively, these data suggest a complex nature of the OGF and OMF at the molecular and crystalline levels, which improves our understanding of these complex systems with direct relevance to sustainable nutrient management.

### Methodology

All experiments were performed on a pilot plant scale using a total of 16.5 tons of raw poultry manure mixed with peat bedding obtained from the poultry farm. Granulation was performed via extrusion with and without mineral additives, such as DAP and KCl. This The synthesis of OGF and OMF is described in detail in our published work (Mazeika, Dambrauskas, et al. 2016; Mazeika, Staugaitis, et al. 2016), the field research methodology is described in already published work (Mažeika et al. 2021).

### Results and discussion

We investigated the effects of moisture content in the manure, energy consumption during the three main stages of the process and the possibility to obtain nutrient balanced fertilizers using conventional straw drying and granulation equipment, common on the farms. We achieved 4-3-3 OGF, as well as NPK content (4-4-2, 4-3-6 and 4-4-9) in OMF. Energy consumption as the manure dried was about 100 kWh/t of product. The maximum achievable drying of sub 10 % water currently commonly used is not necessarily economically optimal. DAP was used to increase water soluble phosphate concentration and was limited to 6% of the total amount by the emission of ammonia during the granulation process. The conducted field experiments with OGF and OMF showed that these fertilizers stably increased the yield, the potato yield increased by 22.6% and 26.9%, respectively, when fertilized at the rate of 2 t/ha. However, compared to mineral fertilizers, their action is "slower", because a large part of the macroelements is bound to organic matter. The influence of moisture is very significant for OMF fertilizers. The soil medium and the amount of organic matter significantly influence the release rate of macroelements from OGF and OMF.

### Conclusion

Engineered granulated OGF and OMF obtained using poultry manure and mineral additives, such as DAP and KCl gave large amounts of the total N, P and K available to the crops. Granulation of manure and other biodegradable waste and mineral inputs allows to use rationally local resources, but the adaptation of these fertilizers to local soil and climate conditions requires new research methods and detailed studies.

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## Session 5 - Air & Water Quality

### Dissolved Organic Matter produced in livestock excreta is an overlooked nutrient source driving eutrophication impacts in fresh waters

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#### Introduction

Multiple stressors acting on fresh waters have caused unprecedented loss of biodiversity and degradation of the goods and services that support human society. Nutrient pollution is the most severe stressor in fresh waters globally and, among other effects, is responsible for producing anoxia, simplification of community structure, fish kills and stimulation of potentially toxic cyanobacterial blooms.

Hitherto, the cause of eutrophication and mitigation efforts have largely focussed on inorganic nutrient forms (nitrate, ammonia, ammonium, phosphate), even though organic nutrient fractions can contribute >80% of the total nitrogen (N) or phosphorus (P) pool in many fresh waters. In research funded under the UKRI DOMAINE (Characterisation of the nature, origins and ecological significance of dissolved organic matter in freshwater ecosystems) Large Grant programme, we present evidence that dissolved organic matter (DOM) exported to freshwaters from livestock farming systems is taken up as a nutrient resource by both stream bryophytes and epilithon (benthic algae). Using compound-specific stable isotope probing under field-ambient conditions, these novel experiments reveal organic N uptake rates comparable to, or in excess of, inorganic N (nitrate and ammonium) uptake rates in streams. The nitrogenous DOM (dissolved organic N) compounds, commonly occurring in livestock excreta, are rapidly metabolised by both biotic groups within 1 hour of dosing and incorporated into protein synthesis within 2 hours.

This work confirms the importance of DOM as an overlooked and highly bioavailable nutrient resource for primary producers in freshwater ecosystems, and also highlights livestock excreta as a primary source in driving nutrient enrichment impacts and water quality decline in freshwaters. This has important implications for the management of nutrient enrichment impacts in fresh waters. Organic nutrient export to freshwaters is rarely targeted in current policy and mitigation efforts, while current economic pressures and moves towards a circular economy mean there is increasing focus on slurry and slurry enhancement methods as an alternative to inorganic fertiliser use.

We will also outline the approach we are taking in our new QUANTUM programme to Quantify the combined nutrient enrichment, pathogenic and ecotoxicological impacts of livestock farming on UK rivers, recently funded under the new NERC Freshwater Quality programme.

## Regionalized modelling of the fate of recycled fertiliser P in agricultural fields: Development of the life cycle inventory model PLCI 2.0.

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### Introduction

Phosphorus (P) in societal waste streams can be recycled or up-cycled to recycled P fertilisers (RPFs). When developing and implementing new technologies for P recycling, Life Cycle Assessment (LCA) can be a useful tool to assess the environmental impact and to support environmentally friendly decisions. In LCA calculations, inventory factors are required that describe for example emissions, resource requirements and potential substitution of products per unit of the use of a product. The Phosphorus Life Cycle Inventory model PLCI (ten Hoeve et al., 2018) is a tool for estimating such inventory factors for the use of RPFs.

The main objective of this study was to develop the PLCI model further to be applicable to regions of the EU, by considering parameters that describe region-specific conditions affecting the loss of P, crop P uptake and potential mineral fertiliser substitution. The target users of the model are LCA practitioners who want to do an LCA on a P recycling technology, including the application of an RPF to agricultural fields of any region in the EU. Therefore, we developed a model that does not require detailed site-specific data.

### Methodology

Parameters that were introduced in the model include soil type, soil P status, soil erosion rate, groundwater leaching, crop P uptake and atmospheric deposition. The model considers regions down to the NUTS3 level (Eurostat, 2022), at the extent of the EU countries. Several RPFs were incorporated in the model, including coefficients to describe the partitioning to the labile, plant available P fraction. To illustrate the applicability of the model, a case study was performed, in which various RPFs were applied in the Copenhagen surroundings in Denmark and in the Piemonte region in Italy. Inventory factors were calculated for the RPFs in both regions, describing the P loss from soil, crop P uptake and mineral fertiliser substitution.

### Results and discussion

Differences between RPFs with contrasting P availability were comparable in the Copenhagen and the Piemonte regions. In both regions, RPFs with a higher share of labile, plant available P, resulted in higher substitution of mineral fertiliser. Moreover, a smaller labile P fraction of the RPF also led to higher P loss in the long term, as more P was lost with soil erosion before becoming plant available. However, there are also differences between the regions. For instance, differences in soil erosion rates and P fertilisation practices between the regions had a strong impact on the calculated P loss and the mineral fertiliser substitution, respectively. These results illustrate the importance of defining region-specific fertilisation regimes, which is now possible with the new, more dynamic version of the PLCI model.

### Conclusion

In conclusion, the new PLCI 2.0 model provides a dynamic tool for LCA practitioners to estimate region-specific inventory factors for RPFs. The model is relatively easy to use and at the same time, it captures differences between fertilisers with varying P availability and between different regions in the EU.

### Acknowledgements

Thanks to Inge de Graaf for providing data on groundwater leaching and to Panos Panagos, for providing the data on P loss from arable land at the NUTS3 level. Thanks also to Kari Ylviaino for providing data on soil total P. We thank the European Union's Horizon 2020 Framework and the FertiCycle project (Grant No.860127) for full support during this work.

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## Higher nitrate leaching under cattle slurry than under mineral fertiliser, but soil N as major source of leached nitrate

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### Introduction

Animal manure is suspected to be a major source of nitrate leaching due to its low nitrogen (N) use efficiency by crops. However, actual measurements of nitrate leaching from animal manure under field conditions are scarce. In an on-farm field trial over 2.5 years, 15N labelled cattle slurry was used to trace the fate of manure N in the soil-plant system and to test whether more nitrate was leached after slurry than after mineral fertiliser application.

### Methodology

The experiment was conducted on two neighbouring fields on loamy soil in the Gäu region, Switzerland – a region with persistently high nitrate levels in the groundwater. Both fields were managed by a local farmer in order to obtain representative results for practice conditions. A common crop rotation (silage maize – winter wheat – grass-clover) was pursued, which was shifted by one year between the two fields. We compared three fertiliser treatments: 0N Control (Con), 15N mineral fertiliser (Min), and 15N cattle slurry (Slu), which was obtained by feeding a heifer with 15N labelled ryegrass hay. According to common agricultural practice, we applied Min and Slu at equal rates of mineral N in 2018. In the following years, fields were fertilised with non-labelled fertilisers by the farmer. Nitrate leaching was measured cumulatively per crop, using ion exchange resin based passive samplers at 1 m depth underneath the undisturbed soil profile (Bischoff, 2007). Tracing the labelled fertilisers into ammonia (NH3) emissions, crop biomass, different soil N pools, and nitrate leaching, we provide a comprehensive fertiliser N balance over several years.

### Results and discussion

In the year of application, 15N recovery of total applied N in aboveground crop biomass was similar for both fields, ranging from 45 to 47 % for Min and 19 to 23 % for Slu. Complementary, recoveries in soil were greater for Slu (53 to 58 %) than for Min (28 to 32 %), despite greater NH3 emissions from Slu. Fertiliser recovery in the succeeding crops was small (<4.6 % in the first and <2.4 % in the second residual year, relative to applied fertiliser amounts) and similar for the two fertilisers. These results relate well to our finding that despite initial differences between Min and Slu, 77 to 89 % of residual fertiliser N in soil after the first crop were recovered in the non-microbial organic N pool, irrespective of fertiliser type. Depth translocation of fertiliser N was marginal and at the end of our study, the majority of 15N was still recovered in the top 30 cm. Along with higher recoveries in soil for Slu, we found significantly more slurry N than mineral fertiliser N lost through leaching. However, although cumulated amounts of nitrate leaching over the three crops reached up to 205 kg nitrate-N ha-1, less than 5 % of this amount originated from direct leaching of the labelled fertilisers. The highest nitrate leaching occurred after termination of grass-clover ley and most of the leached nitrate likely originated from mineralisation of soil organic N. A follow-up study revealed that most of the residual fertiliser N was stored in the mineral-associated organic matter fraction (<20 µm) and that plants could take up N from this fraction, highlighting the importance of this fraction for a better understanding and prediction of N turnover dynamics in soil (Fuchs et al., 2023).

### Conclusion

Our results emphasize the crucial role of soil organic N turnover both for plant nutrition and nitrate leaching losses. Considering the turnover dynamics and processes is necessary to allow for a better synchronisation of mineral N supply and plant N demand and to prevent leaching losses.

### Acknowledgements

This study was conducted in the framework of the research project "NitroGäu". The project received funding and was scientifically assisted by the Swiss Federal Office for Agriculture (FOAG) and the Environmental Office of the Canton Solothurn.

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## Effects of manure and mineral fertiliser nitrogen supply on crop nitrogen utilisation and nitrate leaching on cut grassland

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### Introduction

In the Netherlands, the use of animal manure nitrogen (N) instead of mineral fertiliser N on grassland and its implications for nitrate leaching are a frequent topic of debate. On the one hand, the potential for nitrate leaching of N from manure may be higher due to untimely mineralisation of the organic N in periods with no or limited N uptake by crops. On the other hand, a combination of elevated gaseous N losses, e.g. through ammonia volatilisation and denitrification, a more gradual release of the N from manure, and perhaps a higher N crop uptake due to other benefits from manure, may result in a decreased amount of soil mineral N and a lower associated leaching potential. To test the impact of fertilisation type on N utilisation by grass and nitrate leaching, a multi-year field experiment and a greenhouse experiment were carried out.

### Methodology

In the field experiment, various types of mineral fertiliser and manures were compared. The mineral fertilisers comprised calcium ammonium nitrate (CAN) and urea with a urease inhibitor and the manure types included cattle slurry, digested cattle slurry, and pig slurry. Per fertiliser and manure type, four different fertilisation regimes were applied: a control without N fertilisation and an annual fertilisation of 300 kg N ha-1 for one, two and three consecutive years. This setup was used to determine both the N utilisation and apparent N recovery (ANR) in the year of application, as well as the legacy effect of prior fertilisation. The ANR was calculated as the difference in crop N-uptake between the fertilised and unfertilised plots divided by the N rate. On all plots the crop N uptake, the residual soil mineral N in the autumn in the 0-60 cm layer, and the nitrate concentration in the upper groundwater were measured annually.

In addition to the field experiment, a greenhouse experiment with grass was conducted in which mineral fertilisers, including CAN, and cattle manure products, including slurry and digestate, were compared. The experiment consisted of two growing cycles with a N rate of 100 kg N ha-1 per cycle. Besides crop N uptake, nitrous oxide emissions and nitrate leaching were measured. At the end of the pot experiment, potential denitrification rate was measured in the top soil.

### Results and discussion

Averaged over the years, the ANR in the year of application was 0.75 to 0.80 for the mineral fertilisers and 0.42 to 0.56 for the manure products. No significant differences were observed between the mineral fertilisers CAN and urea. The first year ANR for pig slurry was significantly higher than that for (digested) cattle slurry: 0.56 vs 0.42-0.44. In the second and third year after application, the ANR of the manures increased by 0.06 to 0.13 compared to the first year ANR (legacy effect). No such effect was observed for the mineral fertilisers.

In two out of three years, the residual soil mineral N in the year of application, measured after the last cut in the autumn, was significantly higher for the manure plots than for the mineral fertiliser plots. In the years after the fertilisation was stopped, no differences were observed between treatments. The nitrate concentration in the upper groundwater did not differ significantly between the mineral fertiliser and manure plots, neither in the year of application, nor in the years after the fertilisation was stopped

In the pot trial, the ANR of the mineral fertilisers was also higher than the ANR of the manures. No differences in nitrate leaching were found. In one of the two growing cycles nitrous oxide emissions were higher for the pots that received slurry than for the CAN pots. No clear differences were found in potential denitrification in the top soil.

### Conclusion

The use of manure instead of mineral fertiliser N resulted in a significantly lower N utilisation by cut grassland over the first year. This difference persisted when the legacy effect of the applied manure was taken into account. However, no significant differences in nitrate leaching were observed between manure and mineral fertiliser.

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Session 5 - Nutrient Utilisation

## Estimating co-product management effects on productivity and environment in European farming systems

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### Introduction

A more circular agricultural system has reduced resource inputs with reduced emissions to the environment compared to the current system. Recycling of unavoidable co-products is a key component of circular agriculture. In this context, a proper prioritization of co-product use in an agricultural region is critical to maximise utility. There may be various options to recycle products and materials, which all could be referred to as circular, but the comparative effect of alternative options will be context-specific. In this study, an indicator based approach is formulated, which enables to evaluate multiple alternative co-product management scenarios, related to circular agriculture, on field, farm and region level in four European countries. The European regions to which the method is applied are Drenthe (the Netherlands); Ariège (France); Central Denmark (Denmark); and Fife (Scotland). All case study regions include both crop and livestock farms, with possibilities to increase integration and biomass exchange.

### Methodology

The modelling approach is used to quantify a selection of relevant environmental and agricultural productivity indicators, to compare the scenarios across regions. Selected environmental indicators include emissions of greenhouse gasses (GHG), nutrient balances (i.e., nutrient inputs, outputs and losses), and energy consumption. Productivity indicators included crop- and livestock components. External land-use and related environmental effects were also accounted for. Evaluated scenarios included manure digestion and use of digestate, crop residue and urban waste composting and recycling, and winter cover crop grazing. In each region, these indicators were quantified on field, farm, and regional scale to identify how farm and field management changes may have a regional effect (and vice versa). Farm level evaluations were based on typical crop and livestock farms, and aggregated for regional evaluations.

### Results & Discussion

The model uses a mechanistic approach with little data requirements, to be applicable in various European case study regions. The level of detail is flexible and depends on input data and can be increased using a tiered approach. To allow a fair comparison between regions, the chosen level of detail was equal for each region. Preliminary results will be shared to show how the approach is applied. Besides, the results show the environmental and productivity effects, but also trade-offs between indicators, for alternative co-product management scenarios across divergent European case study regions. This method development and analysis of implementing circular agricultural practices is part of the ERA-NET project MI BICYCLE.

## Cost Benefit Analysis and Environmental Impact Assessment of Compost Use from Food and Organic Waste in Australia

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### Introduction

Food waste has long been an issue for Australia and has gained prominence in the last decade (Reynolds et al., 2015). Australia produces enough fresh food to feed 60 million people daily but annually wastes 7.5 million tonnes of food fit for human consumption (Reutter et al., 2016), approximately 40% of Australia's total food production (KPMG, 2019). The economic cost of Australia's food waste has risen from $5.2 billion (2009) to about $20 billion a year (SARDI, 2015). Whilst landfills have been the most prevalent destination for food waste in Australia, it results in greenhouse gas emissions which is detrimental to the environment, leads to global warming (Porichha et al., 2021) and contravenes sustainable behaviour. Some food waste could best be avoided or upcycled, but opportunities for consumption have limitations. Therefore, food and organic recycling, such as composting, is the most effective way to mitigate the effects of unavoidable food and organic waste and to bring nutrients back into the soil through the application of compost (McGuire, 2015). Several studies focus on the need of composting food and organic waste. However, farmers are focused on making economic gains and sustaining their farms for their future generation. Therefore, it becomes eminent to analyse the economic gains and environmental implication of their compost use to determine its benefit to farmers. This paper aims to deploy a Cost Benefit Analysis and Environmental Impact Assessment of compost use from food and organic waste through a novel farmer-based scenario approach. Outcome from this paper will inform farmers on how their application of compost translates into their income, potentially motivate farmers to practise a more sustainable farming, boost demand for compost and promote the recycling of food and organic waste into compost.

### Methodology

A Cost Benefit Analysis and Life Cycle Assessment will be executed for three categories of farmers: (1) farmers that produce their own compost; (2) farmers that purchase the compost they use; (3) farmers that do not use compost at all (solely dependent on mineral fertilisers). A comparative analysis will be performed for these categories with respect to their yield improvement, fertiliser saving, pesticides demand and fuel demand. The anticipated economic and environmental benefit from each category will be monetised to show gains to various stakeholders.

### Results and discussion

Analysis is underway and results will be presented at the conference.

### Acknowledgements

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SARDI., 2015 Primary Production Food Losses: Turning losses into profit. South Australian Research and Development Institute, Primary Industries and Regions South Australia.

**Can digestate application improve nitrogen use efficiency, reduce nitrate leaching and greenhouse gas emissions in organic cropping?** Mayer, J.[a]*, Scheifele, M.[a], Diener, M.[a], Agostini, L.[b], Krause, H.-M.[b], Efosa, N.[b] & Bünemann-König, E.[b]

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## Introduction

The European Union's Green Deal strategy aims to reduce nutrient losses in agriculture by 50% and fertilizer use by 20%. Reducing nitrogen (N) losses – ammonia (NH3), nitrate (NO3) and nitrous oxide (N2O) – by manure processing and further field application and management will be a key measure to improve organic fertiliser nitrogen use efficiency (NUE) by crops and meet EU reduction goals. Anaerobic digestion of manure and organic waste generates renewable energy and contributes to close nutrient cycles. It is also suggested as an option to improve NUE in organic cropping, but possible trade-offs like increased NH3 losses, N2O emissions or NO3 leaching are not well understood. Biochar amendments to digestate has been advocated to decrease N losses. The aim of this study was to understand the benefits and trade-offs of digestion of manure and organic waste as well as biochar amendments to digestate compared to undigested liquid manure under organic cropping.

## Methodology

We set up a comprehensive field study in Switzerland with digestate from liquid manure with and without biochar amendments and a liquid digestate from an organic waste digestion plant and compared it to undigested liquid manure, mineral fertilization and a zero N control. The study started in 2018 and is still ongoing. We assessed yields, NUE, NH3 losses and N2O emissions and mirrored the experiment in the Agroscope-Zurich lysimeter facility to evaluate NO3 leaching. The ammonium (NH4) N fraction of fertilizers was 15N traced and allowed to study the initial NH4-N flows over three crops (silage maize – winter wheat – winter barley). N application rates were based on total N content of fertilisers (120 - 140 kg N ha-1). We show results from the first 3 years period.

## Results and discussion

Crop yields differed only slightly in maize and wheat. However, in barley digestate produced comparable yields to the mineral fertilization, but undigested liquid manure was significantly lower. Apparent NUE of manure-based digestate tended with 30% to be greater than for undigested liquid manure with 26%. A decrease rather than an increase in apparent NUE was observed when digestate was amended with biochar at 2 t ha-1 yr-1. Crop NH4-N recovery in the year of application was only 36 % for mineral and 16% for organic fertilizers in maize due to the very dry summer 2018, but in wheat in 2019 75% of NH4-N was recovered from mineral fertilizer, 52% to 62% from digestate, but only 40% from undigested liquid manure. Low NH4-N recovery could be explained by partly high NH3 losses after application, which were significantly higher in digestate, 42% of applied, compared to undigested liquid manure with 31%. Emissions of N2O tended to be increased by application of liquid organic compared to mineral fertilizers, but were mainly driven by soil temperature, soil moisture and soil mineral N. NO3 leaching was low and did not exceed 25 kg NO3-N ha-1yr-1 (Bünemann and Mayer 2021).

## Conclusion

Overall digestion could be a measure to reduce N limitations in organic cropping with small environmental trade-offs if NH3 losses after application can be reduced. Biochar additions had no beneficial effect on N losses. A second phase of project (2022 – 2025) will focus on N-loss reduction technologies with slurry acidification and NH4-stripping (see poster Agostini et al.).

## Acknowledgements

We thank the Swiss Federal Offices of Agriculture, Environment and Energy for financial support of the project.

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## French excretions of Nitrogen and Phosphorus: current losses in the sanitation system and (non) circularity in agriculture

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### Introduction

Nitrogen (N) and Phosphorus (P) are critical elements for crops growth as well as animal and human nutrition. However, N and P excesses and losses lead to air pollution and eutrophication, impairing planetary boundaries.

In western societies, N and P present in human excretions are treated in wastewater treatment plants. The main aim is to prevent water pollution but not to recycle these nutrients into agroecosystems, despite their fertilizing potential.

Here we provide an estimation of the destination of N and P excreted by French people and assess how much is recycled in agriculture.

### Methodology

Using a unique dataset of 20,000 wastewater treatment plants and multiple French sources, we produce a complete assessment of N and P flows in the French sanitation system for the period 2015-2020. We also compute wastewater treatment plants yields at the basins and national scale over more than a decade. Combined with wastewater treatment plant sludge destination data, this allows us to deduct the share of excreted N and P recycled into the French agroecosystem.

### Results and discussion

In France, only 5-10% of excreted N is finally spread on crops, contrasting with the ~50% rate for P. This means that more than 90% of N and 50% of P is lost.

Of the 1 Mt of sludge produced in France, ¾ are spread on crops. National wastewater treatment plants yield is ~70% for N and ~80% for P. While most of the treated P is found in sludge, N is denitrified as N2, explaining the large difference in recycling rates. Consequently, about half of the excreted N finally ends up in the air, mainly in the N2 form. For both N and P, most of water pollution is not due to wastewater treatment plants, but rather comes from combined sewers losses, and from individual autonomous systems discharges.

Wastewater treatment plants yields increased during the 2000s and were followed by a decade of stagnation starting the 2010s. This stagnation level is contrasted according to the different basins, and closely matches the classification into "vulnerable zones" as defined by the European Union, highlighting the influence of this policy.

Finally, we compare the N:P ratios of urine (which concentrates most of the excreted nutrients), wastewater treatment plants sludge, and crops nutritional needs. While sludge N:P ratio is too low for crops, urine is adequate, suggesting a potential for direct recycling as fertilizers instead of post-sewer treatment.

### Conclusion

These results suggest that a paradigm shift is needed to escape from the current linear sanitation system, especially for nitrogen. Source separation of urine to produce fertilizers can help decrease water pollution, reduce energy consumption (in wastewater treatment plant and in mineral fertilizers production) and increase regional food security.

### Acknowledgements

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## Session 5 - Treatment & Processing Technologies

### The importance of utilization of swine manure resources for the sustainability of livestock production

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### Introduction

The need to decarbonize the global production systems has encouraged circular logic, prioritizing the recovery technologies and reuse of resources in many different sectors. In livestock, this reality is no different, with significant emissions of greenhouse gases, the proper management of waste is essential to minimize environmental damage (Awasthi et al. 2022). However, an integrated solution for the treatment of animal waste is a challenge. With a distinct range of technologies, the treatment configuration adopted can promote different impacts, both in technical, economic, and especially environmental terms (Tian et al. 2021). In this sense, the present study aimed to compare different systems of swine manure treatment to verify the feasibility of these treatment routes, focusing on the promotion of decarbonization and circularity of the swine livestock chain.

### Methodology

Four configurations of swine manure treatment systems, derived from the SISTRATES® technology (reference scenario), composed of solids separation modules, anaerobic digestion module for the solid and liquid fractions, nutrient removal, and recovery module (nitrification and denitrification, and chemical precipitation of phosphorus) (Cândido et al. 2022), were evaluated environmentally and economically. To determine the environmental feasibility of the plants a life cycle study was conducted, while the economic feasibility was determined based on typical economic indicators used for this evaluation.

### Results and discussion

The results show the importance of prioritizing energy use routes through anaerobic digestion, which reflected directly on the implementation costs of the treatment plants and the economic benefit of resource use. The life cycle assessment confirmed these results, showing that technologies with routes focused on anaerobic digestion, presented the lowest environmental impact, reducing greenhouse gas emissions by 90% compared to a traditional waste management system (in deep pit). In addition, the removal of pollutants such as nitrogen and the recovery of nutrients such as phosphorus, as well as the reuse of water, were important. Thus, of the four scenarios evaluated, SISTRATES® presented the best environmental performance (with an emission of 21.6 kg of CO2 eq) and economic performance (with a NPV of US$ 870,489.59), validating itself as a promising technology in a circular economy context (Hollas et al. 2023).

### Conclusion

The transition to a circular economy is not straightforward and many factors must be coordinated, but with the treatment techniques present in SISTRATES®, waste management can be targeted to generate added value and minimize environmental damage, contributing to the decarbonization of the swine production chain, with anaerobic digestion being the vital part of the livestock waste treatment system.

### Acknowledgements

The authors thank the support provided by the project SISTRATES FUNTEC-BNDES (grant number 15.2.0837.1), the CAPES and CNPq. They thank Dr. Marcelo Miele for the suggestions in economic evaluation.

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## Characterization and valorisation of biogas digestate and derived organic fertilizer products from separation processes

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### Introduction

Biogas production is a sustainable technology that produces energy and reduces the CO2 footprint from agriculture as well as producing organic fertilizer products. The digestate characteristics and the quality of the digestates from anaerobic digestion (AD) depends on several parameters such as input feedstocks and operational parameters of the biogas plants. In Denmark the biogas sector has expanded very quickly over the last few years with a tripling in gas production in 5 years. This expansion has resulted in a great variety of the feedstocks used in the plant, where the first generation of plants mainly treated industrial waste with short retention times, to a new generation of biogas plants where high amounts of lignocellulosic feedstocks are used which has a high impact on the fertilizer quality and the emissions of methane and ammonia from the storage and application of the digestate (Møller et al. 2022). Furthermore, the biogas technology used, and the use of separation technologies plays and important role. In this study, we examined a large number of full scale and pilot scale biogas plants over an 8 year period. The chemical, rheological and biological parameters were evaluated for the whole digestate, the liquid, and the solid fractions for a large number of plants.

### Methodology

Digestates and separated fractions for this study were collected from full-scale biogas plants in Denmark during the period 2015 to 2023. The samples were collected from the final process step at the biogas plants. The samples were divided into two portions. The first portion was used to evaluate the residual methane potential of the digestates, while the second portion was used for rheological and chemical analyses. The chemical analyses included all macro and micro nutrients, fibre analysis and elemental analysis. The rheological properties were examined by a new method measuring viscosity in a simple way where the time necessary to run through a tube is measured. The method has been correlated with data obtained from a laboratory viscometer (Brookfield DV2T) and a particle size analyzer (Mastersizer 2000) and dry matter measurements. Residual gas potentials were measured in triplicates. The bottles were sealed with rubber stoppers and screw caps and flushed with N2. They were incubated for minimum 90 days.

### Results and discussion

The HRT and input feedstocks significantly influenced the rheological, chemical, and residual gas potential. For the rheological parameters, from preliminary data analysis, dry matter correlated rather poorly with both k and n values (k and n were calculated from the DV2T viscometer data), (R2 = 0.299 and R2 = 0.265, respectively) and slightly better correlations of particle sizes >2mm were obtained for k (R2 = 0.419) and n (R2 = 0.325). A relatively good correlation of the tube time difference with k value (R2 = 0.773) was found, while this measurement correlated very poorly with the n value (R2 = 0.068). Substrates varied widely in their viscosities, as manures, whole digestates and liquid fractions (following separation) were examined, Considerable content of fermentable fractions, such as cellulose (7.57-23.36%), hemicellulose (0.91-17.83%), and protein (13.31-22.06%), were present in the digestate dry matter. The ultimate residual methane yields varied between 48.61 and 226.74 ml/g of volatile solids. The chemical composition of the digestate and all fractions were significantly affected by the feedstock, temperature and HRT. The results will give insight in the digestate and derived fractions as an organic fertilizer, the impact of the digestate characteristics in relation to risk of emissions of methane and ammonia during the storage and application as well as the possibilities for mitigation by technologies like separation, maceration etc. Furthermore the results will valorize the solid fractions from a large amounts of plants as a fertilizer resource or feedstock for pyrolysis.

### Acknowledgements

This results is part of the research projects Climoptic (org. RDD4, 34009-18-1384), Fertihood (org. RDD6, 34009-20-1707) and Increased energy and new green products (EUDP 2020, 64020-21139.

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## Ammonia Conversion and/or Recovery from Wastewater containing Nitrate and/Ammonia using Integrated Electrochemical Membrane Flow Reactor

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### Introduction

The Haber-Bosch process has long been employed to produce industrial ammonium for fertilization, which consumes fossil fuels to drive the thermodynamically unfavourable reaction between nitrogen (N2) and hydrogen (H2) at high pressures and temperatures.1 Meanwhile, the extensive use of fertilizers and industrial waste streams causes eutrophic water pollution (e.g., with high nitrate/nitrite content).2 Conventional biological nitrogen removal involves energy intensive nitrification and denitrification processes (~11.7−12.5 kWh·kg-N-1) that eventually converts all nitrogen species into nitrogen gas.3 Clearly, shortening the nitrogen removal processes by converting wastewater nitrate into NH3 can potentially reduce the energy and carbon footprints and enable nutrient recovery and reuse/recycle. This study demonstrates for the first prototype electrified membrane system for synchronizing electrochemical NO3− reduction and upcycling to NH3 without any external chemical addition.

### Methodology

Synthetic wastewater containing NO3− and Cl− was fed into the electrochemical membrane flow-cell, which consists of three reactive chambers, cathodic, anodic and trap chambers. A CuO catalytic layer was fabricated and deposited onto the Cu foam that was attached to the polytetrafluoroethylene (PTFE) membrane to achieve cathodic NO3− reduction and alkalinity production for NH4+ deprotonation. The 3D electrode could provide a multidimensional electron transport avenue, high diffusion efficiency, and allow a sustainable decentralized ammonia recovery. The produced NH3 transferred across the porous PTFE membrane and dissolved into the stream in the trap chamber, which was acidified by the anodic oxygen evolution reaction. The impacts of operational parameters (e.g., cathodic potentials), water chemistry (solution's pH and NO3− concentrations) on total nitrogen removal efficiency, NH3 recovery efficiency, Faradic efficiency and energy consumption for NH3 recovery were examined. Density functional theory (DFT) calculations were undertaken to unravel the in-situ valence state reconstruction of the CuO catalytic layer during the electrochemical NO3− reduction process.

### Results & Discussion

This study presents an electrified membrane made of a CuO@Cu foam and a polytetrafluoroethylene (PTFE) membrane for reducing NO3− to ammonia (NH3) and upcycling NH3 into (NH4)2SO4, a liquid fertilizer readily for use. A paired electrolysis process without the external acid/base consumption was achieved under a partial current density of 63.8±4.4 mA·cm−2 on the cathodic membrane, which removed 99.9% NO3− in the feed (150 mM NO3−) after 5 h operation with a NH3 recovery rate of 99.5%. A recovery rate and energy consumption of 3100±91 g-(NH4)2SO4·m−2·d−1 and 21.8±3.8 kWh·kg−1-(NH4)2SO4 almost outcompetes the industrial ammonia production cost in the Haber-Bosch process. Density functional theory (DFT) calculations unravelled that the in situ electrochemical conversion of Cu2+ into Cu1+ provides high dynamic active species for NO3− reduction to NH3.

### Conclusion

This electrified membrane process was demonstrated to achieve synergistic nitrate decontamination and nutrient recovery with durable catalytic activity and stability. This technology could potentially be used to treat wastewater in agriculture and aquaculture, where nitrate or ammonia are rich and deserve separation for reuse and pollution mitigation.

### Acknowledgements

The study was financially supported by the NSF/BSF project (award number: 2215387) and New Jersey Water Resources Research Institute (award number: G21AP10595-01).

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## Fruit and vegetable waste can be upcycled using different technologies to produce building blocks for bio-based fertilisers blends: upscaling from lab to field

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### Introduction

Production of novel bio-based fertilisers from fruit and vegetable waste can reduce the dependence on mineral fertiliser production and mining, and decrease the nutrient losses in the form of agricultural residues. Moreover, applying such bio-based organic fertilisers into the field can increase soil health. In the Rustica project, 5 divergent technologies producing fertiliser building blocks from organic residues are considered: carboxylic acid platform (CAP), microbial biomass production, electrodialysis, insect breeding yielding biomass and frass, and biochar production. Starting from lab production over small-scale testing towards pilot production, blending and field trials, the project aims to develop environmentally sustainable and marketable end-products.

### Methodology

First of all, biochar, insect biomass and frass, and microbial biomass and NPK solution from electrodialysis of CAP solution, all produced at lab/small scale from various fruit and vegetable waste, were analysed for chemical and biological parameters (nutrients, stability, carbon contents, etcetera). Based on this information, blends composed of these building blocks (with compost as a potential additional one) were designed to match fertiliser and soil quality requirements for several soils, crops and regions (BE, FR, IT, ES and Colombia). Effects of addition of different blends and their building blocks were assessed in incubation trials. During 30 days, changes in respiration, nutrients, microbial biomass and enzymes after blend addition to soil were monitored in the lab.

### Results and discussion

Microbial and insect biomass showed to be very rich in nitrogen (6-12% N), with somewhat higher water extractable NO3- and NH4+ contents for the microbial biomass. Both had a high and easily degradable organic matter (OM)content, interesting to boost the soil microbial life. Compared to the biomasses, insect frass samples showed smaller total N (TN) contents but higher water extractable NO3- and NH4+ contents (up to > 1 mg N/g frass) and contents of other nutrients (especially K). Electrical conductivity (EC) was also highest for this building block, potentially harmful for salt sensitive plants. High pH (up to 10.5), low EC, low TN (0.8-1.7%) contents and high contents of stable OM were observed for the biochars. The NPK concentrate showed a rather high salt, high K and low N and P content. Feedstocks (particular fruit and vegetable waste) influenced partly the building block characteristics, especially for insect frass.

Results of the incubation trials of soil amended with building blocks showed that microbial and insect biomass caused a significant increment in N availability and in the content and activity of microbial biomass, while biochar did not affect these parameters. Insect frass showed an intermediate behaviour between biomasses and biochar.

Adding blends of the building blocks to soil increased microbial biomass, CO2 respiration, enzyme activity and P availability, in most cases. Extractable N and NO3- increased for soil amended with blends that included microbial biomass, whereas high biochar contents in blends reduced the values obtained for these parameters. More incubation trials will be performed in 2023 and presented at the RAMIRAN conference.

### Conclusion

The widely varying characteristics of the different building blocks produced from fruit and vegetable waste allow fot the design of diverging fertiliser blends that are adapted to soil and crop requirements. Compositions of the blends will be finetuned according to the outcomes of the incubation trials and further tested in field trials in 4 European regions (BE, FR, IT, ES) and Colombia. In parallel, a multi-actor approach supported by market, lifecycle and legal analyses will foster the implementation potential of these technologies.

### Acknowledgements

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## Thursday 14th September

### Plenary Session 3 – Promoting Best Practice

### Promoting Best Practices: From research to practical applications

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Translating the latest scientific research into applicable information for farmers is a primary goal of land-grant universities in the United States. Importance has been placed in recent years on reducing environmental pollution locally while continuing to produce food for a global population. Farm consolidation into fewer but much larger production systems is leading to specialization into crop-only or livestock-only farms, and fewer integrated operations. This opens what was once a closed loop when it comes to utilization of livestock manure. Feed (and nutrients) may be shipped across the country to livestock-dense areas, but the nutrients excreted in manure are not returned to where the feed originated. This is leading to areas of excess nutrient build-up and then associated water quality issues like algal blooms and hypoxic zones in our waterways. Even in regions where livestock and cropping systems are better integrated, excess nutrients applied via manure or commercial fertilizer (or both in some cases) are finding their way into waterbodies and causing impairments. Research over the last few decades has focused on production practices to minimize these issues, though challenges remain when it comes to adoption by farmers.

Ideally, science and outreach must be tightly integrated with one another to get applied research into the hands of the folks who need it. It is essentially a cyclical process. First, the problems or questions of interest must be identified with relevant stakeholders. Researchers then work with interested parties to brainstorm solutions and carry out experiments so that evidence-based data can be provided. To close the loop, education and outreach is used to help apply what was learned and promote best practices back to relevant parties. In the United States, an organized program called "Extension" in many states helps to extend university research findings and resources to the community. There are also several national groups, mainly made up of applied scientists and folks that work in Extension, that work across state lines to meet common goals.

Despite this organized effort, the reality is that adoption of best management practices can be slow at times. Competition for the time and attention of farmers is high as they often must play the role of accountant, soil fertility specialist, animal scientist, marketing specialist, agronomist, business manager, etc., to keep their operations running. There is also quite a bit of competition when it comes to where they get their information from, including industry and agricultural consultants. However, there are some success stories of Extension programs that deliver vital, practical information regarding livestock manure management. This talk will discuss these examples, including:

- Evaluating innovative management practices to capture the attention of the "innovators" and "early adopters" along the technology/practice adoption curve that will influence more adoption in the future;
- Working with agricultural professionals to implement best management practices; and
- Using a variety of methods to deliver research information to audiences, including online courses, videos, ArcGIS StoryMaps, blog posts, and podcasts.

Session 6 - Air & Water Quality

## Progress in estimation of ammonia loss from field-applied slurry: ALFAM2 model developments

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### Introduction

Ammonia volatilization from animal slurry applied to fields is a major source of emissions throughout the world. The ALFAM2 model (Hafner et al., 2019) was developed for estimating ammonia emission from this source, and is used for research (Pedersen et al., 2022) and inventories (Hafner et al., 2021). In this contribution we will present recent developments in the ALFAM2 model and software.

### Methodology

The model is semi-mechanistic, with a structure that represents the slurry-soil-atmosphere system in a simplified way. Parameter values are determined by fitting to measurements. The model structure was expanded with an additional sink to reflect longer-term processes such as nitrification and plant uptake (≥ v2.15).

New measurements were added to the ALFAM2 database. A new parameter set for the model was developed from measurements from about 600 field plots. Additionally, some of the new measurements were used to compare micrometeorological and wind tunnel measurements.

The developments described here are available in both the spreadsheet and R package version of the model. See http://www.alfam.dk for links to the data and model. Additionally, the R package was improved for usability and speed.

### Results and discussion

The ALFAM2 database increased by about 300 field plots from 5 countries. A comparison of new measurements made with wind tunnels and a micrometeorological method in the same trials showed that wind tunnel measurements could be used for parameter estimation, if differences in mass transfer are explicitly considered.

The addition of a TAN sink prevents the long-term loss of all applied ammonia but does not strongly affect calculated emission within the 1-7 day duration over which most emission trials typically run. This addition slightly improves model fit, reduces the effect of duration selection in calculation of emission factors, and greatly increases the flexibility of the model.

The new parameter set 3 is not drastically different from previous versions, but provides a better fit to available measurements. The effect of rain was included through the new sink, which leads to a more plausible behaviour than in earlier parameter sets. Results show the model can reasonably accurately predict effects of low-emission application methods, anaerobic digestion, acidification, slurry dry matter, and weather.

A summary of changes to the R package code will be presented. These include additional checks on inputs and related changes that improve useability of the package, as well as speed improvements by a move to compiled code.

Finally, recommendations for use and future work will be presented.

### Acknowledgements

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## DATAMAN: analysis of a global database on greenhouse gas emission factors for manure management

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### Introduction

Globally, manure management practices contribute 22% of nitrous oxide (N2O) and 4% of methane (CH4) emissions from livestock production. Manure management also contributes about 45% of ammonia (NH3) emissions. There is a need for improving our understanding of drivers of these emissions from a wide range of farming systems to aid the development of effective mitigation strategies. We collated a global database ('DATAMAN'; www.dataman.co.nz) of greenhouse gas (GHG) and N emissions from animal housing, manure storage and manure applied to land to refine N2O, CH4 and NH3 emission factors (EFs) and improve our understanding of the influence of key variables.

### Methodology

Emissions data and information on manure management (GHG EFs and all relevant activity and ancillary data) were collated (Beltran et al. 2021; Hassouna et al. 2023) and made publicly accessible as part of the DATAMAN and MELS (www.mels-project.eu) projects. Through statistical analysis of data related to cattle and swine manure management systems, mean EF values have been derived along with the identification of key variables.

### Results & Discussion

Swine housing systems produce mean of 0.16 kg NH3-N/kg nitrogen (N) excreted and N2O mean of 0.032 kg N2O-N/kg N excreted while cattle housing systems produce a mean of 0.06 kg NH3-N and 0.002 kg N2O-N/kg N excreted. Swine and cattle housing CH4 EFs averaged 0.07 kg CH4/kg volatile solids (VS) excreted. Compared to the 2019 IPCC values, our housing NH3 EF values were lower, whereas N2O and CH4 EFs varied. Key variables influencing housing-based EFs include housing type, type of bedding material and ventilation system. Ammonia and N2O EFs were ca 2 times greater from manure heaps compared to slurry tanks, with heaps averaging 0.09 kg NH3-N and 0.012 kg N2O-N/kg N stored, but the CH4 EF was ca 3 times lower (0.025 kg CH4/kg VS stored) compared to slurry tanks. Storage NH3 EF values were lower than the 2019 IPCC values, whereas N2O and CH4 EFs were similar. Our analysis suggested key variables influencing storage-based EFs include manure dry matter (DM) content, manure total ammoniacal N (TAN) and air temperature. For land-applied manure NH3 EFs, broadcast cattle solid manure and slurry were 0.03 and 0.24 kg NH3-N/kg N, respectively, while broadcast swine slurry was 0.29. Low trajectory application methods (trailing hose, trailing shoe, shallow and deep injection) significantly reduced swine and cattle slurry NH3 EF values by 46-62% compared with broadcast application. Apart from the method of application, our analysis showed manure DM, manure TAN concentration and manure pH significantly influence NH3 EFs, suggesting mitigation strategies should focus on these. Cattle manure N2O EFs (kg N2O-N/kg N applied) were disaggregated by wet (0.005) and dry (0.003) climate. The swine manure N2O EF for wet climates was 0.011. Livestock and manure type influenced whether our NH3 and N2O EFs were higher or lower than 2019 IPCC EFs.

### Conclusion

Our study has generated a large range of revised NH3, N2O and CH4 EFs for cattle and swine housing, storage and land-application of manures. By adopting a statistical analysis of the dataset, we have identified key variables that should be studied further for GHG and NH3 mitigation strategies for livestock production systems.

### Acknowledgements

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## Mitigation potential of greenhouse gas and nitrogen emissions in key European dairy farming systems

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### Introduction

Dairy production is one of the primary agricultural sources of greenhouse gas (GHG) and N losses. As a consequence, European dairy production systems (DPS) are facing increasingly binding requirements. In this context, about 10% of total GHG and almost all NH3 emissions from DPS are related to manure management (Sefeedpari et al. 2019). However, European DPS are highly diverse (Díaz de Otálora et al. 2022). Different structural characteristics and contexts largely determine performances and mitigation potentials (Gonzalez-Mejia et al. 2018). There is a lack of knowledge on the effects of different mitigation measures applied to different DPS. The "MilKey" and "DairyMix" projects (www.milkey-project.eu; www.dairymix.eu) contribute to fill this gap. In particular, this study aims to assess the effect of selected mitigation measures on GHG and N emissions from manure management and fertilization in four key DPS in Europe.

### Methodology

An updated version of the SIMSDAIRY model (Del Prado et al., 2011) was applied to evaluate the effect of selected mitigation measures on different DPS. This whole-farm system model could simulate interrelated processes, allowing evaluating the effect of combined mitigation methods on GHG and N losses. In detail, the effect of i) rigid slurry covers, ii) slurry injection (compared to broadcast application), iii) anaerobic digestion and iv) urea replacement with ammonium nitrate (AN) was modelled.

### Results and discussion

Manure storage was identified as one of the major hotspots for NH3 emissions (33% of the N losses on average) in those scenarios with low efficient practices. Anaerobic digestion resulted in a lower GHG emissions and N losses in all the considered DPS; slurry covers reduced N emissions; slurry injection reduced N losses while increasing GHG emissions in the modelled DPS; urea substitution with AN reduced N losses while increasing GHG emissions. The tailored application of more than one mitigation measure resulted in a reduction of the negative trade-offs observed for single measures.

### Conclusion

The application of adapted measures in different DPS leads to a substantial reduction in farm emissions of GHG and N. The combined application of different mitigation strategies favours positive synergies while reducing negative trade-offs. However, the opportunity to install circular mixed crop-livestock systems is evident. Identify options for the integration of dairy and crop production systems at farm or regional level can further contribute to the current challenges.

### Acknowledgements

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## A simple spreadsheet model for estimation of methane emission from pig and dairy cow barns and external storage of manure

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### Introduction

A spreadsheet model for estimation of slurry methane emission has been developed based on feed input to the animals, their excretion of organic matter, information of the design and size of the pen and the slurry pits, hydraulic retention times in the barns and storages, and the Arrhenius model for description of temperature dependency. The aim was to make a simple and transparent spreadsheet model that could give estimates of methane emission from slurry when changing parameters.

### Methodology

The excretion of organic matter from the animal is calculated based in feed input and digestibility following the Danish Normative system for animal manure (Børsting et al., 2022). The hydraulic retention time (HRT) is estimated based on slurry pit area and depth, the residual slurry after emptying (flushing) the pit, and flushing frequency. Methane emission is estimated using the Arrhenius model with input of temperature of the slurry, activation energy (Ea) and the Arrhenius parameter (A) (Petersen et al., 2016). This model is adopted by IPCC as a Tier 2 estimation method and used with a country specific emission factor in Denmark (Nielsen et al., 2022).

The use of abatement technology (slurry cooling, weekly flushing, use of the slurry for biogas production, and emptying of the slurry tanks can be calculated directly. Use of acidification in the barn or slurry tank and end-of-pipe technologies, e.g. collection and flaring of methane gases from covered slurry tanks, can be estimated used a specific reduction constant.

### Results and discussion

As an example, a pig barn with fully slatted floor, an average slurry height of 19 cm, and flushing every 29 days with 3 cm residual slurry has an estimated methane emission of 1.9 kg per tonne slurry from the barn and 2.5 kg per tonne slurry from the following outside storage if slurry is stored up to one year and applied in the spring. Weekly flushing reduced the emission from the barn to 0.8 kg but increased the emission from the storage to 2.9 kg per tonne slurry giving an overall reduction of 16 percent. The emission from the storage could be further reduced to 0.1 kg per tonne if digested in a biogas plant with 30 days retention time and a conversion of 74 percent of the organic matter. Altogether, a reduction of 80 percent. Furthermore, the produced methane in the biogas plant can substitute natural gas.

### Conclusion

A simple and transparent spreadsheet model has been developed. The model can estimate methane emission from barn and the external slurry tank based on feed intake, excretion of organic matter in faeces and urine, design and management of the barn manure system and slurry tanks. Various methane abatement strategies can be examined by coupling with reduction factors. The model estimates emphasize the importance of reducing the methane emission from the external slurry tanks, which is increased when slurry is flushed frequently from the barn. Another result is that estimates of methane emission always should include the whole chain from barn, slurry tanks and use of reduction technologies

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## Effects of pig diets with low nitrogen content on nitrogen excretion, manure characteristics and gas emissions

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### Introduction

Livestock production significantly contributes to global environmental change. In particular, ammonia (NH3) emissions from pig production contribute to soil acidification and water eutrophication. NH3 volatilisation during pig housing and manure management is related to nitrogen (N) excretion in faeces and urine. Previous studies have shown that reducing dietary protein content is an efficient way to reduce N excretion (Portejoie et al., 2004) but few studies have examined the environmental impact of pig production from the perspective of the entire feed-animal-effluent-soil system. Therefore, the objective of this study was to investigate the effectiveness of a diet with low protein content in reducing environmental burden associated to the management and valorisation of slurry issued from pig production.

### Methodology

In this study, three feeding strategies with different protein contents were conducted to examine nitrogen excretion, manure characteristics, and gas emissions associated. Diets with different contents of crude protein (CP): 13% (Control-diet) vs 11.5% (Intermediate-CP-diet) vs 10% (Low-CP-diet), were formulated. A total of 36 Pietrain x (Large White x Landrace) entire males (mean body weight (BW): 45±10 kg) were used in this study and received one of the three experimental diets (n=12 per experimental diet). Animals were housed individually in digestible cages equipped for feed and water intake measurement and separated collection of faeces and urine. After an adaptation period of 14 days to experimental conditions and diets, total faeces and urine were collected per pig during 7 subsequent days and slurries were reconstituted at the end of the collection period. The following characteristics of the collected slurries were determined: pH, total solid content (TS), volatile solid content (VS), total carbon (TC), total nitrogen (TN), total ammonia nitrogen (TAN) and total volatile fatty acids (TVFA). The biomethane potential (BMP, mL CH4.g-1 VS) was measured during 25 days with a method adapted from Wang et al. (2020). Samples of each slurry were placed for 8 weeks in a laboratory pilot scale system designed to measure gas (NH3, CH4, N2O) volatilization in storage condition with a method adapted from Portejoie et al. (2004). The agronomic value of slurry (TS, VS, N, P, K) will be also determined.

### Results

In this study, no significant differences were observed in animal performance under the experimental diets, with an average gain of 768±233 g day-1, an average feed conversion ratio of 2.97±1.03 kg.kg-1, and an average water consumption/feed ratio of 3.68±0.32 kg.kg-1. The amount of fresh faeces and urine excreted was similar among the three experimental groups, with an average of 785±135 g.day-1.pig-1 of faeces and 1948±715 g.day-1. pig-1 of urine. Reduction of dietary CP from 13% to 10% decreased TN content in the slurry by 17% (4.1 gN.kg-1 vs 3.4 gN.kg-1, respectively) and TAN content by 33% (1.8 gN.kg-1 vs 1.2 gN.kg-1, respectively). The slurry obtained with the Intermediate-CP-diet had intermediate value of TN (3.8 gN.kg-1) and TAN (1.5 gN.kg-1) content. There was no significant difference in pH of slurry among the three experimental groups. As a result of the TAN content in slurry, the NH3 emissions measured during the 1st week of volatilization were higher in the Control-diet group (957 mg NH4+-N kg-1 of slurry) compared to the Intermediate-CP-diet group (839 mg NH4+-N.kg-1 of slurry) and the Low-CP-diet group (657 mg NH4+-N.kg-1 of slurry). During the BMP test, the cumulative methane productions among the three experimental groups were similar, with an average of 144±28 mL CH4 per g of VS of slurry.

### Discussion and conclusion

Decreasing the CP content of diet reduced N excretion by pigs. Slurry from pigs fed with a lower CP diet had lower TN and TAN contents. These changes in slurry characteristics resulted in lower ammonia emissions during the first week of volatilization measurement without affecting the slurry's biogas production potential. It is necessary to further confirm these results in a long-term run and analyse N2O emissions under storage conditions.

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## $NH_3$ and GHG emissions from maize cultivation for silage on a sandy-loam soil fertilized with three different slurries.

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### Introduction

Livestock is estimated to emit about 14.5% of anthropogenic greenhouse gases (GHG) (FAO,2017), in particular methane (CH4), carbon dioxide (CO2) and nitrous oxide (N2O); furthermore, the sector contributes in emitting 75% of anthropogenic ammonia (NH3) (Gerber et al., 2013). Gaseous emissions from livestock production systems arise from several stages, including field fertilization with animal slurry (Hou et al., 2015). The entity of emissions from field fertilization strongly depends on the distribution technique, slurry characteristics, and environmental conditions, such as soil properties. It has been demonstrated that the direct injection distribution system allows for a NH3 emissions abatement of up to 90% (Santonja et al., 2017). On the other hand, this technique could lead to higher N2O emission fluxes from the fertilized soil. An experiment was carried out to assess GHG and NH3 emissions from a sandy-loam maize field fertilized with three different slurry types under typical conditions of northern Italy.

### Methodology

The experiment was conducted in a dairy cattle farm in Candiolo, province of Turin (Italy). Three different slurry types (Digestate, DIG; cattle slurry, CAT; pig slurry, PIG) were spread to supply approx. 280 kg N ha−1 before maize sowing using a direct injection system in three plots of 30 x 30 m each. The field had a sandy-loam soil, managed with a furrow irrigation system. GHG and NH3 emissions were monitored for two years (2020-2021) for the whole maize growing cycle. GHG emissions were measured with the closed static chamber method , while NH3 emissions were estimated by using ALPHA passive samplers coupled with the bLS WindTrax model. The effect of the slurry type on cumulative GHG emissions was assessed through a one-way ANOVA using a linear mixed model, considering the year as a random factor. The ANOVA was followed by Tukey post hoc tests (significance was set to 0.05).

### Results and discussion

The statistical analysis highlighted differences in terms of N2O and CO2 emissions only. In particular, N2O cumulative emissions expressed as % of applied N were significantly ($p<0.05$) higher from DIG (1.61%) than from PIG (0.81%), while CAT (0.91%) was not statistically different ($p>0.05$) from the others. Regarding CO2 emissions, they were higher from PIG (5209.5 kg C-CO2 ha-1) compared to CAT (3411.2 kg C-CO2 ha-1), while PIG (5209.5 kg C-CO2 ha-1) was not different from the latters. Average CH4 emission fluxes over the measurement period were often negative, ranging from 0.15 to

- 5.6 kg C-CH4 ha-1. Measured NH3 emissions were generally low in all the experimental plots, as expected. Cumulative NH3 emissions were higher from DIG (4.2 kg N-NH3 ha-1), followed by PIG (2.8 kg N-NH3 ha-1) and CAT (2.3 kg N-NH3 ha-1).

### Conclusion

N2O emissions averaged 1.11 % of applied N, this result is in line with those presented in IPCC (2006).

In terms of Global Warming Potential (GWP) (IPCC, 2013), DIG had the highest impact (7065 kg CO2 equivalents ha-1), followed by PIG (6311 kg CO2 equivalents ha-1) and CAT (4713 kg CO2 equivalents ha-1).

### Acknowledgements

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Session 6 - Nutrient Utilisation

## FERTIMANURE: Producing and testing high-added value fertilisers from animal manure

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### Introduction

Europe's total farm livestock population excrete around 1400 Mt of manure annually1, and more than 90% of manure produced is returned to agricultural fields. However, this is not done in the most efficient and least leaky way. The H2020 FERTIMANURE project aims to develop, integrate, test and validate innovative Nutrient Management Strategies to efficiently recover mineral nutrients and other products from manure to obtain reliable and safe "bio-based fertilisers" (BBFs) that can compete in the EU fertilisers market. The technological approach in the project is covered by implementing 5 innovative & integrated nutrient recovery on-farm experimental pilots in Spain, France, Germany, Belgium, and The Netherlands, in which 18 different BBFs are recovered. The Spanish biorefinery was implemented in a pig farm in Catalonia, where several innovative and conventional technologies were combined to selectively recover nutrients from pig slurry. The nutrients recovered are aimed to be used (i) directly as a BBF or (ii) as a raw material to produce high-added value tailor-made fertilisers (TMFs) to cover the specific needs of crop-soil pairs.

### Results and discussion

All tested BBFs resulted in a similar crop yield as the synthetic mineral fertiliser reference; however, each BBF showed some specific patterns. E.g., for ashes, during the early stage of the incubation (days 5-10), an increasing P release was observed; from day 10 to 80, the rate of P release decreased. From an environmental point, ammonium salts, with a nitrogen release of up to 80% after 100 days of incubation, did not differ from synthetic counterparts related to the GHG emission when applied in soil– except for N2O, where ammonium salts performed better. Compared to the negative control, biostimulants increased the dry weight of lettuce under hydric stress. Nutrient-rich concentrate had an average of 60% total N release after 100 days of incubation, and P-rich organic amendment had an 80% P release measured after 80 days of incubation. The effect of TMFs applied in the field is currently under evaluation.

### Conclusion

FERTIMANURE can provide an innovative circular economy model to favour sustainable rural development in the agricultural sector by creating synergies between farmers and other industrial activities. The technologies developed can be a natural solution for manure treatment/valorisation at the farm level, giving value to a challenging resource. Furthermore, the BBFs developed demonstrated to be good fertilisers that can partially substitute mineral fertilisers.

### Acknowledgements

FERTIMANURE has received funding from the European Union's Horizon2020 research & innovation programme under grant agreement No 862849.

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Activities in Europe - Project reference: ENV.B.1/ETU/2010/0007

**The assessment of organo-mineral fertilisers as a viable commercial product in the UK.**

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## Introduction

With the increasing energy prices and subsequent impact on fertiliser prices, a more sustainable form of fertiliser is essential. The process of making organo-mineral fertilisers (OMF) takes organic waste material and enriches it with mineral additives. This produces a hybrid product that has balanced nutrient content whilst promoting a circular economy. They also act as an avenue for reintroducing organic matter into agricultural soils all the while reducing the reliance and environmental cost of mineral fertiliser production. This is why Yara UK, in conjunction with Cranfield University have embarked on a joint venture to trial these fertilisers with the aim of moving towards more nature positive agricultural practices. So far, we have been evaluating the impact these fertilisers have on yield, running consecutive field trials on several crops (Spring barley, oats, oilseed rape, and winter wheat). The first year of trials, completed in 2022 incorporated an 8-3-3 + 19% SO3 OMF with a composted food waste feedstock and ammonium sulphate mineral component. For the 2023 growth season we have repeated the previous year's experiments and expanded the range of crops to include oats and winter wheat and incorporated another OMF (12-4-4 + 1% SO3) with a digestate feedstock and urea mineral additive). The field trials are revealing that OMF can perform comparatively to mineral alternatives however, there are still large knowledge gaps regarding its performance, optimum application, and impact on the environment. The studies reported here aim to fill some of these gaps and investigate how readily OMF nutrients are taken up by crops and their potential to volatilise into the atmosphere.

## Methodology

To further understand the performance of these fertilisers and gain an understanding on the dynamics of their nutrient availability we applied the OMF (8-3-3 + 19% SO3) at varying rates (20, 28, and 30 Kg N/ha) to 5ltr pots filled with sand and planted with perennial ryegrass and compared to an NPK mineral fertiliser. The ryegrass was left to grow for 4 weeks and then cut to 2cm above the sand and cut again after another 4 weeks. The nutrient of this plant material was analysed to measure how effectively the nutrients from the OMF were utilised by the plants and cores analysed at the end of the experiment to assess residual nutrient content.

The production process of OMFs is more sustainable and have a lower impact on the environment but the impact the fertilisers themselves have on the environment is still relatively unknown. To start to fill these knowledge gaps, we applied the fertiliser to small pots (10cm ID) mimicking the recommended application rate for a spring barley crop (160 kg/ha N with a 60/40 split between two applications). These pots were incorporated into an automated sampling system with a Picarro G2508 Gas Concentration Analyzer to continuously measure the CO2, N2O, and CH4 fluxes in a loop of approximately 2 hours for 3 months. Two OMFs (12-4-4 + 1% SO3 and 8-3-3 + 19% SO3) were compared to purely mineral treatment and an unfertilised control with three replicates.

## Results

For the nutrient uptake of ryegrass, the OMF tended to yield less biomass than the MF treated pots for both the first (15.5g and 9.0g for MF and OMF, respectively) and second (21.7g and 8.3g for MF and OMF, respectively) cut. However, there was no treatment effect on leaf nitrogen content for the first cut (4.15% and 4.13% for OMF and MF, respectively) and for the second cut, the OMF produced grass with a higher nitrogen content than the MF (3.14% and 2.84% for OMF and MF, respectively).

Initial findings from the first month of the emissions experiment reveal that the compost based OMF tended to produce the most CO2 (0.212 ± 0.004 umol/m2/s), followed by the digestate based OMF (0.164 ± 0.003 umol/m2/s) and the mineral fertiliser (0.129 ± 0.004 umol/m2/s), with the control producing the least (0.112 ± 0.003 umol/m2/s). The N2O emissions corresponded to the CO2 emissions with the compost based OMF tending to produce the most (0.540 ± 0.032 nmol/m2/s) followed by the digestate based OMF (0.190 ± 0.015 nmol/m2/s), mineral fertiliser (0.125 ± 0.015 nmol/m2/s), and the control (0.004 ± 0.001 nmol/m2/s). However, none of the treatments showed a CH4 response with most measurements being ± 0.02 nmol/m^2/s above and below 0 and no obvious trend over time.

## Conclusion

The initial trials suggest that organo-mineral fertilisers are a promising alternative and/or compliment to traditional mineral fertiliser practices which can achieve comparable yields in the short term. However, they have a tendency to emit more GHGs after application, though this may depend on the type of mineral fertiliser it is compared to.

## Bottom ash from combustion of chicken manure as a fertiliser material

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### Introduction

farms have to face nowadays. The combustion of the chicken manure to obtain thermal energy for the animal holdings is being demonstrated through the research project Avienergy in Spain. To ensure the circularity of the process, the combustion by-product, bottom ash, needs to be recycled and used. The European legislation for fertiliser products (Regulation (EU) 2019/1009) has recently added the materials from thermal oxidation to the list for component material category, CMC 13 (Commission Delegated Regulation of 06/07/2021). The objective of this work is to establish the possible use of ashes from chicken manure combustion as a fertiliser product and to determine their capacity for mineral fertiliser substitution.

### Methodology

Ashes from co-combustion of chicken (broilers) manure with wood at different proportions were chemically analysed to determine the concentration of nutrients. Then, one of the ash samples was used as a fertiliser for lettuce cultivation in a pot experiment, using different application rates according to the phosphorous content of the ash, equivalent to 50, 65, 80 and 100 % of the standard inorganic P fertilisation.

### Results and discussion

The results indicated that the ash from combustion of broiler manure fits with the requirements for inclusion in the component of fertiliser component material category CMC 13, with nutrient concentrations above the limits established for PFC 1(C)(I)(a)(ii): Compound Solid Inorganic Macronutrient Fertiliser (multi-nutrients), and also with characteristics for PFC 2: Liming Material (Regulation (EU) 2019/1009). Although the plant production was slightly reduced with ash fertilisation, the ashes reach a fertiliser capacity able to substitute 80 % of the inorganic P fertiliser, with a liming capacity of 30 %.

### Conclusion

The ash from broiler manure combustion can be applied to soil, especially for acid soils, in partial substitution of mineral fertilisers to supply P.

### Acknowledgements

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Commission Delegated Regulation amending Annexes II, III and IV to Regulation (EU) 2019/1009 of the European Parliament and of the Council for the purpose of adding thermal oxidation materials and derivates as a component material category in EU fertilising products. Brussels, 6.7.2021. C(2021) 4751 final

## Reduction of mineral fertiliser use without sacrificing yields while contributing to a circular economy with RENURE ammonium nitrate

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### Introduction

The Flemish agricultural sector is currently dealing with the paradoxical situation of having a surplus of animal manure while additional nutrients in the form of synthetic mineral fertilisers are supplied, as the Nitrates Directive (91/676/EEC) limits the use of animal manure to 170 kg N ha-1 year-1. Ammonia-stripping is an innovative and marketable technology that upgrades nutrients from manure to ammonium salts. This technique can contribute to a circular economy as an alternative to synthetic fertilisers, yet the ammonium salts are still seen as animal manure. In 2020, the European Commission published the report SafeManure (Huygens et al., 2020), which concluded that ammonium salts meet the criteria of "RENURE" (REcovered Nitrogen from manURE). The Operational Group RENURE wants to prepare the agricultural sector for the use of these fertilisers by making the transition from previous research-based field trials to a practical evaluation at the farmer's fields. It also serves as a learning experience for the best practices of using RENURE.

### Methodology

In 2022, field experiments with ammonium nitrate (AN) from ammonia-stripping were carried out on farmers' fields inspired by the principle of 'on-farm experimentation' (Lacoste et al., 2022). This entails that AN was applied in strips of 21-24m wide as substitution of the synthetic fertiliser the farmer normally uses, on top of 170 kg N ha-1 of animal manure. Strips following the farmers' practice, which served as reference, and strips with treatment of AN alternated each other on the field. Experiments were set up on five fields: four cultivated with maize, one with potato. The dose of applied AN varied between 24 and 105 kg N ha-1. Yield and nitrate were monitored. In 2023 an experiment with analogous setup will be carried out with winter wheat, where AN will replace animal manure instead of synthetic fertiliser.

### Results and discussion

The experiment on two of the maize fields resulted in a significantly higher yield on the strips treated with AN from ammonia-stripping, while no significant differences were measured on two other fields. However, the variance on some maize fields was high as a result of the extremely dry growth season. No significant differences between treatments were observed in the potato field. From the farmers' perspective, one point of attention is the lower percentage of nitrogen in the AN compared to a typical synthetic fertiliser. This means higher volumes of AN need to be applied on the field, which requires some logistic preparation. Nevertheless, the RENURE AN proves to be a valuable fertiliser, performing at least as well as its synthetic counterparts when applied in the same dose.

### Conclusion

Results from experiments in potato and maize suggest that RENURE under the form of AN is a good alternative to synthetic fertilisers. In some cases the treatment with AN even resulted in higher yields than the reference with synthetic fertiliser. Nevertheless, there are some points of attention such as method of application and stability of the product between batches. The experiment in 2023 on winter wheat will give an understanding of the value of AN as substitute of animal manure.

### Acknowledgements

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## Effect of soil tillage on agronomic efficiency of two novel biobased fertilising products

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### Introduction

The EU-funded project "LEX4BIO" aims to decrease the European dependency on energy-intensive mineral nitrogen and finite and imported, apatite-based phosphorus fertilisers. Biobased fertilising products (BBFs) obtained from nutrientrich side-streams from agriculture have the potential to replace such conventional fertilisers and lower the related negative environmental and climate consequences.

The aim of this study is to evaluate the effect of two novel BBFs on biomass yield of spring barley. A further objective is to investigate the influence of different soil tillage measures.

### Methodology

A field experiment with spring barley was established at University of Hohenheim in Stuttgart, Germany (48.714944, 9.214498) to study the fertilising effect of two BBFs in combination with different soil tillage measures. After mustard as cover crop, field plots were prepared either by plough or stubble cultivator. Spring barley was sown in late March 2023. Two BBFs (OGR, based on horn meal, 14% N; and BIO, based on meat and bone meal, vinasse and chicken manure, 7% N) and a mineral N fertiliser (Entec, 26% N) were surface-applied at 107 kg N ha-1 with a fertiliser spreader. The experiment also included a negative control. All treatments were performed in four replications. It is planned to determine the grain yield with a combine harvester and the grain:straw ratio from a subsample of 1 m² harvested by hand. The biomass is analysed for relevant quality characteristics, e.g. N content.

Ten different BBFs had already been tested in a two-year field experiment with maize and winter wheat at this site in 2021 and 2022. OGR and BIO were chosen to be tested once more in this new study to confirm the previous results. OGR had shown a somewhat contradictory fertilising effect in the two years, whereas BIO resulted in biomass yields comparable to the mineral reference in both years.

### Results and discussion

Results are available after harvesting the plots in July 2023.

Soil tillage influences soil characteristics and processes, including soil temperature, moisture, and soil microbial activity. This can affect the mineralisation of N provided with fertilisers and in consequence also potential losses via leaching or volatilisation. We therefore expect this experiment to provide more in-depth results on the influence of different soil cultivation measures on the fertilising performance of BBFs.

### Acknowledgements

This study has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement no. 818309 (LEX4BIO). The authors are grateful to Thomas Ruopp for help with managing the field trial.

## Testing and evaluation of laboratory methods for the assessment of mineralizable nitrogen from bio-based fertilizers

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### Introduction

Bio-based fertilizers (BBFs) are an increasingly popular source of nutrients in agriculture which enables to close nutrient cycles on the regional scale. The recently reinforced European Fertilizer Regulation (Fertilizing Products Regulation (EU) 2019/1009) represents the legal basis to facilitate the international commerce of BBFs by laying the foundation for a BBF categorization approach. However, a more refined categorization reflecting the mineralization-dependent nutrient release of BBFs is key for the appropriate use of these fertilizers.

### Methodology

In this study we assessed mineralizable nitrogen (N) and carbon (C) of a representative selection of 32 BBFs with biological mineralization assays (84-day incubations). Based on mineralizable N and C we grouped BBFs using the hierarchical clustering approach proposed by Parnaudeau et al. (2004). Tested chemical predictors for mineralizable N of BBFs were CN ratio, cold water extractable mineral N, hot water extractable N (adapted from Curtin et al. 2006a), hot potassium chloride extractable N (adapted from Chadwick et al. 2000) and sulfuric acid extractable N (adapted from Martínez & Galantini 2017). The suitability of chemical predictors was evaluated based on correlation coefficients between chemically extractable N and mineralizable N at different stages of incubation. A potential reconstruction of the mineralizable N and C based BBF grouping using multiple suitable chemical predictors was evaluated based on analyses of variance.

### Results and discussion

In 84-day aerobic incubations, cumulative mineral N release from -134 (net immobilization) to 1056 mg Nmin-N g-1 amended N was achieved. Mineralized C ranged between 14% and 112% of amended C. Based on the results of the biological mineralization assays, BBFs were classified into five significantly different groups which did not reflect the categories specified by the European Fertilizer Regulation. Hot water extractions presented the lowest extraction intensities, followed by hot potassium chloride and hot sulfuric acid extractions. Cold water extractable N was most strongly correlated to mineralizable N at the start of incubation ($r = 0.99$), while hot sulfuric acid extractable N was correlated to mineralizable N after the first month of incubation ($0.73 < r < 0.85$). The CN ratios showed highest correlations to mineralizable N at the end of the incubation ($-0.83 > r > -0.86$). However, the combination of those three indicators could not discriminate BBFs into the five mineralizable N and C based groups without ambiguity.

### Conclusion

The categories specified in the current European Fertilizer Regulation are not sufficient to characterize the N release of BBFs. A multiple-predictor approach exclusively based on chemical indicators targeting differently labile organic N pools of BBFs is regarded as a realistic alternative to biological characterization methods, provided that a sufficient number of suitable predictors is available.

### Acknowledgements

This study was financially supported by the EU Horizon 2020 project "LEX4BIO".

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## Session 6 - Promoting Best Practice

### Using advice to make a difference – the story of Catchment Sensitive Farming, so far

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#### Introduction

CSF Catchment Sensitive Farming: advice for farmers and land managers - GOV.UK (www.gov.uk) is led by Natural England in partnership with Defra and the Environment Agency. It works with farmers, and partners in catchments across England to improve the quality of air, water, and natural flood management, through the Agricultural Transition. Since 2006, CSF has worked with over 21,000 farms and helped farmers take more than 150,000 positive actions to reduce diffuse pollution from agriculture (CSF internal figures).

#### Methodology

CSF Advisers are locally based with an understanding of the challenges farmers face. They organise farm events, demonstrations, workshops both online and face to face, or make proactive phone calls before one to one on-farm visits, to meet people for the first time; although agents and farmers can make Countryside Stewardship grant support requests triggering discussions. They will work alongside the farmer to take the latest advice and information and tailor it to best benefit the farm business.

CSF Advisers offer locally-informed, confidential on-farm advice to help farmers make decisions on:

- Soil Management
- Nutrient, Slurry & Manure Management
- Ammonia Reduction
- Farm Infrastructure & Machinery set-up
- Pesticide Handling
- Water Resources & Natural Flood Management
- Local Environmental Priorities
- Land Management
- Agricultural Transition, & Grants

#### Benefits

- Saves farmers money, improves nutrient use efficiency, reducing pollution losses to air and water off-farm
- Increases farm resilience, helps with future proofing
- Improves the local environment, such as building soil health, from which biodiversity benefits- CSF advice focuses support to farms that can make the greatest contribution to our environmental goals.
- Helps farmers meet current regulations, and gives peace of mind.
- Helps farmers 'look before they leap' - before investment, grant applications, potential changes in farm practices or land use, and to decide on scale, or to have confidence in relevant research.

#### Results and discussion

CSF-advised farmers have achieved reductions in agricultural pollutants - nitrogen levels down by 4%, phosphorus levels down by 8% and a 12% reduction in sediment (Environment Agency, 2019).

#### Conclusion

Advice makes a difference. Farmers often want someone to support them to improve their decision-making and to help evolve their businesses (Vrain, 2015; Thomas, et al, 2020). This CSF programme has had significant expansion in UK Government funding because it innovates, it undertakes evaluations (Environment Agency, 2019) and builds support. CSF is not a 'silver bullet' we all need to play a part in better nutrient recycling, and by our relationships, research and making it accessible with relevant grants we can lubricate the wheels of change, to make things better.

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## 20 Measures: methods to minimise diffuse pollution and increase nutrient use efficiency from biosolids recycling

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### Introduction

Biosolids are a sustainable product from treating sludge from wastewaters and are used globally to provide valuable nutrients and organic matter to agriculture and other outlets. Approximately 3.6 million tonnes of biosolids are recycled to agricultural land in Great Britain every year. Recycling biosolids to agricultural land aligns with Government strategy for beneficial recycling in preference to other forms of recovery or disposal (e.g. incineration or landfill). In conjunction with food chain and wider stakeholders the UK water industry introduced the Biosolids Assurance Scheme (BAS) to provide reassurance to stakeholders and the public that BAS Certified Biosolids can be safely and sustainably recycled to agricultural land. Member organisations are audited by an independent third-party Certification Body with UKAS accreditation to ensure they conform with the scheme standard.

The BAS Standard includes a range of requirements relating to the treatment, storage and recycling of biosolids. The Standard has always included requirements to protect the environment from harm, including water quality, air pollution and soil health. However, issues around water quality came to the fore in autumn 2020 in England when it became apparent that there were different interpretations of the requirements of the Farming Rules for Water (FRfW), formally known as The Reduction and Prevention of Agricultural Diffuse Pollution (England) Regulations. In response to these discussions, as well as wider increased focus on water quality more broadly, the water industry created a package of measures to minimise the impact biosolids recycling could have on agricultural diffuse pollution.

### Methodology

The 20 Measures were developed in line with the 'Source, Pathway and Receptor' approach, in that the measures address all three aspects by reducing the quality of potential pollutants subject to loss, remove pathways that could lead to losses and protect the receptor to prevent pollutants reaching them. Moreover, they also protect sensitive sites/catchments (such as Sites of Special Scientific Interest, Special Protection Areas (SPAs), Special Area of Conservation (SAC), which have also come under increased scrutiny in recent times.

### Results and discussion

This presentation will outline the measures and how they combine with existing controls to reduce diffuse pollution. The presentation will also discuss the benefits of this type of approach in addressing diffuse pollution, while balancing competing pressures (e.g. water quality vs. air quality vs. food production) and working with stakeholders, regulators and policy makers. In particularly this will include the role of quality assurance schemes in increasing compliance in conjunction with (or even in preference to) regulatory inspections, and especially the role of Earned Recognition.

The water industry committed to comply with the 20 Measures from the 1st of July 2022. Moreover, it was agreed that the measures following a suitable consultation period would be incorporated into the BAS Standard. Assured Biosolids Ltd (ABL) are currently discussing the measures with relevant stakeholders ahead of a formal consultation this winter.

### Conclusion

The feedback for the implementation of the 20 Measures so far has been positive and can been seen as building on existing good practice providing environmental protection. The 20 Measures have clarified certain interpretations of the requirements of Farming Rules for Water with the aim of providing reassurance to stakeholders and the public that biosolids can be safely and sustainably recycled to agricultural land.

### Acknowledgements

The invaluable inputs from the ABL Directors and the wider water industry in developing and implementing the measures is greatly valued and appreciated, as is the assistance from technical advisors.

## Farm Specific N and P fertilisation budgeting in Dutch Dairy Farms.

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### Introduction

On Dutch dairy farms nitrogen (N) and phosphorus (P) supply with manure and mineral fertilisers is legally limited in order to agree with water quality goals. These limited application standards are based on average crop N and P uptake levels. This means on farms with low crop production environmental goals are not met, while on farms with high crop production the agronomic potential cannot be fulfilled. Therefore, in 2015 a pilot was started with the aim to develop and test a system with farm specific nutrient budgeting (FSN) (Verloop et al., 2022).

### Methodology

The FSN pilot was done on commercial farms. The pilot started with 3 farms with a gradual increase to 15 farms in 2020. The calculation of the allowed FSN standards consisted of two steps. First, the maximum FSN manure N and P budget was calculated based on the farm specific 3year average P yield of the crops (P balance fertilisation) and the farm specific N/P ratio in the manure in the last year. In the second step the FSN mineral fertiliser N budget was calculated based on the farm specific crop N utilisation (based on realised N fertilisation levels and N yield over 3 years) and the maximum allowed soil N surplus. During the pilot the data regarding fertilisation, crop yield and surpluses was monitored by the ANCA-tool. In addition the water quality was assessed on a farm level by the National Institute for Public Health and the Environment by the LMM-protocol (van Duijnen, et.al, 2021). By comparing the period before and after the implementation the FSN system was evaluated. Absolute results were analysed but annual results were also ranked within a group of representative benchmark farms in order to distinguish between annual fluctuations due to weather conditions and effects of the application of the FSN standards.

### Results and discussion

The allowed Nmanure budget according the FSN method was on average 78 kg.ha-1 higher compared to the generic application standards. The allowed Nfertiliser budget decreased on almost all farms compared to the generic Nfertiliser allowance as a result of the increased Nmanure budgets. Generally, the allowed FSN manure N budget was not completely used. Averaged over all farms and years the Nmanure supply increased with 34kg per hectare compared to the generic system. The FSN approach gave a strong impulse to the participating farmers to utilise manure and fertilisers as good as possible because a low N-utilisation in one or more years will decrease the Nfertiliser budget in the next years. Averaged over all farms and years the soil N surplus exceeded the allowable soil N surplus by 8 kg.ha-1. On farms on sandy soils the allowable soil N surplus was exceeded by 20 kg.ha-1 while on farms on clay soils the realised N soil surplus was comparable with the allowed soil N surplus. Averaged over al farms and years the allowable soil P surplus was not exceeded (-1 kg.ha-1) but it ranged from -4 kg.ha-1 on farms on clay soils to +3 kg.ha-1 on sandy soils. On 5 farms the water quality was measured over a period long enough before and after the implementation of the FSN. For 3 farms the relative average ranking of the nitrate concentration in the leaching water to a benchmark group was the same before and during FSN. On 2 farms the relative ranking increased from 0.30 and 0.35 to, respectively, 0.6 and 0.72. However, it appeared that these 2 farms renewed grassland swards as a result of extensive droughts occurring in the FSN pilot that may have affected nitrate leaching. At implementation of the FSN system the on- and off-farm ammonia emissions due to in- or decreased manure rates deserves attention. As well as lower manure application rates and increased manure export costs at farms with below average crop N and P yields.

### Conclusion

Compared to the generic system the FSN system resulted in higher manure N budgets and lower N mineral fertiliser budgets. Farmers not always utilised their entire FSN budgets especially when weather conditions did not allow a high utilisation of applied nutrients thus risking future lower FSN budgets. The soil N surplus increased on farms on sandy soils while om clay soils no differences were observed. The soil P surplus increased on farms in sandy soils and became less negative in soils on clay soils. There is no clear evidence that nitrate leaching was affected by FSN.

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**Developing an integrated approach to enhance soil fertility and favour recarbonization of Mediterranean agricultural soils: a case study from Valencian Region**

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## Introduction

Mediterranean countries are the most sensitive to climate emergency in terms of the sustainability of the agri-food sector, in addition, being one of the most oxidizable environments for the soil organic matter. In this line, IPCC (2019) highlighted the increase of organic matter in soils and the waste management as the main drive forces/measures to mitigate climate change. However, the agri-food sector in Mediterranean countries has a wide waste diversity to produce balanced and high-quality compost not only to reconstruct C stock but also to rebuild soil properties that increase resilience of agricultural soils against erosion, water shortages and other negative impacts. Therefore, significant rethink of the existing model must be developed, with reduction of agricultural fires to manage the organic waste fluxes.

## Methodology

In this line, Agrocompostaje project is being developed in the Valencian Community (Spain) (2017-now) to produce a significant environment to promote this model change. This project includes: i) monitoring, quantification and analysis of organic waste fluxes (>400 different sources); ii) development of co-composting pilots with actors (>120 pilots into the region); iii) optimizing of "zero km" co-composting mixtures and in low cost scenarios (>260 different combinations); iv) monitoring of the process and quality assessment for final compost, including agronomic advisement. In this project, a powerful knowledge platform (www.agrocompostaje.edu.umh.es) has been developed including a composting calculator as an open access app.

## Results & Discussion

The results of the project include sectorial solutions (wine, olive oil and rural urban sectors), with validated "recipes" to produce and use advanced composts. The averaged N/P2O5/K2O/humic-like compounds values of these composts are: 1.9/1.2/2.5/5.0, 2.3/1.4/3.3/9.2, 2.4/2.0/2.0/6.7 respectively expressed as percentage (dry weight basis). The economic equivalent values ranged from 27 to 34 euros per ton, considering only NPK contents in developed composts with 25% of water content. The impact of these procedures in organic waste value chain related to the project itself and the extension of these strategies were also estimated, especially considering agricultural fires depleted and organic matter input in soils. The composting calculator (© Compost Calculator by UMH) has been downloaded over 5.300 times in 31 months. The formative contents have been widely viewed (44K views with more than 180K acumulated minutes) into the website (44K visits).

## Conclusion

Using the results of the Agrocompostaje activities during 2017-2022, the Government of Valencia is developing a specific framework to favour the composting in the agricultural and agri-food sectors, in terms of requirements for the facilities, specific procedures for the processes including the recommended recipes and the quality assessment for the composts in order to produce circular economy loops. These loops are defined for each one of the identified Valencian areas and linked to their specific organic waste fluxes and territorial synergies. The perspectives to all this route map will be the reduction of agricultural fires, the reduction of the costs of waste management and of the GHG emissions, but especially the availability of high-quality composts to increase organic matter and organic carbon in the Valencian soils.

## Acknowledgements:

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## Manure and Organic Amendment Test Database Development in the US

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### Introduction

Manure nutrients serve an important role in crop production. However, compared to commercial fertilisers there is a lack of standardised information. When manure values are not known, manure book values have been referenced, many of which are decades old. Our team based at the University of Minnesota in the United States (US), is creating a US-based manure database (ManureDB) to collect updated values. With changing animal genetics, feed sources, manure handling and storage systems, climatic conditions, and improved laboratory testing, having current manure test values will improve nutrient management planning, manure storage design, prioritisation of conservation programmes, and agricultural modelling.

### Methodology

The University of Minnesota received a National Institute of Food and Agriculture (NIFA) grant to create a manure nutrient database (ManureDB) using FAIR principles (Findable, Accessible, Interoperable, and Reusable). Working with a stakeholder group, the Minnesota Supercomputing Institute, and Minnesota Department of Agriculture (MDA), we developed a database schema, sample template, laboratory data use agreement, data standard operating procedures, data validation and upload process, and website. The project is still in the laboratory collaboration phase, where we are adding more laboratory partners and data from various regions, animal types, production systems, and time periods. Laboratories can share past manure data and annual data going forward with no customer names or addresses shared to avoid privacy concerns. We plan to conduct a power analysis to determine the quantity of manure samples that need to be considered a representative sample in ManureDB.

### Results and discussion

With a dozen laboratories signed on so far and the first official data sets coming in, we will have over 100,000 samples in the database in the next year. Eventually a public-facing website will show aggregate summary data for a region, animal type, and time frame. While this manure database resource will give better manure nutrient estimates, this should also encourage farmers to test their manure more frequently. Fertiliser prices are higher than ever, so utilising manure nutrients where they get the most value is of fiscal importance. Reducing manure overapplication where appropriate should lessen risk of nutrient loss to the environment. With many US states working on nutrient reduction strategies for water quality improvements, knowing more about manure characteristics can improve those strategic plans. Determining how many samples create a representative sample value will also give confidence in using these dynamic nutrient values.

Animal feeding operation regulations could be more effective with updated manure values to better estimate how much land would be required for new animal feeding operations. Knowledge of what are appropriate manure application rates for agronomic and environmental reasons can assist environmental regulators in farmer education and relevant nutrient management regulation. With more interest in carbon modelling, carbon sequestration, and carbon markets, we have received queries already for estimates of manure carbon content. Having a larger database of many manure types can create a useful resource for manure carbon and other analyte reference numbers. This database can also show us improved estimates of other less studied manure components such as chloride, which has become a water quality concern in some regions. Having up to date numbers can improve models and environmental programmes.

### Acknowledgements

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## Dirty Matters: The Soil Game

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### Introduction

Soil is an integral aspect of several vital functions, services and socio-economic activities, such as biomass production (e.g. food and fodder), and clean water supply (Helming et al. 2018). Consequently, many of the UN Sustainable Development Goals (SDGs) relate either directly or indirectly to soil functions and management (Tóth et al. 2018; Bouma et al. 2019) and therefore are inherently linked to soil, such as SDG 2: food security, SDG 6: clean water, SDG 13: climate change, and SDG 15; life on land. Despite its necessity, there is a general lack of awareness regarding the importance surrounding soil as a resource leading to the continued decline in soil quality over large areas of the EU and globally (Veerman et al. 2020). With our project, we wanted make soil literacy and awareness accessible to a wide audience in both educational and recreational settings. Board games have been shown to help increase the understanding of complex themes through the medium of play (Chiarello and Castellano 2016). Our aim was to create a fun and educational game that could be used as an aid to increase awareness and understanding of the complex and interlinking ecosystem that is soil and illustrate how human activities can impact its function and health. By introducing a social activity where winning is important, but winning individually is not possible, we hope to highlight the importance of interdisciplinary collaboration in solving real-world problems.

### Methodology

The process of making this boardgame initially involved brainstorming sessions to form a game design and then rigorous research to make sure our concepts were backed by up-to-date science. Once a playable game design was achieved, we started play testing with other soil scientists and a variety of other communities to make sure both the mechanics and science worked, tweaking the game after each session to incorporate feedback. The final stages included making it look appealing by engaging with a graphic designer.

### Results and discussion

The resulting game is called Dirty Matters: the Soil Game. It focuses on how soil management practises affect soil, which in turn affect the SDGs. Dirty matters is a fully cooperative game where the players embody soil organisms (including the mole, earthworm, and mycorrhizal fungi) and move around the soil implementing soil management techniques (such as cover crops, no tillage regimes, and adding manure) to counteract events that negatively impact the soil (such as soil compaction, acid rain, and erosion). This is all done with the overarching aim of keeping the soil healthy enough to meet the yield requirements of a growing population whilst trying to avoid polluting water and excessive carbon loss.

### Conclusion

As of today, Dirty Matters is a free to download, printer friendly, educational tool to advance the understanding of soil and how we should take care of it and everything in it.

### Acknowledgements

This project was funded through the Interdisciplinary Grants for Early Career Researchers and Professionals granted by the British Society of Soil Science.

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Plenary Session 4 – Future Challenges

## Effects of Dutch manure policies on nutrient emissions from silage maize cropping systems: historic trend and challenges for the future

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### Introduction

Silage maize was introduced in the sixties in the Netherlands. In the seventies and eighties, livestock numbers and manure production strongly increased. The area of silage maize also increased during this period, because silage maize is a crop to which very large amounts of livestock slurry can be applied without a yield penalty. Since 1989, the area of silage maize remained relatively stable at approximately 200,000 ha, accounting for 10% of the agricultural used area in the Netherlands. The high slurry application rates on silage maize resulted in environmental pollution by nitrogen (N) and phosphorus (P) leaching to ground and surface water, and ammonia (NH3) emission to the atmosphere. A series of nutrient policies and measures were implemented from the eighties onwards to mitigate these environmental effects, including N and P application limits, low NH3 emission application techniques of slurry, a mineral accounting system, closed periods for slurry application, and the mandatory growth of catch crops.

### Methodology

A literature review was conducted to establish a time series for the period 1985 – 2019 for the use of mineral fertilizer and slurry, yields, N and P surpluses, nitrate (NO3-) leaching, NH3 emission, and nitrous oxide (N2O) emission in silage maize cultivation. The effectivity of the different policies and measures to decrease N and P losses to the environment was assessed.

### Results & Discussion

The N and P inputs of fertilizers and slurry, as well as emissions to the environment in silage maize cultivation systems peaked in the eighties. Overall, the N and P use efficiencies increased steadily from the eighties onwards, because of decreasing N and P inputs and increasing maize yields. The implementation of low NH3 emission application techniques in the early nineties led to a strong decrease of NH3 emissions, but exacerbated N2O emissions. These application techniques increased the N use efficiency, due to smaller NH3 losses. The introduction of application standards in the late nineties was particularly effective at decreasing nutrient inputs. This, in combination with closed periods for manure application and the obligation to grow catch crops after silage maize, led to significant reductions in NO3- leaching. However, NO3- concentration in the upper groundwater under maize fields on many sandy soils are currently still exceeding the 50 mg/L norm of the Nitrates Directive. Silage maize is particularly prone to NO3- leaching, because of the short period of N uptake by the crop. More measures to mitigate NO3- leaching are needed. Replacement of grass roughage by silage maize in cattle diets may reduce the N excretion of cows, while simultaneously decreasing methane (CH4) emissions from enteric fermentation. Feeding cows with maize is therefore seen as an option to mitigate both CH4 and NH3 emissions. Clearly, there is a challenge for the future, as the accompanying conversion of grassland to arable land would increase the risk of NO3- leaching for many soils. Trade-offs like these require particular attention in the design of measures and policies that aim to maintain high agricultural production while decreasing the impact on climate and the environment.

### Conclusion

The implementation of a series of environmental polices strongly reduced N and P leaching from silage maize cultivation since the eighties in the Netherlands. However, further improvements in nutrient management are needed, because of the challenges related to the mitigation of $NH_3$, $NO_3$-, and $CH_4$ emissions.

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## Plenary Session 4 – Future Challenges

### Managing livestock manures to reduce phosphorus pressures on future water security

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In livestock dominated food systems, manures are produced in large quantities and often drive surpluses of nutrients at a range of scales that lead to leakage of nitrogen (N) and phosphorus (P) to the environment and the consequent damage to the multiple ecosystem services our natural resources provide. We have examined the impact of manure generation on the surpluses of P in the UK food system at national, regional and catchment scale using Substance Flow Analysis (SFA) (Rothwell et al 2020, 2022), and conclude that more sustainable manure management policies are required to alleviate the P pressures in our farming landscapes that are causing widespread phosphorus pollution of our rivers, lakes and coastal waters. We suggest that the P surpluses that drive agricultural P losses to water are more a system problem than a farmer problem, and that system change is required to alleviate the P pressure on our freshwater ecosystems. We relay these results using cross-scale examples and report the impact of a range of food system change scenarios on food system sustainability metrics and their potential environmental benefits. The results suggest that policies that recover P from livestock manures, and can substitute this recovered P for imported inorganic P fertilisers, will have greater impact on the sustainability of our food system than destocking, but that a combination of both is most effective.

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## Implication of enforcement and monitoring in nitrate pollution policy: the case study of Flanders, Belgium

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### Introduction

Despite governmental efforts to meet with EU water quality standards, nitrate concentrations in surface water do not reach the policy target set in the 1991 nitrates directive in most, if not all, of the Member States. Nitrate leaching in general, is linked to use of Nitrogen fertilizers and manure. The objective of this paper is to analyse different policy instruments that steer farmers to a more efficient fertilization using products that are based on manure but that reduce the risk on nitrate losses because of their more accurate concentration or more timely application. The paper stands out from previous research because it also includes the aspect of transaction costs and enforceability of the policy instruments. The last aspect is important because the marginal pollution contribution by farmers cannot be accurately measured yet. Due to the price inelasticity of Nitrogen fertilizers, many authors suggest that significant increase in input tax must be imposed to obtain a remarkable decrease in fertilizer use intensity. On the other hand, environmental policies enforcement and monitoring remain incompletely understood and a controversy among economists and researchers. Voluntary programs seem to be favoured by scholars and politicians over monitoring and enforcement as argued by Harrison 1995. The research in the area of environmental law is dominated by administrative scientists and lawyers, which explains why enforcement and application issues haven't been touched on enough. It is important to note that the theory of monitoring and enforcement is part of the broader theory of the public enforcement of law. (Shimshack, 2014). It wasn't until 1999, that a publication included a collection of papers on compliance and enforcement: "Compliance and Enforcement of European Community Law" by Vervaele. Nonetheless, the latter addressed the issues from a legal perspective rather than environmental. (Demmke, 2001)

### Methodology

In this paper, we build on previous work done by (Buysse and Bral 2018), and couple an agronomic simulation model with a linear programming mathematical model to evaluate the economic impact of N taxation policy, monitoring costs included, on farmers' revenue and nitrate leaching in Flanders.

### Results & Discussion

Preliminary results show that an economic or policy environment with more competition for limiting resources such as fertilizer nutrients is more conducive to implenet fertilizer recovery technology.

Acknowledgements: This project has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Sklodowska-Curie grant agreement No.860127

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**Assessment of antibiotic pollution in rivers from livestock production in China** Zhang, Q.[a,b]*, Kroeze, C.b,[c], Li, Y.N.[a,b], Xu, W.[a], Wang, M.R.[a], Ma, L.d, Zhang, F.S.[a] & Strokal, M. [b]*

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## Introduction

Rivers are often used as water sources for irrigation. Thus, rivers are esstential for sustaining food security. Many water systems in China are polluted with antibiotics. Livestock production is an important contributor to antibiotic pollution. Antibiotics from livestock production can enter rivers through different pathways, such as erosion, runoff, and direct discharge of manure. River pollution with antibiotics can influence biological and microbial communities and contribute to antibiotic-resistance genes. Existing studies are limited in quantifying inputs of antibiotics to rivers from specific livestock species. This study aims to quantify annual flows of antibiotics to rivers by livestock species and antibiotic types at the sub-basin scale in China.

## Methodology

We developed and evaluated a new version of the MARINA-Antibiotics (Model to Assess River Inputs of pollutaNts to seAs) model for 395 sub-basins in China. This model quantifies the inputs of 24 antibiotics in six groups to rivers from seven livestock species. The model considers the following six antibiotic groups: Sulfonamides, Tetracyclines, Fluoroquinolones, Macrolides, B-lactams, and Lincosamides. Livestock species include pigs, chickens, cattle, buffalo, ducks, sheep, and goats. Our model account for the direct dishcarges of livestock manure, the degradation (persistence) in manure during storage, soil degradation and sorption, runoff, and soil erosion to determin the fate and trafer of antibiotics from livestock production to rivers.

## Results and discussion

Model results show that livestock production contributes around 0.8 ktons of Sulfonamides, 1.4 kton of Tetracyclines, 4 kton of Fluoroquinolones, 0.7 kton of Macrolides, and 0.4 kton of B-lactams to Chinese rivers in the year 2013. Direct discharges are calculated to be responsible for over 90% of these inputs into rivers. Manure from pigs and cattle is responsible for over 60% of the antibiotics in rivers.

## Conclusion

We develop a modelling approach with an assessment of livstock production contribute to antibiotic pollution in rivers in China. This helps to better understand which species an what efforts are neede to reduce livestock production-related river pollution. Balanced fertilization of crops with manure application is needed to avoid direct discharges of manure. Advantaged technologies are needed for future manure management. Regional livestock-specific policies are necessary for effective water pollution mitigation to achieve Agricultural Green Development in China.

## Acknowledgements

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## Assessing the effectiveness of European regulations on decreasing nitrate concentrations in groundwater

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### Introduction

Groundwater nitrate contamination from agriculture has been a concern for the European Union (EU) environmental policies since the establishment of the Nitrates Directive (ND) in 1991 and the Groundwater Directive in 2006. To address excessive $NO^{3-}$ leaching from agricultural areas, Member States need to designate areas at risk of $NO^{3-}$ pollution (≥ 50 mg $L^{-1}$) as Nitrate Vulnerable Zones (NVZ). Because Member States have some flexibility in how to meet the main objective of reducing NO3- pollution, there is a lack of consensus on the criteria to designate NVZs. Furthermore, countries often use monitoring networks to track nitrate contamination in groundwater but these often have large data gaps and may not provide complete coverage of all hotspots. We aim to overcome these gaps by predicting nitrate hotspots in groundwater across Europe at 0.04°x0.04° during the period 1992-2019. This allowed us to perform a trend analysis to gain insight on how nitrate concentrations have responded to EU legislation and assess whether the current NVZs cover all regions threatened by nitrate pollution.

### Methodology

We trained a random forest (RF) model with annual average nitrate concentrations across Europe from EEA Waterbase (2000-2019) and different predictors that may influence nitrate in groundwater, ranging from pedoclimatic predictors (e.g., soil texture, monthly precipitation), groundwater properties (e.g., thickness, water table depth) to management practices (N surplus and N inputs). We used the trained model to predict annual nitrate concentration in groundwater in Europe at 0.04°x0.04° during 1992-2019. We quantified the size of hotspots according to the ND nitrate threshold of 50 mg $L^{-1}$. We computed the hotspot coverage for each country as the ratio of hotspots inside NVZs and total hotspots. We used spearman's correlation coefficient (rho) to identify statistically significant trends in any given period.

### Results and discussion

The RF model attained a good overall performance (R2=0.85, RMSE=12.98 mg L-1, KGEM = 0.76). On average, the hotspots in Europe covered 109 ± 35 thousand km2 yr-1 which is equivalent in size to Bulgaria. Hotspot size was rather stable (rho=0.04, p = 0.83) during the period 1992-2019, but we found an increasing trend (rho=0.76; p≈0) for recent years (2004-2019). The main hotspots in Europe were located in the European NW plains, ranging from Flanders to Northern Denmark, Southern Europe (e.g., Guadalquivir and Ebro basins in Spain, Thessaly in Eastern Greece), Central Europe (Vienna in Austria and throughout Hungary) and Eastern Europe (Bulgaria and Romania). Our simulation show diverging trends for the NVZs between the period following the implementation of the ND (1992-2003) and recent years (2004-2019), with an average rho of -0.26 and 0.28, respectively. There was a marked variation in terms of national hotspot trends with some countries (e.g., Denmark and the Netherlands) showing clear declining trends, others showed that stable hotspot sizes (e.g., Belgium, Portugal) while hotspot size increased in Greece, Germany and France. We detected hotspots outside NVZs mainly in Southern Europe but close to the current NVZs. This resulted in a hotspot coverage ranging from 39% in Italy to 68% in Greece, suggesting low ambition in designating NVZs.

### Conclusion

We postulate that despite the overall decrease in N surpluses and a higher nitrogen use efficiency in agricultural systems, some regions are still experiencing the consequences of unrestrained N application since the 1960s-1980s due to the time-lag of nitrate storage in groundwater. This time-lag applies not only to nitrate pollution in groundwater but also to the time required until groundwater quality reflects improvements in agricultural practices.

### Acknowledgements

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## The REAL Research Hub: Funding Research to Support the Organics Schemes

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### Introduction

The Research Hub works alongside the REAL Compost Certification Scheme (CCS) and Biofertiliser Certification Scheme (BCS). BCS and CCS certify compost and digestate to a set of independent quality Standards (PAS 100 and PAS 110). Composts and digestates that meet the standards required for certification under CCS and BCS are considered safe, reliable and of consistent high quality.

The Research Hub was established by REAL with the aim to provide research support for technical and regulatory developments related to the production, testing, and use of quality-certified compost and digestate. The Research Hub does this by funding research in support of the following three objectives:

1. Maintain and improve the robustness of the CCS and BCS and related Standards

2. Reinforce confidence in the compost and anaerobic digestion markets

3. Contribute to the development of new markets, including identifying barriers

Within these objectives there may be scope for research focused on improving nutrient utilisation and minimising the environmental impacts of composts and digestates used in agricultural systems.

### Methodology

The Research Hub sources research ideas via an open Call for Proposals at the start of each year. CCS and BCS participants are invited to feedback on proposals before they are evaluated for funding. Selected projects are funded through an annual Research Fee paid by CCS and BCS participants. REAL appoints a contractor to deliver each project.

### Results and discussion

To date, two projects have been delivered via the Research Hub and four further projects have been selected for funding.

Completed projects:

- The development of a Research Library for the Organics Recycling industry (Completed January 2021)
- This project resulted in the launch of the Organics Recycling Research Library, an online platform that collates hundreds of articles, policy papers, and market reports related to the organics sector.
- To develop a 'data pack' on the properties, characteristics, and content of digestate that will provide context for the development of new uses of outputs from Anaerobic Digesters (Completed December 2021)
- This project culminated in two reports: The Digestate 'Data Pack' contains information on the properties, characteristics, and content of digestate. The Digestate Valorisation Report explores alternative markets and the development of new uses of outputs from Anaerobic Digesters.

Current projects:

- Evaluation of the potential for the improvement of the Residual Biogas Potential test and investigation of alternative test procedures for PAS110 biofertilisers (Expected to complete June 2023)
- How the benefits of applying compost and digestate to soils can be accounted for under the Greenhouse Gas (GHG) Protocol (Expected timeline tbc)
- Plastic contamination method assessment: Evaluating current mass-based method and possible alternative methods of assessment for plastics in compost and digestate (Expected timeline tbc)
- Plant Response Test Interpretation and Comparison: Investigating performance of the PAS-Specified Tomato Plant Response Test and Spring Barley Test on Quality Compost (Expected timeline tbc)

### References

https://www.realresearchhub.org.uk/research-projects

## Are crop and livestock wastes too good to waste?

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### Introduction

Avitabile et al. (2023) found that in terms of dry matter, about 40% of the agricultural biomass production was in the form of crop residues. Of these crop residues, about 60% were not harvested and only about 13% of the harvested residues were utilised. About 86% of the dry matter harvested is used for feed and food production, with about 18% used for plant-based food and 82% for livestock feed. Only a small proportion of the energy and nutrients consumed by livestock, with much biomass excreted as dung and urine (Leip et al, 2022). Crop residues and livestock manure are currently considered a waste, albeit wastes with a value.

As we move towards net zero carbon, we will need to find alternative sources for the raw materials and fuels that are currently sourced from oil and gas. The requirement for raw materials and fuels needs to be seen against the background of increasing demand, due to increasing global population and wealth. The extent to which new technologies will be able to satisfy future demand depends considerably on the rate of development of new technologies, such as Power-to-X and novel recycling processes, and the cost of renewable energy. Nevertheless, biomass is likely to be a major source (e.g. Henkel, 2023; IEA, 2022), especially during the next 20-30 years, while the alternative technologies are under development (Royal Society, 2023).

There are two potential methods to increase the use of biomass as sources of raw materials and energy; repurposing existing biomass streams and creating new streams. A recent report to the Danish government (Rasmussen et al., 2022) considered both options. Here, we discuss the possible knock-on effects of these options for food production and the environment.

### Discussion

It appears that there will be significant demand for agricultural wastes to be harvested and processed to produce new raw materials and fuels. Redirecting these wastes from direct input to the soil raises the concern that this would impair soil functions, as a result of a loss of nutrients and a reduction in the soil organic matter concentration. Whether these concerns would be realised in practice depends on the fate of the carbon and nutrients removed as agricultural wastes (e.g. if some of this can be returned after utilization) and the extent to which changes in crop and land management could partially or fully compensate for the reduction of direct inputs to the soil. For example, pyrolysis and biochar production could be used to produce biofuels while sequestering significant quantities of carbon but would result in a loss of nutrients. The introduction of cover crops containing legumes would increase carbon and nitrogen fixation, with the harvested material contributing to the bioeconomy and the crop residues to organic matter in the soil. Dedicating land currently used for crop and roughage production to biomass production could remove pressure on crop and livestock wastes, reduce greenhouse gas emissions and enhance biodiversity but at the expense of livestock production. Here, we will discuss the benefits and trade-offs resulting from using agricultural biomass sources to replace fossil-based raw materials and fuels, illustrated with some Danish examples from Rasmussen et al. (2022)

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**Assessment and Comparative Analysis of Willingness-to-pay for Bio-based Fertilisers among Farmers and Agricultural Advisors in the EU** Moshkin, E.[a]*, Garmendia-Lemus, S.[b], Bamelis, L.[a] & Buysse, J.[c]

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## Introduction

Bio-based fertilisers form a new, rapidly developing market, with great prospect but also with high uncertainty. Although bio-based fertilisers have proven to be as effective as mineral sources (Numviyimana et al., 2020), there is still a great challenge of integrating social, economic and political aspects in a fair manner ensuring the long-term sustainability of bio-based fertiliser industry. Yet, there is very little marketing data that could assist managers and politicians to assess the viability as well as the potential of the bio-based fertiliser market. This study aims to contribute to the understanding of the market potential of bio-based fertilisers by providing data on willingness-to-pay (WTP) for a set of currently available or soon-to-be available bio-based fertilisers along with insights on the price sensitivity of farmers and agricultural advisors in the EU.

## Methodology

In this study we ran an EU-wide survey of farmers as well as agricultural advisors and utilised a direct technique for the assessment of WTP – Van Westendorp methodology (Westendorp, 1976). The extension of Van Westendorp technique elaborated by Lipovetsky (2006) allowed us as well as to compare: (1) potential prices; (2) % of the market willing to buy at given price; (3) potential revenue for a set of bio-based fertilisers at given price. Given the collected information we explored the differences between different demographics as well as the regions of the EU. Additionally, we put the results into perspective by comparing them with the actual prices for mineral fertilisers sold in the international markets.

## Results and discussion

Among the analysed fertilisers Ammonium Nitrate (AN) and Struvite (STR) had the highest prices and revenue potentials, whereas Mixed Pelletised Fertiliser (MPF) and Ammonium Sulfate had the lowest. Interestingly, given the interaction of price and demand, the results suggested that to ensure most rapid uptake of the new products by the market the producers would have to miss out on 25-32% of their potential revenue. Notably, to achieve that the prices would have to be set below the level of mineral fertilisers with the discounts ranging 30-46%. The results are the indication of the support the new market needs to grow, given the current legal developments. Looking at the differences between demographics and regions, we note that agricultural advisors exhibit higher willingness-to-pay than farmers for all analysed fertilisers. Also, we have seen notable differences between the regions grouped by the nutrient availability. The work is ongoing and we expect to uncover additional insights before September.

## Conclusion

Our study contributes to the marketing field of bio-based fertilisers the data on the potential prices and their impact on revenues, which is one of the key aspects that are needed for financial modelling and business case analyses. Combining the results with production cost estimations as well as analyses of non-financial aspects of business modelling is of great value for the understanding of the industry potential.

## Acknowledgements

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**"APIVALE scientific consortium": an integrated approach for organic effluent recycling and valorisation** de Quelen, F.[a]*, Jardé, E.[b], Le Maréchal, C.[c], Lendormi, T.[d], Menasseri, S.[e] & Béline, F.[f]

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About 400 million tons of organic waste is produced each year in France with a major contribution of animal production (300 million tons) and agroindustry (45 million tons). Agriculture is thus at the heart of organic waste recycling and valorisation (organic matter, energy, nutrients…). This challenge requires the production of scientific knowledge, the development of technical or organizational innovation and a more holistic approach to better consider the possible synergies on the territories. Organic effluents are subjected to numerous biological, chemical and physical processes that modify their composition, generate emissions to the environment and finally affect the availability of nutrient to plants and soil fertility. An improved knowledge of these different processes is thus required to quantify more precisely the emissions (for environmental evaluation) as well as for their reduction (for mitigation strategies).

Different research institutes located in Western France including INRAE, ANSES, CNRS, UBS, Institut Agro, Université de Rennes and ENSCR, have decided to share their skills, experimental facilities and equipment in a scientific consortium named "APIVALE" in order to develop an integrated approach of organic effluent recycling and valorisation.

The scientific consortium provides skills and facilities to perform integrated studies over the whole chain of production and valorisation of organic effluent, possibly in combination with other sources of organic waste (urban or agro-industrial) :

- a feed mill and equipment for the production of forages, and access to pasture, in a precisely controlled way
- experimental facilities for the raising and the collection of fresh excreta from animals of different species (pigs, dairy cows and heifers, dairy goats, poultry)
- equipment and facilities, including a dedicated bioclimatic hall named "Megeve" and respiratory chambers for the measurement of gaseous emissions from manure samples at the laboratory, on individual animals or small groups,
- lab-scale and medium scale facilities for studies on a large variety of treatment technologies (liquid and solid), including aerobic and anaerobic digestion, composting, phase separation, extraction of nutrient, production of microalgae…,
- facilities for the evaluation of the fertilization value of the organic products issued from different technologies,
- a large variety of laboratory equipment for the preparation of samples and the characterization of the organic products, including their micro-organism contents
- tools for the multi-criteria evaluation of the different chains of organic matter valorisation

Examples of research projects in APIVALE scientific consortium:

"**Optimization of copper and zinc recycling from animal feeding to the soil in pig production**": the objective of this project is to reduce environmental impact of copper and zinc elements generate by pig production by accommodate animal feeding and slurry management.

"**Impact of thermal and electrochemical treatments on spore-forming bacteria (Clostridium) and non-spore-forming bacteria (enterococci)**": The objective of this project is to study the impact of the thermal treatment imposed by European regulations (70°C, 1h) as well as an alternative strategy based on electrochemical treatments on the fate of bacteria during anaerobic digestion of manure.

"**Effect of biogas digestate, catch crop and climatic determinants on dissolved organic carbon, nitrates and orthophosphates transfer to subsoil**". This study aims to evaluate the effect of climatic and agronomic determinants (organic wastes products and winter cover crops) on dissolved orthophosphate, organic carbon and nitrate dynamics in soil.

## Assessment of trade-off balance of maize stover use for bioenergy, soil erosion, and nutrient use

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### Introduction

Kakamega Forest in Western Kenya where population growth is quite high is the only remaining patch of tropical rainforest in the country, covering about 238 square kilometres, and is threatened by deforestation due to the demand for firewood, charcoal, and agricultural expansion. Smallholder farmers in sub-Saharan Africa can benefit from anaerobic digesters and bioslurry, which can address deforestation, poverty, and reliance on chemical fertilisers. Maize stover has high lignocellulosic content and is readily available, making it a promising feedstock for biogas and bioslurry production. It can yield approximately 200-400 litres of biogas per kg of dry matter, which can generate around 3.6-7.2 kWh of electricity per kg of dry matter (Omondi & Zhang, 2016). However, leaving maize stover in the field after harvest can promote sustainable soil management, maintaining soil fertility and preventing soil erosion. This study aims to analyse the trade-off balance of utilising maize stover for energy generation and soil erosion in the Western Kenya region, considering biophysical conditions and the socio-economic status of each household. The study also explores the potential use of bioslurry as a partial replacement for chemical fertilisers.

### Methodology

Socio-economic information about farmers was collected during interviews conducted at the beginning and end of the cropping season. The interviews obtained data on household status, socio-economic background of the household, and agronomic practices that were applied in the past. A digital questionnaire consisting of 33 questions was used and implemented in a smartphone application. All sections were entered into digital forms using Open Data Kit (ODK) software, which is available on Android-based mobile phones. Completion of the questionnaire took approximately 30 minutes per farmer. After collecting data from 91 households, the energy consumption per household was calculated. To understand the contribution of maize stover to soil erosion, we deployed The Revised Universal Soil Loss Equation (RUSLE), which is an empirical erosion model recognised as a standard method to calculate the average risk of erosion on crop fields (Benavidez et al., 2018). We used geographical data, including slope, altitude, and landside, from the digital elevation model of SRTM. Soil texture type of 91 different fields was obtained from ISRIC dataset. Lastly, we applied an agent-based model approach (Gan et al., 2014) to assess different values of maize stover in terms of energy balance and greenhouse gas emissions.

### Results and discussion

The majority of farmers use firewood and charcoal for energy consumption. The large number of fields are located in the regions of Ferralsol and Acrisol, which are weathered acidic soils. Soil textures are mostly loamy soil type. Maize yield is approximately similar to the average value in Kenya, which is 2.0 tons/ha. Manure is commonly used as an organic fertilizer, in addition to chemical fertilizers like DAP and CAN. As for the RUSLE model and agent-based model, the results have not yet been finalised.

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## Precision agriculture approaches for managing winter blockages to manure landfills

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### Introduction

The European directive concerning the protection of waters against pollution caused by nitrates from agricultural sources (91/676/1991 EEC) establish restriction for winter in field distribution of livestock manure, sewage sludge, fertilizers and waste-water and all the comparable products. The Italian implementation (DM 5046/2016) imposed a closing period for 90 days between November-February period, 60 days continuously from 1st December to the end of February each year. On the other hand, The Po Valley is one of the areas in Europe, where the highest concentrations of particulate matter are detected in the air . Despite the progressive improvement trend (2003-2021 period), the number of exceedances in many air quality monitoring stations in Lombardy remains above the limit established by the reference standard. The incidence of ammonia in the formation of particulate matter in Lombardy has been estimated about 27% on PM10 and 36% on PM2.5. Therefore, agriculture contribute to the production of nano particulates of secondary origin and this phenomenon is particularly critical and significant during the October-March semester. Proper management of fertilizations of livestock manure can contribute to significantly reducing atmospheric emissions of ammonia and significantly limiting the formation of secondary particulate matter. It is therefore necessary to develop integrated management systems able to reduce the impact on the quality of both groundwater and air at once.

### Methodology

A study was conducted to evaluate the effectiveness of a more flexible approach based on a modeling system that simulates the daily water status of the soils using measured weather data and taking into account prevalent soils occurring in the area and a historical series of meteorological data of 10 years (2010-2020) coming from 7 weather stations located all over the Lombardy Po Plain. Additionally, conditions have been placed within the model setup to assure the nitrate leaching risk. The model output highlighted that the variability due to soil type and geographical location was significant. In fact, due to the increasing climatic variability there are years in which the distribution of manure could be carried out in the winter period without real environmental risks due to leaching towards deep waters. According to the model simulations, In many areas of Lombardy, on average, the number of days in which fertilization could be carried out is around 40 days out of the total period of 120, with peaks, in some years, even exceeding 100 days. Therefore, a more flexible management approach could only improve environmental results through effective and specific operations for homogeneous portions of territory. A web service was implemented for the definition of the soil accessibility, providing the mandatory information at the municipal scale. The service is based on the resolution of a daily water balance performed on a 4 km2 grid for all the agricultural soils of Lombardy. The web service has 3 components: 1) the meteorological processing system, 2) the hydrological processing system, 3) the soil accessibility processing system.

### Results and discussion

The use of the new webgis system allowed to schedule the optimal times for fertilization according to the actual soil and weather conditions. The PM10 values and the exceedances between the years preceding the application of the flexible system and the last two years were then compared. The results showed how flexible management was able to mitigate the effects on air quality without increasing negative impact on groundwater quality.

### Conclusion

Results of the study suggest that approaches more flexible than those based on a pre-fixed closing period are sustainable and could be even more effective when conflicting demands – such as the protection of both air and water quality - must be considered.

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## Effect of diet and manure management chain on Cu and Zn flows from feed to soil in pig breeding

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### Introduction

Copper (Cu) and Zinc (Zn) are trace elements with a potential negative environmental impact by accumulation in soil with the pig manure spreading (López Alonso et al., 2000). Indeed, Cu and Zn are essential elements in swine mineral nutrition but more than 90% of ingested are rejected in manure due to the low retention rate of these elements by animals (Dourmad et al., 2015). Thus, a better understanding of the behaviour of Cu and Zn throughout the animal-manure-soil continuum, according to feed composition and manure management chain, is required to propose alternative ways to reduce environmental impact. Among these alternative ways, two different strategies could be used to manage the level of these trace elements in spread pig manure. The first one is the optimisation of Cu and Zn in pig diet by adding more bioavailable form of minerals and reducing their levels. The second one is to plan a treatment chain adapting manure characteristics to requirements. Within this framework, the aim of the project was to determine the fate of Cu and Zn throughout the animal-manure-soil continuum by studying the effect of (i) Cu and Zn levels in animal feed and (ii) manure management chain including anaerobic digestion and composting and the interaction between both.

### Methodology

Faeces were collected from 24 finishing pigs fed with 4 different feed treatments : NC, negative control, without any supplementation of Cu and Zn (native content of 5 and 29 mg.kg-¹ Cu and Zn respectively) ; O1, containing an oxide source of Cu and Zn (Cu2O and ZnO; CoRouge® and Hizox®, Animine, France) with low levels of minerals (on average 7.4 mg.kg-¹ Cu and 47.5 mg.kg-¹ Zn) ; O2, containing an oxide source of Cu and Zn with European regulation level of minerals (25 and 120 mg.kg-¹ for total Cu and Zn) and S2, containing sulphates of Cu and Zn (reference sources) at European level. Faecal samples were exposed to two types of treatments: anaerobic digestion and composting. For anaerobic digestion, faeces were diluted with water (1:1) and the mixtures were used to feed weekly 200ml semi-continuous anaerobic digesters maintained at 38°C. A hydraulic residence time of 30 day approximatively was applied and the trial lasted 90 days. At the end, samples were taken for analyses. For composting trial, a mix of faeces and straw was put in aerobic bioreactor during 5 weeks. Straw was used to structure the product and represented less than 5% of Cu and Zn of the blend. The mixture was returned twice during the trial. At the end, samples were taken for analyses. Cu and Zn of each product before and after both treatments were analysed to know the effect of the diets on level of minerals and to characterize fluxes of Cu and Zn in two different type of manure treatment chains. Every analysis of Cu and Zn content were performed by ICP-AES (Agilent®).

### Results and discussion

The contents of fresh faeces obtained vary from 38 to 188 and 191 to 728 mg.kg-1 DM for Cu and Zn, respectively, depending on the diet. The less pigs received Cu and Zn in the feed, the lower the amount of excreted Cu and Zn in the faeces were. There were no significant differences between the level of Cu and Zn in the faeces from pigs that received the treatment with oxides than the ones with sulphates. Further statistical analyses are in progress. Samples obtained with in vitro studies analyses are being processed and will be presented in the final paper.

### Acknowledgements

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## Slurry acidification: a case study exploring the costs and benefits of slurry acidification in the United Kingdom

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### Introduction

The UK has set legally binding targets in the National Emission Ceilings Regulations to reduce ammonia (NH3) emissions by 16% in 2030, based on a 2005 baseline (HM Government, 2018). Agriculture is responsible for approximately 90% of total UK NH3 emissions, with the manure management continuum contributing 60% of agriculture emissions (Misselbrook and Gilhespy, 2022). Such a loss of NH3 must be targeted if the 2030 target is to be achieved. Ammonia emission reduction has the potential to improve farm sustainability by increasing crop available N supply form manures which reduces the need for manufactured fertiliser applications to meet optimum crop demand. This case-study outlines the potential cost and-benefits of using slurry acidification to reduce ammonia emissions from the English pig and dairy cattle herd.

### Methodology

Three scenarios were modelled using a purpose built model, centred on latest UK greenhouse gas and ammonia emissions inventory, and farming practises survey. The scenarios used a combination of in-house, pre-storage, and in-field acidification with changes to ammonia emissions, nitrate leaching and indirect nitrous oxide emissions costed using UK government societal benefit figures. The scenarios were 1) a hypothetical maximum, 2) maximum based on acid availability and 3) in-field only scenario based on acid availability. Each of the stages used an assumed NH3 abatement of 64%, reflecting the VERA verification for slurry acidification. Costs of installation and management of acidification systems were based on manufacturer costs for cattle (£133/per cow/year) and in-field acidification (£4.22/m3 if currently broadcast, £2.72/m3 if currently bandspread), while costs for pig systems (£41/per pig place /year) were based on figures derived from the installation of acidification equipment on a commercial pig farm.

### Results and discussion

All three scenarios showed that the cost of acidification was greater than the societal benefit arising from the reduction in $NH^3$ emissions. Scenario 1 had an overall cost of £190 million per year and delivered a saving of 10 kt NH3-N while increasing fertiliser value of crop available N by £15.7 million. However the overall cost to society was estimated at £57.5 million for the maximum potential implementation (i.e. all pig slurry acidified in-house, and 6% and 94% of cattle slurry acidified in-house and pre-store, respectively). Scenario 2 modelled 87% of pig slurry acidified in house and 18% of cattle slurry acidified pre-store maximising the potential for the additional acid available. The total cost was £71 million per year, delivering a $NH^3$-N saving of 3.4 kt and an increase in fertiliser value of £5 million. Overall, there was a shortfall of £25 million between total costs and societal benefits. The final scenario modelled the lowest cost option with 87% of pig slurry and 18% of cattle slurry acidified in-field. This abated 1.4kt $NH^3$-N and increased fertiliser value by £2 million but was estimated to cost £25.7 million per year. The final scenario had a societal cost of £8 million per year.

### Conclusion

Slurry acidification is most effective when it is applied at housing, as NH3 mitigation occurs at each stage of the manure management process (i.e. housing, storage and land spreading). The modelled scenario estimated that the maximum potential for reducing ammonia emissions from pig and dairy management systems was 10 kt NH3-N , equivalent to 8% of agricultural NH3 emissions in England. This scenario assumed that sulphuric acid supply was not limiting. For all 3 scenarios, the overall costs of acidification exceeded the societal benefits from reduced ammonia and indirect nitrous oxide emissions and savings in fertiliser nitrogen.

### Acknowledgements

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## Evaluation of milk urea content as a proxy for N-excretion of dairy cows

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### Introduction

In countries with high livestock density, ammonia (NH3) released from livestock and manure management is the principal constituent for nitrogen input into natural ecosystems which promotes eutrophication and consequently shift in species composition, soil acidification and degradation of water quality. In Switzerland especially, dairy cows are responsible for a substantial portion of ammonia emission. N-excretion is at the beginning of the manure cascade which includes housing, manure storage and application. Reducing the N-excretion is an efficient measure to mitigate NH3 emissions. In forage based diets for ruminants which are common in regions with a high proportion of grasslands it is difficult to balance the ratio of crude-protein: energy thus explaining the common N-excess in the rumen. Milk urea content has been shown to reflect ruminal N-excess and N-excretion especially with urine (Spek et al., 2013). In this study, we modelled the urine nitrogen excretion (UN) based on the milk urea nitrogen content (MUN) and estimated UN based on milk samples obtained from tank milk collected at dairy farms. In addition, we evaluated the effect of the breed on MUN. Finally, we estimated the effect of a reduced N-excretion based on a lowered MUN regarding NH3 emissions from dairy farms calculated with the emission model Agrammon.

### Methodology

We examined UN and MUN data from 22 feeding experiments involving 175 Braunvieh (including Brown Swiss, Braunvieh, Original Braunvieh), 368 Holstein, 50 Swiss Fleckvieh and 44 Jersey 44 cows. The relationship between the coefficient of UN and MUN was evaluated by a linear mixed model based on 544 observations. The model included the fixed effects MUN, breed and their interactions, feeding experiment as random effect and animal as experimental unit. The model was calibrated using an independent dataset with 60 observations. In addition, we determined the breed effect on MUN based on 2'344'787 data from regular milk analysis. We then estimated the effect of a reduction from a medium MUN content (22 mg 100 ml-1) to a low MUN content (16 mg 100 ml-1) on UN and ammonia emissions using the model Agrammon (www.agrammon.ch).

### Results and discussion

Two models were created for the relationship between UN and MUN, one with and one without interaction between breed and MUN. Both models achieved an accuracy with R2 of 59.3 (with interaction) and 57.7 (without interaction). To estimate the N-excretion, we recommend the model without interaction which facilitates its application in future model-based tools. According to the model, an increase of 1 g MUN 100 ml-1 milk is equivalent to an increase of 9.96 g UN day-1. The breed effect was also significant, i.e., the level of N excretion varies across breeds at an identical MUN content. The evaluation of the regular milk analysis data also revealed significant breed differences in MUN with Brown Swiss cows exhibiting the highest average MUN (24.7 mg 100 ml-1) and Holstein cows the lowest (21.8 mg 100 ml-1). Reducing a medium MUN (22 mg 100 ml-1) to a low MUN (16 mg 100 ml-1) was estimated to cause an emission abatement for NH3 by 12% over the entire manure cascade for a typical farm with dairy cows including replacement heifers.

### Conclusion

We showed that modeling of UN by MUN is feasible and offers opportunities to reduce UN of dairy cows. The model can be used for estimating NH3 emission and thus as an incentive to mitigate NH3 emissions from livestock production. We showed that the effect of the breed on MUN must be considered for such applications.

### Acknowledgements

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## Use of poultry manure compost and pig slurry to replace mineral fertilizers in the basal fertilization of maize production: impact on GHG emissions and maize yield

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### Introduction

Portuguese farmers need some evidence that organic fertilizers, namely manure-based fertilizers, can be used" safely" for partial replacement of mineral fertilizers, taking advantage of their nutrients and organic matter content. Some issues regarding the management and application of such materials need to be clarified, namely the effects of their application when no-till is used (conservation agriculture practices), avoiding their incorporation to soil (Silva et al., 2022). This experiment was used as a lighthouse demo site for the Nutri2Cycle project (H2020-SFS-30-2017), replacing mineral fertilizers by poultry manure compost and pig slurry, as basal fertilization in maize production, assessing their effects on maize yield and on greenhouse gases (GHG) emissions, in three contrasting fields.

### Methodology

A real scale experiment was set-up in a commercial farm located at Azinhaga (Quinta da Cholda – Portugal) in three contrasting sites, all dedicated to maize production, in the 2021 campaign: Site 1) Sandy soil ("Pessegueiro"), lower OM content (1.96%), application of organic amendments in a yearly basis, and conventional agriculture practices; Site 2) Loamy soil ("Melhorada"), medium soil OM content (2.32%), no history of application of organic materials, using conventional agriculture practices; Site 3) Sandy loam ("Vinha"), with no-tillage over the last 15 years, higher OM content (2.9%), no history of application of organic materials. Each sub-plot (18 m x 500 m) received a different basal fertilization with: (A) pig slurry (approximately 32 $m^3$ $ha^{-1}$), equivalent to 90 kg N $ha^{-1}$; (B) poultry manure compost (approximately 10 t fresh compost $ha^{-1}$), equivalent to 90 kg N $ha^{-1}$; (C) mineral fertilizer (control), equivalent to 60 kg N $ha^{-1}$ in site 1 and 2 (conventional tillage) and to 160 kg N $ha^{-1}$ in site 3 (no-tillage). Basal N fertilization was complemented with top dressing fertilization and fertigation to supply a total of 300 kg N ha-1, levelling the total N applied to each plot. All other operations (e.g., P and K fertilization, herbicides application, irrigation) were equally applied to the three plots. Greenhouse gases emissions were measured during maize growth (static chamber method), soil physicochemical properties, nutrient recovery, and crop productivity were assessed at the end of the experiment.

### Results and discussion

Pig slurry application led to the higher maize yields in the three fields, and the best productivities were obtained in the loamy soil (Site 2, conventional agriculture practices), but without significant differences between mineral and organic fertilizers (19.3 to 20.3 t ha-1). In the no-tillage field, maize yields (15.9 to 16.1 t ha-1) were significantly lower than when using conventional agriculture practices, but the organic fertilizers led to similar or higher productivities than when using mineral fertilizers. No significant differences were observed between treatments in terms of N2O emissions in the sandy soil and sandy loam soil but, the use of poultry manure compost in the no-tillage plot led to a significant increase of N2O emissions relative to the other treatments. Methane emissions remained residual in all treatment in sandy and sandy loam soil but a significant emission was observed in the "no-tillage" plot with the application of compost and pig slurry. Pig slurry's $N^2O$ emissions were always lower in all the treatments than when using the mineral fertilizer.

### Conclusions

The present experiment evidenced that it is possible to replace approximately 30% of the total N applied to maize production using organic fertilizers, namely those derived from manures (saving 30% of applied via mineral fertilizers), with similar or better yields. Nevertheless, the use of organic fertilizers might induce an increase of some GHG emissions, namely when using the no-tillage conservation practices, without the incorporation of the manure-derived fertilizers.

### Acknowledgements

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## In-season application of swine manure to maize to improve nitrogen management

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### Introduction

In agricultural areas with cool climates, application of livestock manure for crop production can be challenging. For example, spring in the upper midwestern United States can be short and is increasingly wet due to climate change, making it difficult to apply manure and plant crops in a timely manner. This results in a significant amount of manure applied in the fall after the cash crop is harvested. The nitrogen in fall-applied manure has ample time to mineralize and leave the root zone before next season's crop can utilize the nutrients. This excess nitrogen outside of the growing season can end up in ground and surface waters. Applying manure to maize (Zea mays) during the growing season, referred to as sidedressing, could provide farmers with another window of opportunity to apply their manure, maximize nutrient uptake efficiency, and protect water quality.

### Methodology

Replicated, on-farm studies were initiated in 2018 to evaluate sidedressing slurry swine manure to maize using tanker or drag hose (umbilical cord) application systems. Both systems were able to inject the manure between maize rows to reduce ammonia volatilization. In the first study using a drag hose applicator, liquid manure was compared to sidedressed anhydrous ammonia, 32% urea ammonium nitrate, and a no-sidedressed-nitrogen control. At planting, 45 kg ha-1 of nitrogen (N) was applied to the whole field. The remaining 157 kg N ha-1 was applied at sidedress with the different nutrient sources. For manure, about 33,000 L ha-1 was applied. Each treatment strip was replicated four times in the field. In the second study using the tanker applicator, manure application timing was the experimental factor. Manure was applied when the first, fourth, and seventh maize leaf collars had emerged and compared to the farmer's traditional practice – applying anhydrous ammonia around the fourth leaf collar growth stage. At planting, 45 kg ha-1 of N was applied to the whole field. The remaining 185 kg N ha-1 was applied at sidedress. For manure, about 37,000 L ha-1 was applied. Each treatment strip was replicated three times in the field.

### Results and discussion

In the first study using a drag hose applicator, we observed that N-deficient striping had occurred in the maize in the swine manure plots due to possible issues with flow distribution or soil compaction. At harvest time, all sidedressed N sources resulted in similar maize yield in 2018 but not 2019. In 2019, we found out afterwards that the application rate had been much lower than expected, applying only 100 kg N ha-1 instead of 157 kg N ha-1. This likely explains the lower yield in the manured plots compared with the commercial fertilizer plots. In our post-harvest soil samples, we found that anhydrous ammonia resulted in higher soil nitrate levels (0-60 cm) than other treatments. More information can be found in Pfarr et al. (2020).

In the second study using a tanker applicator, maize sidedressed with swine manure resulted in a 6 to 15% yield decline compared with the anhydrous ammonia treatment. This may have been due to compaction issues as the manure tanker system is much heavier than a dragline system. The narrow-row tires that were used to fit between rows of maize, compared to the much wider flotation tires used during the non-growing season, may have enhanced compaction, thus affecting crop growth and nutrient uptake.

### Conclusion

Swine manure was a good nutrient source for sidedressing maize during the growing season, particularly when applied with a dragline hose system. A tanker application system, however, may have caused too much compaction during application, leading to reduced maize yield. More research is needed to determine if there are adjustments to the implements that can be made to reduce compaction issues.

### Acknowledgements

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## $NH_3$-Min project: What is the impact of the application techniques (injection fertilization CULTAN vs. area application) in terms of nitrogen use efficiency in winter wheat?

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### Introduction

Agriculture is facing multiple challenges- such as adaptation to climate change, providing high sustainable harvest yields but at the same time reducing ammonia emission and increasing nitrogen use efficiency. Environmentally friendly plant production sets one efficient use of fertilizers. The application solid or liquid fertilizers on the soil surface and - depending on fertilizer and crop type - in one or more shares is the most common form of fertilizer application. This form of nutrient application comes to the ideal of a placement that plant nutrients "direct and the root" not very close. The CULTAN (Controlled Uptake Long Term Ammonium Nutrition) is a technique where ammonium based fertilizer injected inside depots of the soil. The fertilizer is applied in only one rather than the conventional 2 to 3 doses which is supposed to inhibit nitrification from bacteria due to the high pH and salinity

### Methodology

The research project NH3-Min, we conducted a multi-plot field experiment on winter wheat, set up at 10 sites across Germany. In three of the sites, we fertilized plots also with the "Controlled Uptake Long-Term Ammonia Nutrition (CULTAN)" method, where liquid ammonium-based fertilizer is injected only once at the beginning of the growing season at high concentration into depots near the root zone, as opposed to usually three fertilizer applications throughout the growing season. We measured soil mineral nitrogen content in the CULTAN treatment four times during the growing season, each time directly in the depot, between the depots, and between rows. Additionally, we monitored soil mineral nitrogen dynamics, pH, weather conditions and various plant parameters, such as yield, biomass and protein content.

### Results & Discussion

Using our data, we will compare yield, dry protein and nitrogen use efficiency of urea ammonium sulfate injections (CULTAN) with conventional solid urea ammonium sulfate surface application. Preliminary results show that CULTAN injection resultedammonium was completely absorbed by the plants during the first two to three months after application as observed in soil mineral N dynamics. No significant difference in yield was observed between the different fertilizer treatments, although at one site a decrease in grain dry protein content was found with the CULTAN treatment. The final aim is to assess the suitability of the CULTAN method increasing nitrogen use efficiency, yield and dry protein vs. the area application.

### Acknowledgements

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www.nh3min.de

## Using soil microorganisms to improve the fertiliser capacity of anaerobic digestate

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### Introduction

Anaerobic digestate (AD) is a nutrient rich slurry by-product derived from biogas production, often used as a fertiliser due to its high nitrogen content. However, nitrogen losses from its application can lead to major environmental issues (Nkoa, 2014, Nicholson et al. 2017). Novel strategies are needed to keep the nitrogen from the digestate in the soil. Materials high in organic carbon are known to stimulate microbial immobilisation of nitrogen in their biomass (Robertson and Groffman, 2015). AD has a low content of organic carbon (Risberg et al. 2017), so the aim of this project was to investigate the suitability of adding materials high in organic carbon with varying decomposition rates to the digestate to stimulate microbial nitrogen uptake.

### Methodology

Incubated soil (at 20°C) was amended with digestate (45$m^3$ $ha^{-1}$, equivalent to 250kgN $ha^{-1}$) and additional carbon (12kg C·$m^{-3}$) as either glycerol, straw, woodchip, or biochar. Soils were sampled at 0, 30, 90 and 150 days after application. The quantity of microbial N was measured (immobilisation), as well as bioavailable nitrogen and microbial biomass (carbon). A second study was carried out to investigate the dose response of carbon (glycerol) application rate (12, 24 and 36kgC ·$m^{-3}$) on immobilisation when added to digestate (at equivalent to 250kgN $ha^{-1}$). These soils were sampled at 0, 7, 14, 30 and 50 days after application.

### Results and discussion

Study 1: Although glycerol significantly increased microbial biomass during the first month, it did not cause significant nitrogen immobilisation, however the quantity of nitrogen within the microbial biomass was on average higher following glycerol than for other treatments. After three months straw significantly increased nitrogen immobilisation (at 120µgN $g^{-1}$ dry soil); neither woodchip nor biochar stimulated nitrogen immobilisation. These results suggest that mixing a moderately labile organic carbon amendment into AD has the potential to reduce nitrogen losses following AD application through microbial immobilisation.

Study 2: The addition of glycerol significantly increased microbial biomass for a month after application with the two higher doses resulting in a similarly greater and longer lasting effect. Bioavailable nitrogen in the soil decreased throughout the study and remained at lower concentrations than the digestate only control treatment by the end of the study. These results show that increasing carbon rates results in higher levels of microbial nitrogen immobilisation due to more carbon available to microorganisms. However, 36kgC·$m^{-3}$ digestate did not result in increased growth compared to 24kgC·$m^{-3}$ digestate, as either nitrogen (or other essential nutrients) became the limiting factor for microbial growth instead of carbon. This demonstrates that increasing carbon dose is effective at increasing microbial nitrogen immobilisation up to 24 kgC·$m^{-3}$ with higher doses providing no greater immobilisation.

### Conclusion

Carbon addition into digestate results in microbial growth and nitrogen immobilisation, but this is dependent on the carbon being relatively labile and therefore available for microorganisms to utilise. The rate of carbon addition is important, with 24kgC·m-3 of liquid digestate found as optimal for microbial immobilisation of nitrogen.

### Acknowledgements

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## Effect of split applications in organic winter wheat for bread quality

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### Introduction

The objectives of this study are to evaluate different application strategies of organic fertilizers to obtain high yield and bread quality in organic winter wheat production. Studying the timing of topdressing at GS21, GS32 and GS45 in two field trials, showed 2020 (dry spring) that there was a tendency for reduced yield and increased protein content with later fertilisation. In 2021, both yield and protein were significantly reduced by later fertilisation for all organic fertilisers, but the reduction was smaller with biogas digestate than for the other fertilisers. Comparing a split application with applying the entire N-rate early, in four field trials 2021 and 2022, showed that nitrogen in most organic fertilisers is best utilised if all is applied early. Only fertilisers with a large fraction of very readily available N are suitable for application at stem elongation or later. Therefore, the main amount should be applied early and a later top dressing for adjustment to the site and season can be done with biogas digestate or other fertilisers with readily avaible nitrogen.

### Methodology

To study the effects of and interactions between fertilizer type, timing, soil incorporation and irrigation, two large 4-factorial experiments in small plots were conducted in 2020 (4 m²) and 2021 (8 m²). In order to separate the effects of different topdressings from the first fertilizer application, all plots received the same amount of N with mineral fertiliser in early spring and then received different organic fertilizers as top dressing at various times. The organic fertilisers were biogas digestate (BD), poultry manure (PM), mixture of BD and PM (BD/PM), meat bone meal pellets (MP) and vinasse (VI). The different times for top dressing compared were at start of crop growth in spring (GS21), at stem elongation (GS32) and late boot stage (GS45). In four other field experiments with standard plot size (20m2), on silty clay and sandy loam in 2021 and 2022, applying the entire nitrogen amount (150 kg total-N/ha) with the organic fertiliser at GS21 was compared with splitting it into two halves. The second application occurred either at GS 32 (for MP in 2021 and MP and VI in 2022) or at GS39-45 (for BD and VI in 2021 and BD in 2022).

### Results and discussion

In the dry year 2020, the irrigation increased yield by on average 650-700 kg/ha but reduced protein content (9.5% with soil incorporation and 9.2% without) compared to non-irrigated (12.0% with soil incorporation and 11.1% without). Nitrogen yield was also reduced by irrigation (74 kg Nha-1 with soil incorporation and 71 kg Nha-1 without) compared to non-irrigated (81 kg N/ha with soil incorporation and 74 without), at least in plots with BD or VI. Soil incorporation did not affect yield, but had a positive effect on both protein content and nitrogen yield, at least in treatments without irrigation. There was a tendency for reduced yield and increased protein content with later fertilization.

In 2021, protein, yield and N offtake were all larger after early (GS21) than later (GS32 and 45) fertilisation. For BD this reduction was very small. Due to satisfactory amounts of precipitation in spring 2021, irrigation was only performed after the fertilization in GS45. That did mainly have an effect in the treatment with late fertilisation with PM. In the four other field experiments, a split application compared with one single early application reduced yield and nitrogen offtake for for BD and MP but for VI the effect was similar. For BD and VI protein was higher after split application, whereas for MP protein was lower but generally at a higher level than BD. The lower protein levels for BD than the other fertilisers could be due to N-losses at application. It was not economically profitable to split the application for any of the fertilisers.

### Conclusion

In conclusion, most organic fertilizers is best utilized if all is applied early. Only fertilizers with a large fraction of very readily available N is suitable for application at stem elongation or later, and then mainly to be able to make a later decision on total fertilization rate. For BD the total N rate of 150 kg/ha was obviously not enough, to obtain protein > 10,5% (limit for milling flour) when yield was as high as in this study and possibly N-losses occurred. It was difficult to obtain protein >10,5% at the site with low soil N availability (silty clay).

**The effect of row-injected cattle slurry on maize yields depends on tine tip width and the use of nitrification inhibitor.**

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## Introduction

Silage maize (Zea mays L.) is an important forage crop on intensive dairy farms in north-western Europe. Maize requires an ample supply of phosphorus (P) early in the growing seasons to reach the yield potential. Mineral P fertilizers produced from rock phosphate are routinely placed near the seed at sowing (starter fertilizer) to ensure adequate levels of available P. In addition, cattle slurry is typically injected into the soil with random lateral positions relative to the maize row (non-placed slurry), resulting in a P input surplus. To ensure a more environmentally friendly silage maize production with less accumulation of P and to avoid depletion of the phosphate rock reserve, there is an urgent need to replace the use of mineral P fertilizers with new management strategies. Injection of slurry near the maize row (placed slurry) has been shown to have the potential to replace mineral starter P fertilizer in maize cropping. However, the effect of placed slurry on final yields may depend on placement depth and the design of the injection tine. Addition of a nitrification inhibitor may also influence the early uptake of P in maize.

The main objective of this field study was to investigate effects of slurry row-injection placement with different tine geometry (operation depth and tine width) and use of the nitrification inhibitor 3,4-Dimethylpyrazole phosphate (DMPP) on early growth and final yields of silage maize.

## Methodology

A two-year field experiment was carried out on a sandy loam and a loamy sand with Olsen-P contents ranging from 24 to 43 mg P kg-¹ soil. Before sowing of maize, cattle slurry with a nitrification inhibitor (DMPP) was row-injected using newly developed goosefoot tine tips of three widths (8, 17 or 26 cm). For the widest tine, slurry was placed at 7 or 10 cm depth under the coming maize row, and for the other tines slurry was placed at 10 cm depth. The placement method with widest tine was tested with and without DMPP. The placement strategies were compared to plots receiving non-placed slurry and increasing rates of mineral P starter fertilizer with and without DMPP. Concentrations of nitrogen (N) and P in leaves at the five-leaf stage and dry matter, N and P yields at normal harvest time were measured.

## Results and discussion

Addition of DMPP to slurry placed at 10 cm depth increased early P concentrations in maize leaves on the sandy loam soil and early N concentrations in leaves on the loamy sand soil, whereas addition of DMPP to non-placed slurry had no effect on early P and N concentrations. Row-injection of slurry using goosefoot tines of 17 or 26 cm width injected at 10 cm depth combined with DMPP provided similar final yields (up to 17 Mg DM yield ha−1) as when using mineral P as a starter fertilizer with non-placed slurry on the sandy loam in one of two trial years. By replacing traditional non-placed slurry injection and starter mineral P fertilizer with row-injected slurry, the P surpluses were significantly reduced.

## Conclusion

The effect of placed row-injected cattle slurry was affected by tine tip width. On the sandy loam soil, the yield potential could be reached by row-injection placement with medium or broad goosefoot tines combined with DMPP addition, while avoiding a P surplus in maize cropping.

## Acknowledgements

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**Optimisation of manure allocation in view of crop requirements and environmental impacts in Chinese agriculture** Sun, W.[a b]*, Ros, G. H.[a], Zhu, Q.[b], Xu, D.[a b], Hou, Y.[b] & de Vries, W.[a]

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## Introduction

The average manure-recycling ratio in China is lower than 40%, implying that over half of the nutrients in manure are lost to the environment (Jin et al., 2021). Enhancing manure recycling in China on a regional scale could reduce manure nitrogen (N), phosphorus (P) losses and soil acidification rates (Carvalho et al., 2018, Ma et al., 2022, Zhang et al., 2019). Optimisation, which requires comparisons between crop nutrient demands and manure nutrient availabilities, is until now limited to N, P and potassium (K), not accounting for the input of other nutrients such as calcium (Ca), magnesium (Mg) and sulphur (S), that are driving (S) and counteracting (Ca, Mg) soil acidification. More insight is needed in assessing the requirements of all those, combined with minimal N and P losses in view of impacts on soil quality (soil acidification) and water quality. The study aims to fill this knowledge gap by identifying optimal manure recycling strategies in a typical Chinese city, focusing on the major nutrients N, P, K, Ca, Mg and S, considering the above-mentioned impacts.

## Methodology

An assessment is made of the optimal manure allocation in six Chinese counties that are part of a typical Chinese city Quzhou, by calculating the required N, P, S. K, Ca and Mg input to fulfil their crop demand using current crop yields, while accounting for the need to minimize soil nutrient surpluses and soil acidification. The maximum manure application is limited by either the availability or the maximum P demand, being the crop P demand, accounting for the need for the possible need for extra P or less P, depending on the soil P status. If the optimal dose to meet the P requirement fails to meet BC demand, we also calculate how much lime needs to be given to fulfil the BC demand and avoid acidification, induced by crop BC uptake and BC leaching accompanying the unavoidable leaching of nitrate.

## Results and discussion

The current nutrient balance in Quzhou city indicated that under the current manure and straw recycling rate, extra mineral fertiliser is needed in view of remaining nutrient demands of N (-8100 tonnes), K (-2800 tonnes), P (-240 tonnes), and S (-390 tonnes). However, at full manure and straw recycling, nutrients from livestock manure can meet crop demands except for N (-2300 tonnes). The current and potential nutrient balance varied strongly between the six counties with some counties having a deficit in N and K, even at full recycling, and other counties having an excess implying the need for manure transport out of the county if full recycling is attained More results will be presented in the conference.

## Conclusion

Quzhou city has a big potential to recycle manure for crop fertilisation, fulfilling or even exceeding the crop demands for most nutrient. However, large spatial differences in nutrient balances imply that a regional manure allocation model is crucial to avoid too large manure inputs, especially of P and optimising application rates in view of impacts on soil and water quality.

## Acknowledgements

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## Nitrogen in apple orchard: organic fertilisation strategies in a circular economy approach

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### Introduction

The European Farm to Fork strategy demands a 50% reduction in nutrient losses and a 20% reduction in the use of fertilisers by 2030. The use of livestock-derived amendments to replace quick-release fertilisers is a valid strategy of nutrient recovery in a circular economy perspective. The application of nitrogen fertilisers has the purpose of satisfying crop requirements and ensuring the availability of this element when plants need it the most. Achieving this goal is not an easy task as excess nitrogen is harmful to crops and the environment. The aim of this research, conducted in cooperation with the Fruit and Vegetable Growers' Association of Trentino, was to study nitrogen availability by organic amendments in order to rationalise external inputs and reduce their impact.

### Methodology

The study was carried out in an organic apple orchard of Gala in north-east Italy. In 2019, the orchard was organised in randomised blocks fertilised with commercial organic pellets, mature cattle manure and the solid fraction of digestate obtained from cattle slurry, resulting in three theses, PEL, MAN and DIG, respectively. For four years, the soil was sampled on the row (0-20 cm layer) in four replications per thesis during the apple's vegetative cycle and the leaves were collected at the phenological development phase BBCH 76-77. The fruits were harvested at commercial ripening. Total nitrogen in leaves was determined by the Dumas method, while mineral soil nitrogen (N-$NO^3$- and N-NH4+) was quantified colorimetrically after extraction in K2SO4. The orchard yield for each thesis was calculated as tons of apples per hectare.

### Results and discussion

Mineral nitrogen measured in the soil during the growing cycle from 2019 to 2022 showed significantly higher values in both amended theses (MAN and DIG) than in PEL three and four years after the start of the study. The annual dynamics highlighted that both manure and digestate are able to gradually release promptly available nitrogen into the soil, especially during the periods of greatest demand by the apple tree, reducing the risk of losses into the environment. The supply of mineral nitrogen by digestate has been shown to be closely linked to post-digestion stabilisation processes. The nitrogen concentration in leaves did not differ among theses from 2019 to 2022. However, in the fourth year of trial the nitrogen content decreased significantly for all theses, reaching values below the characteristic range for apple trees (2.1%-2.8% - Porro et al., 2001). The yield was similar between the theses fertilised with organic amendments and the thesis with pellet during the entire period of study, whereas it varied significantly over time.

### Conclusion

Cattle manure and the solid fraction of digestate have been shown to be able to provide nitrogen available to the plants during the periods of greatest need for the apple orchard. However, the different fertilisation strategies did not affect leaf nitrogen and yield.

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**The nitrogen, phosphorus and potassium balances in olive groves of Andalusia** Domouso, P.[a]*, García-Ruiz, R.[a], Calero, J.A.[b], Ruiz-Cátedra, G.[a] & Torrús-Castillo, M.[a]

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## Introduction

Olive groves represent 47% of the arable land of Andalusia, the southernmost region of Spain. Therefore, changes in the management of this crop have a great impact on ecosystem services at regional scale. Modern agriculture severely alters nutrient cycles and leads to environmental pollution due to the acritical use of fertilisers. Consequently, European policies such as CAP 2023-2027 are driving the implementation of sustainable fertilisation strategies. In this study the nitrogen (N), phosphorus (P) and potassium (K) balances in different cultivation models of olive groves are examined.

## Methodology

17 commercial olive groves along a gradient of management practices with impact on nutrient flows were selected across Andalusia. For each olive farm, a survey was conducted to gather basic information such as the average fruit yield, the irrigation doses, the types and amounts of fertilisers and amendments applied, the degree of livestock integration and the fate of crop residues. Additionally, the main biomass flows throughout the farm were quantified and N, P and K in soil, rainwater, irrigation water, biomass and fertilzers were analysed. Finally, GIS methods were applied to estimate potential soil erosion, whereas gaseous N emissions were estimated from EMEP (2019) and IPCC (2019). With these data, the main nutrient flows, the nutrient balances and relevant index were calculated.

## Results and discussion

N, P and K annual inputs range from 17.0 to 144.8 kg N ha-1 y-1, 0.5 to 24.7 kg P ha-1 y-1 and 10.3 to 189.0 kg K ha-1 y-1, of which natural entries accounted for less than 10%. Natural-to-total input ratio for olive groves with spontaneous cover crops tended to be the highest, mainly due to the contribution of legumes. Fruit harvest was, usually, the major nutrient output of the olive groves, followed by soil erosion and, in the case of nitrogen, by ammonia volatlization. On average, 12.5, 2.4 and 31.3 kg ha-1 y-1 of N, P and K were annually exported with the harvest, respectively.

The spontaneous cover crop contributed significantly to total nutrient recycling, therefore reducing the potential losses of inorganic forms of nutrients. The reuse of the olive pomace, which contains most of the nutrients found in the fruit, and the shredded of the tree pruning avoid the two main potential outputs, turning them into internal loops.

Nutrient use efficiency was negatively related to total and anthropic nutrients inputs, showing that there is considerable scope to reduce the external amount of nutrients and to improve their use efficiency.

In 16 out of the 17 olive groves, the gross balances for N and P were positives. The gross balance of nitrogen was not related with the stock in the soil, suggesting that it can be either stored as organic nitrogen or lost in inorganic forms.

## Conclusion

Results of this study highlight that i) by implementing the shredded of the tree pruning and the application of composted olive mill pomace nutrient outputs and external inputs requirements are largely reduced, ii) the cited practices together with the spontaneous cover crop result in a greater closure of the nutrient cycle at local scale and, iii) soil erosion can account for a significant contribution to the total N, P and K outputs and therefore this process should be integrated in the nutrient balances.

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## Innovative agricultural technologies to reduce the nitrogen footprint of tomato production – nitrate leaching of direct monitoring

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### Introduction

Nitrogen (N) is a key indispensable nutrient for all living organisms including humans. For over one century, synthetic fertilizers and agriculture intensification allowed to feed the world population, but this came with high environmental costs. Nitrogen use efficiency is the solution to improve soil, water and air quality while avoiding increased costs to the farmers. Tomato is one of the most consumed crops worldwide and requires high amounts of N inputs to achieve high yields. Therefore, there is an urgent need for sustainable practices capable to reduce N inputs and promote N losses mitigation. To find the best agriculture practices and technology measures, this work focused on developing low N footprint production systems for industry tomato.

### Methodology

One field experiment was set up to increase N use efficiency and decrease tomato production N footprint. Two different treatments were applied on the same tomato variety (Heins 1534): with and without a bio-fertilizer named Blue-N.

Both treatments were tested together with 3 different rates of N fertilization inputs along the plant growing cycle: treatment "N100", corresponding to the conventional N fertilization practice used by the farmer, which we assume 100% of N input and also served as control; and treatments "N50" and "N0", corresponding to 50% and 0% N inputs from the conventional practice of 100% N inputs, respectively. Blue-N was developed from the selective N-fixing bacteria Methylobacterium symbioticum to naturally provide N to the plant. It is applied by pulverization and was tested in tomato plants for the first time. This bio-fertilizer converts N from the air (atmospheric N2) into ammonium (NH4+) which is then constantly metabolized directly into amino acids. To help farmers and the environment in the production process, a promise agricultural technology was tested for the first time in Portugal. The higher (N100) and lower (N0) N fertilization input rates applied in the experimental field were provided with innovative soil probes able to carefully measure nitrate (NO3-) leaching in real time at two different depths. It gives the N content that are being leached trough the soil column (not uptaken by plants) while the fertirrigation practice occurs. Several samples of soil, plants and fruits were collected for chemical analysis and N monitoring along the growing cycle. At harvest, tomatoes from each treatment were collected, quantified and weighted to determine productivity. Fruit samples were analysed for quality validation.

### Results and discussion

Tomato production yield was affected by the different N doses applied in the field, but no significant differences were found between treatments. Fruit quality achieve good results in both treatments: none quality parameter analysed was affected by the different fertilization practices tested in the field. N uptake by plants was significantly higher in the treatments with Blue-N and lower N input. Blue-N promote significant differences in productivity when 50% of N rate were applied. The new nitrate probes were a useful technology to directly monitor the N losses by leaching in real time.

### Conclusion

Blue-N presents an alternative for the use of higher mineral N fertilizer inputs. By avoiding aquifer contamination through nitrate leaching, this bio-fertilizer proved to be an efficient fertilization practice cable to reduce the N-Footprint of tomato production and fertilization costs to farmers. Tested nitrate probes are a promising tool able to improve N use efficiency and decrease the N footprint of tomato production. This technology helps farmers in their decisions regarding agricultural practices to avoid soil and water contamination, maintain soil health and increase productivity at long-term. Allowing the control of N inputs and the assessment of soil pollution risks, this innovation is an added value for farmers and to achieve a sustainable agricultural footprint.

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## Effect of C/N ratio and bedding type on nitrogen mineralization from cattle slurry

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### Introduction

Previous studies have suggested that nitrogen fertilization effect of animal slurries is dependent on C/N-ratio. However, the bedding material characteristics may affect this relationship. The objective with this study was to compare net N mineralization at different C/N-ratios depending on source and particle size of bedding materials in slurry.

### Methodology

An incubation study was conducted. The liquid fraction (LF) from mechanical solid-liquid separation of cattle slurry was mixed with chopped straw, ground straw, sawdust or solid fraction (SF) of slurry to create manures with different C/N-ratios and bedding materials. For mixtures with SF and chopped straw, mixture C/N ratios of 10, 12 and 14 were studied, and for ground straw and sawdust C/N ratio 12 only. The materials were added to a sandy loam soil at a rate of 102 mg total N/kg dry soil in all treatments, while the amount of total C varied with C/N ratio. The samples were incubated in a climate chamber at 15 C°, and at day 0, 3, 7, 14 and 28, three replicates from each treatment were destructively sampled and analysed for mineral N content. In a parallel incubation including the same treatments, C mineralisation was studied as an indicator of C availability for the different bedding materials. For this, three additional replicates of soil samples with manure added were placed in glass jars together with beakers containing KOH solution absorbing the $CO_2$ evolved. By changing the $CO_2$ traps and measuring the electrical conductivity in the KOH solution at days 2, 5, 10, 15, 21 and 28, cumulative $CO_2$ evolution could be calculated. The net release of mineral N and C from manures was estimated by subtracting the release from a control soil.

### Results and discussion

The differences in net N release between C/N ratios (only chopped straw and SF included) were significant ($p<0.001$), and the amount of N mineralised (as percent of total N added) at the end of the experiment (day 28) was on average 36%, 30% and 26% for C/N ratio 10, 12 and 14, respectively. There was a negative linear correlation between C/N ratio and mineral N content, at day 14 and 28. At day 14 there was a steeper relation for SF than for chopped straw, while at day 28 the relationship did not differ between bedding materials. At C/N ratio 12, slurry with sawdust had significantly higher ($p=0.001$) soil mineral N release at day 28 with 39% of added total N, compared with 28-30% for the other bedding materials. Cumulative $CO_2$ emission (as percent of total C added) was negatively correlated to C/N ratio at all sampling dates except day 28, where the difference between C/N ratio 10 and 12 was non-significant. At C/N ratio 12, cumulative $CO_2$ emission at day 28 was highest for SF and ground straw (46% of added total C), followed by chopped straw (38%) and lowest for sawdust (33%) ($p<0.001$).

For sawdust, showing the lowest cumulative $CO_2$ emission and the highest mineral N release at the end of the experiment, the results indicate that a lower C availability caused less immobilisation of N. The higher $CO_2$ emission from ground straw compared to chopped straw indicates an effect of bedding material particle size on C availability, while for N release there were no difference.

### Conclusion

The net release of mineral N from total manure N showed a negative linear relationship with manure C/N ratio after four weeks decomposition in soil, while no difference was seen between the bedding materials, except the sawdust treatment that had a higher mineral N release. The higher N release from slurry containing sawdust was related to a lower C mineralisation rate in soil. For straw, the particle size had an effect on $CO_2$ emission, but not on N release.

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## Digestate use in rice cultivation – greenhouse gases, nitrogen and microbes

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### Introduction

Digestate, the organic rest from biogas production, is a good fertiliser with ample plant nutrients (Möller and Müller 2012). However, there are fewer studies on environmental effects of digestate use, such as on microbial community, soil properties and greenhouse gas emissions. Our previous work showed the impact of digestate on greenhouse gas emissions in aerobic soil (Dietrich 2020). The microbial community in soil will be altered when applied with the digestate will be quite different from that in aerobic soil as digestate contains rich organic compounds and an inherent anaerobic flora. However, in flooded paddy soil the microbial community composition might be more similar to that in digestate. Flooding also changes greenhouse gas emissions. The aim of this study was to assess the use of digestate as fertiliser in rice growing, any interaction with water management, and effects on greenhouse gas emission and impact on functional microbes.

### Methodology

Incubations were performed waterlogged and non-waterlogged. Two paddy soils with different history were sampled in India, and digestates as well as mineral fertiliser (urea) were used as additions. The digestates were from two plants, and unseparated and solid fraction were used. A treatment where the digestate was heat-treated (105°C for 24 hours) to kill all microbes before application was included. Greenhouse gas fluxes ($CO^2$, $N^2O$ and CH4) were measured during the incubation. Samples for mineral nitrogen (N) and for DNA extraction were taken out during the incubation. Genetic markers for idenitrification, CH4 production and oxidation were quantified during the incubation. A growth trial with rice plants grown submerged or at field capacity and two digestates as well as mineral fertiliser and no fertiliser as controls was also performed. Mineral nitrogen and DNA and the same markers as well as plant root and shoot biomass were analysed twice during growth.

### Results & Discussion

Digestate from one of the plants induced larger CH4 emissions than the others, and emissions were largest waterlogged. However, the smaller emissions observed with the other treatments gave somewhat unexpected result, with smaller emissions observed with digestate application than soil only and smaller emissions when waterlogged. Heat treatment had little effect, but emissions started somewhat later. Populations of methanogens also increased slower when heat-treated. Populations of CH4 oxidisers peaked late in the incubation. $N^2O$ emissions were largest after application of the digestate with low methane emission non-waterlogged, but when waterlogged it gave almost no emission. For the urea, however, waterlogged or not did not matter for $N^2O$ emissions. The number of copies of $N^2O$ reducer genes peaked at about the same time as $N^2O$ emission, but $N^2O$ reduction could not explain the effect of watelogging. Urea was a better fertiliser for rice than any of the digestates, and mineral N data suggest that more N is lost shortly after application from digestate than urea. $CO^2$ production did not vary so much with treatment, indicating that most of the available carbon had been used during digestion, so that the carbon left is relatively stable.

### Conclusion

Digestates can trigger greenhouse gas emission. Our results suggest that any effect of the microbial community applied with the digestate are short-lived. In rice production, digestates should be applied in split applications, similar to mineral fertilisers.

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## Exogenous thermophilic bacteria promoted N retention and enhanced compost quality in aerobic composting

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### Introduction

Ammonia volatilization loss is the main technical bottleneck of aerobic high temperature composting of organic solid wastes such as livestock and poultry manure(Liu et al., 2015). The high temperature accelerates the loss of ammonia and the transformation of NH4+-N may help to decrease the volatilization loss. Here two thermophilic strains (Bacillus L8 and Saccharopolyspora L17), which were screened during thermophilic period (63°C when sampling) of dairy manure composting and demonstrated the conversion of NH4+-N into stable $NO^3$--N, were used to explore their effects on the nitrogen conversion and compost quality in composting. The results were conducive to new microbial resources for the improvement of compost technology.

### Methodology

An aerobic composting experiment with chicken excrement and Chinese medicine residue was conducted with an aerobic composting device for solid waste (patent NO.: ZL 201010589910X). There were 5 treatments, L8 (inoculating L8 agent), L17 (inoculating L17 agent), L8+L17 (Inoculating L8 and L17), CK1 (adding equal volume of sterile water), CK2 (adding equal volume of sterile medium) with three replicates of each treatment. The strain densities reached 1× 107 CFU/g matrix. The changes of ammonia daily volatilization, total nitrogen (TN), NH4+-N, NO2--N, NO3--N and humus, humic acid (HA), fulvic acid (FA), total nutrient (N+P2O5+K2O), and maturity of compost were monitored.

### Results and discussion

With the inoculating of strain L8 and strain L17, the ammonia daily and cumulative volatility were much lower than CK1 and CK2 with L8 showing the lowest volatilization. This was consistent with the highest accumulated total N being observed in the L8 treated compost. CK1, CK2 and L8+L17 treatments composts showed significantly higher NH4+-N content than L8 and L17 treatment, while the content of $NO^2$--N and $NO^3$--N were to the contrary. At the end of composting, both the inorganic and soluble organic N in L8 were significantly higher, followed by L7 and L8+L17, both of which were higher than the controls CK1 and CK2. There was no difference between CK1 and CK2. These results indicated, in agreement with previous studies (Jiang et al., 2015), that the inoculation of L8 could effectively promote NH4+-N being transformed to $NO^2$--N/$NO^3$--N in compost, or even promote NH4+-N to be converted into soluble organic nitrogen by microbial cytoplasmic synthesis, which was beneficial to nitrogen retention in compost. Notably, even though the inoculation of L17 could contributed to the N conservation to some extent, it was not as good as L8 and when in combination would impair the effects of L8.

All the composts were up to the maturity standards in the terms of the germination index higher than 80%, C:N ratio lower than 10 (Bernal et al., 2009), and HA:FA ratio higher than 1.7 (Shan et al., 2013). The treatment inoculated with L8 showed the lowest humus and FA content, but the highest HA:FA ratio and total nutrients content. The L17 and L8+L17 combined treatments showed no difference to CK1 and CK2 controls in humus content. However, there was no significant difference in the total content of HA and FA between all treatments. The higher the HA:FA ratio is, the higher the degree of humus polymerization and humification (Chen et al, 2019). This indicated that the inoculation of L8 was showed the greatest effect in promoting humification and improving the fertility of the compost.

### Conclusion

The results demonstrated that the exogenous thermophilic bacteria efficiently reduced the loss of ammonia volatilization to preserve more nitrogen in compost, and it also improved the compost quality. Bacillus L8 is a novel promising microbial resource for improving compost quality and decreasing ammonia loss and requires further development.

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**S-VALOR: Valorisation the fertilising value of decontamination by-products.**

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## Introduction

The indiscriminate use of fossil fuels is leading society into an energy crisis that affects not only the economy but also the environment. One alternative is the production of biofuels such as biogas from organic waste. Biogas has associated gases as hydrogen sulphide, which is highly toxic and corrosive, limiting its use in industry. As solution, there are currently several treatments with different materials (the most common is the activated carbon), that allow the removal of hydrogen sulphide. However, activated carbon has high purchase price and it is classified as hazardous waste (Georgiadis et al., 2020). In this context, the replacement of activated carbon with a mineral adsorbent is aimed not only at obtaining it at a lower price or eliminating the cost of managing a hazardous waste, but also at obtaining a new valuable by-product that can be generated economic benefits. On the other hand, the decontamination systems allow the recovery of the sulphur (S) content which is highly valued in agriculture as an essential nutrient for plant development. It is obvious that in fertilisers where sulphur is present in the form of sulphate, it is easily absorbed by the plant and it has a rapid effect, but unfortunately sulphate is very soluble and therefore leaches out very easily, limiting the time that it remains bioavailable to the plant (Rodriguez et al., 2006). In this sense, S-VALOR project proposes to study a new raw material with a high sulphur content and in an unusual state, such as pellets, which could favour the persistence of sulphur in the soil and thus improve its availability. Also, S-VALOR is in line with the objectives of the SDGs, so the development of a desulphurisation process will make biogas available to society, and the development of sulphur formulations will improve the soil by mitigating the effects of synthetic compounds, improving nutrient retention, and reducing leaching.

## Methodology

A decontamination system based on iron oxide beds will be developed. For the valorisation of the by-product obtained, the composition and the possible applications and formulations for its use as an input will be studied. For that purpose, a fully characterise analysis of the by-product will be carried out: water holding capacity, nitrate and ammonium content, nitrogen content and macro and micronutrient profile. Finally, the validation of the new formulation will be carried out in field trial conditions.

## Results and discussion

S-VALOR is currently in the development phase of a demonstration-scale pilot plant with a decontamination system based on iron oxide beds. According to the initial physicochemical characterisation of the by-product generated by other adsorption treatments, the water holding capacity was 297.31%, indicating that it is a hydro-absorbent waste with the capacity to absorb hundreds of times its own weight in water. The electrical conductivity was 2.78 mS $cm^{-1}$, indicating a very high salinity. On the other hand, the results for macro- and micro-nutrients show a high calcium content with a value of 108,073 mg $kg^{-1}$. The Fe content is also noteworthy, with a value of 81.959 mg $kg^{-1}$. On the other hand, micronutrients such as copper and nickel had a concentration of 14.04 and 34.86 mg $kg^{-1}$ respectively. The nitrate and ammonium content were 38.7 and 13.8 mg $kg^{-1}$ respectively. Based on these preliminary results, possible uses have been defined as soil structure improver, chemical improver for pH reduction and exchangeable sodium substitution, and as a crop substrate. Additionally, a field trial is currently being designed in a horticultural crop to determine the efficacy of the byproduct as a substrate compared to other conventional substrates such as perlite and coconut fibre.

## Conclusion

In conclusion, and in line with the SDGs, the S-VALOR project will directly benefit society. Firstly, because it develops technical innovations to increase the use of green energy. Second, because it will explore more environmentally friendly fertiliser alternatives. And third, because it will provide the end consumer with a more sustainable and healthier product.

## Acknowledgements

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## Biological approaches to increase plant phosphorus availability from meat and bone meal biochar and digestate solids biochar

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### Introduction

Biochars and ashes derived from P-rich wastes could be a used as sustainable P fertilizers improving P recycling, but their immediate P fertilizer value is low. An acidification pre-treatment with sulphuric acid can increase P availability from ashes and biochars (Sica et al., 2023). Using biological processes for acidification could be more sustainable than using inorganic acids. Lactic acid fermentation of a carbohydrate source together with biochar could decrease pH and solubilize P from biochars like with slurry or sewage sludge (Piveteau et al., 2017). Application of NH3 together with a nitrification inhibitor can decrease rhizosphere pH, which has been shown to increase P availability from sewage sludge ashes (Raymond et al., 2019). The goal of this experiment was to test lactic acid fermentation and rhizosphere acidification on plant P availability from biochars and compare it with sulphuric acid activated biochars.

### Methodology

For the fermentation, meat and bone meal biochar (MB-BC) and digestate solids biochar (DS-BC) were mixed with homogenized municipal food waste and pH was measured, after 11 days glucose was added to enhance fermentation, after 24 days the mixtures were dried and grinded. The sulphuric acid (SA) acidified biochars were prepared by applying sulphuric acid to the MB-BC and DS-BC and subsequent drying. The water-extractable P (WEP), as an indicator for P availability, and pH were measured for the biochars. The untreated biochars, sulphuric acid activated biochars, fermented biochars and biochars together with a nitrification inhibitor and ammonium N were applied in a pot experiment with maize using a sandy soil with low P and low pH (5.4). Soil solution pH and P concentration were sampled using rhizons. After 60 days shoot biomass and maize P uptake was analysed and mineral fertilizer equivalent (MFE) calculated.

### Results and discussion

The fermentation lowered pH of MB-BC and DS-BC to 4.3 and 3.9 respectively and WEP was around 30% total P (TP) for both. The SA acidified biochars had a lower pH (3.9 and 2.2) and higher WEP (39 and 28 % TP). Due to the lower P content of DS-BC, the fermented product had a low P (8.8 mg g-1) content and the use as P fertilizer is questionable. In the pot experiment, the untreated biochars had a threefold higher P uptake than the unfertilized control resulting in an unexpectedly high MFE (approx. 60%). The SA biochars had a MFE of almost 100%. Addition of nitrification inhibitor did not increase P uptake. Rhizon sampling showed a higher soil solution P concentration at the beginning of the experiment in the bio-acidified MB-C and also P uptake was slightly higher than with the untreated MB-BC. In case of the DS-BC, fermentation resulted in an increase in soil pH and decrease in P uptake and shoot biomass compared to the untreated biochar. Probably, the addition of carbon with the food waste and the increased pH lead to immobilization of P. The already high MFE of the untreated biochars, probably due to the low soil pH, might have masked the effect of the biological approaches.

### Conclusion

The fermentation approach is only feasible when the biochar has both a low buffer capacity and high P content, as the MB-BC. Potentially, the rhizosphere acidification and the fermented MB-BC could have an advantage over untreated biochars at a higher soil pH. In this experiment, the fertilizer value of the untreated biochars was already high implying that under certain conditions some biochars do not require a pre-treatment.

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## How soil biogeochemical gradients in the placement zone of acidified biomaterials affect wheat root growth and phosphorus (P) uptake

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### Introduction

Increasing prices of mineral P fertilizers enhances the need for an efficient recycling of P-rich biomaterials. Thus, acidification of biomaterials (Regueiro et al., 2020) or localized application have been suggested as alternative ways to increase the P-use efficiency of different biomaterials. However, so far, no studies have assessed the combined effect of acidification and localized application of biomaterials on root and plant growth. Therefore, the aim of this study was to assess how wheat's early growth and development were affected by the localized placement of acidified biomaterials and to couple this with important biochemical gradients in the fertilizer placement zone.

### Methodology

Wheat was grown in rhizoboxes for 35 days. All nutrients, except P, were provided by nutrient solutions. The following biomaterials were placed 5 cm below the seeds as P fertilizers (60 mg P/kg soil): meat and bone meal (MBM); acidified meat and bone meal (A-MBM); solid fraction from biogas digestate (BGF); acidified solid fraction from biogas digestate (A-BGF). A negative control (without P) and a positive control (triple superphosphate) were also used as treatments. After harvest shoots and roots dry matter, P uptake, and root architecture were analyzed. In another experimental setup, the same biomaterials were incubated (without plants) in rhizoboxes for 14 days. After incubation, diffusive gradient in thin gels (DGT) were deployed in the fertilizer-soil interface to assess P diffusion from the biomaterial to the soil. A parallel setup was equipped with planar optodes for 21 days to visualize pH changes in the placement zone and in the surrounding soil.

### Results and discussion

The placement of BGF created a 'hot-spot' for root proliferation. On the other hand, no root growth was observed in the placed A-BGF, in which the roots proliferated in the soil surrounding the placement zone. Although there was not a significant difference in shoot dry matter between BGF and A-BGF, A-BGF P uptake was significantly higher (4.56 > 2.69 mg of P per plant). Images from the DGT indicated that for the A-BGF high amounts of P were released to the soil as could be observed after 14 days, this is in agreement with Sica et al. (2023), who found that after 12 days, 77% of the total P of A-BGF is released from the biomaterial to the soil. The placement of MBM and A-MBM created an ammonium toxicity zone (2-3 cm) in the soil surrounding the placement zone, not allowing roots to have access to the biomaterial. The A-MBM had significantly higher shoot dry matter (1.37 > 0.90 g per plant) and P uptake (2.84 > 1.72 mg of P per plant). The DGT imaging indicated that for the MBM, low amounts of labile P were released to the soil, whereas for the A-MBM, the labile P diffused further than 2.5 cm. We speculate that the increase in the P diffusion due to the acidification allowed the plant to access higher amounts of P outside the ammonium toxicity zone.

### Conclusion

Placement of acidified BGF and MBM significantly increased plant P uptake and P diffusion in the soil, being a promising approach to improve P use efficiency from biomaterials.

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## Short and long-term phosphorous availability from recycling derived struvite, ash and dairy processing sludge fertilisers; results of a three-year field study

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### Introduction

Current European agricultural systems are highly reliant on mined mineral phosphorus (P) fertilisers, with the majority of this P resource imported from countries outside of the E.U. (Schoumans et al., 2015). European agricultural policies, such as the 'Farm to Fork Strategy', aim to reduce the overall consumption of fertilisers, while encouraging the uptake of recovered & recycled nutrients (EUROPA, 2020). An understanding of the mineral fertiliser replacement value of such recovered & recycled nutrients is critical in order to incorporate such products into a nutrient management plan for farmers. Within the present study, six recycling derived bio-based fertilisers were tested on grassland to assess both their respective agronomic performance and mineral phosphorus fertiliser replacement value (P-FRV), when compared against triple super phosphate (TSP) based P fertiliser.

### Methodology

Seven bio-based fertilisers were tested to determine their short and long-term P-FRV on a grassland site of sandy loam surface texture. The fertilisers tested were 1) struvite derived from potato wastewater processing (PWStruvite); 2) struvite derived from municipal wastewater processing (MWStruvite); 3) poultry litter ash (PLAsh); 4) sewage sludge ash (SSAsh); 5) aluminium precipitated dairy processing sludge (Al-DPS); 6) calcium precipitated dairy processing sludge (Ca-DPS), and, 7) a combination of cattle slurry and mineral P fertiliser to replicate farmer practices. In addition, the trial also consisted of five treatments of TSP based P fertiliser at rates of 15, 30, 40, 50 & 60kg P ha-1, along with a zero P control. The bio-based fertilisers were applied once at the beginning of the study in spring 2019 to deliver 40 kg P/ha. So too was the mineral fertiliser P reference applied once in 2019. All plots received both basal & subsequent dressings of nitrogen, potassium & sulphur chemical fertiliser to ensure these nutrients were not limiting for the first and subsequent 12 silage cuts over the three-year duration of the trial. Both the yield and P uptake of the treatments were evaluated.

### Results and discussion

While yields from the treatments were similar, marked differences in the pattern of P availability, as characterised by plant P uptake, were detected. For example, there were marked differences in P supply in the first harvest between fertilisers, with the mineral fertiliser, cattle slurry + mineral fertiliser, and, struvites supplying the most P to the plant. However, when examined over the first year, the Al-DPS treatment also matched the mineral fertiliser treatment, while over two years of harvests the Ca-DPS treatment preformed similarly to the mineral fertiliser in terms of P supply. Over three years of harvests, the cattle slurry + mineral fertiliser, along with both struvites, out-performed the mineral fertiliser in terms of P supply. In addition, over three years of harvests the PLAsh treatment preformed similarly to the mineral fertiliser in terms of plant P uptake. What is clear is that the duration of P-FRV studies affects the conclusions concerning P-FRV. Full results and analysis will be presented.

### Conclusion

A key finding of this work is that the duration of the trial has potential to impact the conclusions regarding P-FRV. Some products performed well over both the short-term and long-term (e.g. struvites). Whereas, other fertilisers show their strongest performance over either the short-term (e.g. mineral P fertiliser) or the long-term (e.g. Al-DPS), or, indeed, relatively poor availability over both the short-term and long-term (e.g. SSAsh).

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## Phosphorus Recovery from Biosolids: Challenges and Opportunities for Agricultural Use

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### Introduction

Phosphorus (P) is essential for life, food production and therefore food security (Cordell et al. 2008). Although the total P content for some agricultural soils in the UK is high, the availability of P can be low, limiting plant production (Johnson and Paulton, 2019). Food production systems currently rely on mining mineral P (i.e. rock P) however, this represents a limited, non-renewable resource. In 2013 it was estimated that 20.3 Mt of mineral P was added to agricultural soils globally (Chen and Graedel 2016). Consequently, alternative and sustainable sources of P are needed for agricultural use (Ott and Rechberger, 2012). Wastewater treatment by-products offer the possibility for P recovery, whilst decreasing the waste sent to landfill or incinerated (Cordell et al. 2022; Egle et al. 2016). Around 78% of the sewage sludge produced in the UK is currently applied to agricultural land, this equates to 3-4 million tonnes of biosolids over an area of ca. 150,000 ha-¹ annually (BAS, 2019). Concerns around land contamination from biosolid application due to the presence of microplastics, excess nutrients and persistent organic chemicals, however still remain (Torri et al. 2017). There is therefore an urgent need to increase the efficiency and acceptance of biosolids for agricultural use as a sustainable source of P (Brownlie et al. 2022).

### Methodology

This MSc project is exploring P availability from biosolids via a number of research activities. 1) P analysis of UK agricultural soils with and without a history of biosolid application are being analysed for total P and bioavailable P. Total and available P are being analysed using either acid digestion or acetic acid extracts with P analysis undertaken using the colorimetric molybdate blue method of Murphy and Riley (1962). 2) Analysis of total and available P and heavy metal content of biosolids and return liquor from four wastewater treatment plants in Wales. This is being undertaken to establish concentrations and variation of nutrients over time and between sites. 3) A field experiment comparing soil P availability and grass yield responses to applications of biosolids, green compost, food digestate, cattle slurry and a range of Triple Super Phosphate (TSP) rates to determine the P fertiliser replacement values 4) Smaller scale pot experiments and incubations using 33P labelled biosolids to assess the fate of biosolid-derived P following application to soil.

### Results and discussion

Data on bioavailable P from activity 1) has been collected and analysed. The extractable P for soil depth 0-10cm for all treatments ranged from 0.49 to 33.33 mg P kg-1. Results showed that available P increases when biosolids are applied in consecutive years and in some cases after one recent application. Increases in available P continue for several years after application on some of the farms, when compared to unamended fields. TXRF analysis of these soils for Fe, Al, As, Cu, Ni, Pb, and Zn is currently in progress and a field experiment on the influence of biosolids on P dynamics is currently being set up.

### Acknowledgements

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## Adaptation of maize-based food-feed-energy systems to limited phosphate resources

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### Introduction

Of all nutritional elements essential for plants, animals and humans, phosphorus (P) is one of the most limited resources worldwide, available approximately for the next 300 years. Large amounts of P are currently released into the environment in a non-reversible diffuse distribution, causing severe eutrophication of water bodies. Germany is characterized by a strong misdistribution of P resulting in high surpluses in areas with high livestock and biogas plant densities, and fertilizer deficits in other intensive cropping regions. Large amounts of P contained in sewage sludge and kitchen waste are not reused for primary production but dumped. The recycling potential for P in Germany, including organic fertilizers, P in sewage sludge and other waste materials, is huge. In an estimate of changes in P use and losses in the food chain of China from 1950 to 2010, more than 50% of excreted P was lost to the environment. The greatest losses were due to the direct discharge of manure into water bodies or landfills. The current fate of P can therefore be considered as an open cycle where P is supplied by mining, and fertilizer and food/feed additive production followed by different steps of P utilization including crop production, animal feed, human food, and conversion of biomass to energy and raw materials, with severe losses in each compartment. The aim of this approach is to achieve a future scenario with maximized phosphate-use-efficiency and minimized losses.

### Methodology

The interdisciplinary and complementary research is driven by the hypothesis that under phosphate limited conditions, high productivity and high phosphate use efficiency can be achieved simultaneously by adapting phosphate cycling and availability (sources) to the multipurpose phosphate demands (sinks) in maize-based food-feed-energy systems (Müller and Zhang, 2019). Thirteen complementary research groups (RS) at the China Agricultural University (CAU) and the University of Hohenheim investigate (1) the genetic potential of maize populations and mechanisms of their ability to adapt to limited phosphate supply, (2) maize cultivation under limited phosphate supply at field scale, (3) mechanistic interactions of related products with their utilization in human and animal nutrition, and phosphate recovery by biomass conversion. (4) An economic evaluation is done at plot, farm, region and sector levels, including market effects. Joint central field experiments in China and Germany allow for complementary and comparative analyses.

### Results and discussion

Metadata about experiments conducted by the single RSs are brought together in a joint metadata database. The database is the point of departure for identification, request, provision, and exchange of original data by project partners, and in particular as input for the modelling of P flows in different modifications of the investigated systems and at different scales using the NUFER-farm (Zhao et al., 2017) and the FarmDESIGN (Groot et al., 2010) models.

### Conclusion

In the Sino-German International Research Training Group (IRTG) AMAIZE-P, twelve doctoral researchers and a post-doc on the German and Chinese sides, respectively, plus several external ones form each three-year cohort. In total, three cohorts will pass through this nine-year programme. This poster gives a general introduction to the IRTG AMAIZE-P.

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## Application of pig slurry as a phosphorus fertiliser at different application rates: impact on soil nutrient dynamics and GHG emissions

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### Introduction

Typically, animal manure is applied based on its nitrogen (N) content to meet crop demands, but this can lead to excessive phosphorus (P) application and consequently soil P accumulation or P losses through runoff or leaching. Application of animal manure based on its P content, especially considering the intravariability of soil P status, can help mitigate this issue. Our study applied pig slurry to different soils at varying rates and was focused on studying the impacts on soil nutrient dynamics and greenhouse gas (GHG) emissions. It was also included a comparison between PgS and superphosphate (SPP), a mineral P fertiliser.

### Methodology

Two separate aerobic incubations were conducted to study soil nutrient dynamics (using PVC containers) and GHG emissions (using Kilner jars) following the application of PgS or SPP. Three distinct soil P levels were studied: very low (VL, 8 mg P kg-1), low (L, 12 mg P kg-1), and medium (M, 31 mg P kg-1). Each soil had four fertilization treatments: a control (CTRL, no P), plus three rates of PgS or SPP applications tailored to the soils: 174 kg P ha-1 (R3), 131 kg P ha-1 (R2), and 87 kg P ha-1 (R1), respectively (four replicates each). The GHG emissions study only used R2 to investigate underapplication (VL soil), optimal application (L soil), and overapplication (M soil) effects of the P fertilizers. Soil samples from the PVC containers and air samples from the Kilner jars were collected regularly for analysis, measuring soil nutrients and CO2, N2O, and CH4 gas concentrations.

### Results and discussion

Soil P dynamics in PgS and in the SPP treatments were very similar. Soil P throughout the experiment showed a positive correlation with added P, specifically with PgS as the P source. Unlike SPP, PgS effectively raised soil P levels to the target range (22 – 44 mg P kg-1) in all three soils, whereas SPP achieved this only in L and M soils. In the initial two weeks, most of the NH4+-N from the slurry was nitrified, with higher PgS rates correlating with increased soil N content and nitrification rates. GHG emissions showed highest CO2 and N2O emissions in the very low-P soil (VL). In M soil, PgS increased CO2 and N2O emissions, possibly by addressing soil C limitations. In VL soil, PgS and SPP yielded similar cumulative emissions, but SPP showed higher CO2 and N2O emissions initially, suggesting that SPP was better at alleviating short-term P-limitation. Also in the L soil, SPP led to higher CO2 and N2O emissions. CO2 and N2O emissions were positively correlated, while CH4 emissions were negligible in this experiment.

### Conclusion

Using PgS as a soil fertilizer yielded similar outcomes to SPP, but with better results in the very low P soil (VL). PgS application also increased soil N, showcasing its advantage over mineral fertilizers as it provides a broader range of nutrients. We also found that the application rates (based on national recommendations) could be lowered without impacting soil P levels. It was concluded that soil type and characteristics, along with the interaction with fertiliser type, held a greater influence on GHG emissions and that excessive application of PgS or SPP (in M soil) did not increased GHG emissions compared to optimal (in the L soil) and suboptimal fertilizer application (in the VL soil).

### Acknowledgements

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## The role of phosphorus-solubilising bacteria in improving the quality of compost from plant waste

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### Introduction

The continued use of chemical fertilisers has resulted in large areas of cultivated soil being deficient in nitrogen, phosphorus and potassium, because they are naturally present in insoluble or complex forms and are not available to plants. Therefore, the development of new biofertiliser products allows us to move from conventional mineral nutrition to biological nutrition through the application of products based on microorganisms, which improve plant nutrition through mechanisms such as nitrogen fixation, potassium and phosphate solubilisation (Arif et al., 2020). In this regard, a practical solution could be the use of compost as an alternative to chemical fertilisers. This organic amendment is composed of a large amount of nutrients and its bioaugmentation with phosphate and potassium mobilising agents could improve the quality of the final product from an agronomic point of view. Among the microorganisms suitable for inoculation in the composted material, we were interested in those with enzymatic activities aimed at enhancing the transfer of phosphorus to plants, due to their importance for energy storage and transfer systems, for the synthesis of nucleic acids and phospholipids, and indispensable during the photosynthesis process. Therefore, the objective of the present work was to evaluate the effect of bioaugmentation with phosphorus solubilizing microorganisms in pre-mature compost, as a strategy to improve the agronomic qualities of compost and to enrich soils poor in bioavailable phosphorus.

### Methodology

Two semi-pilot scale composting processes were started from a mixture composed of vegetable and pruning residues. The following physical-chemical parameters were determined as process monitoring parameters: temperature, organic matter, ashes, humidity, C/N ratio, electrical conductivity, pH, total phosphorus and soluble phosphorus, humic and fulvic acids. After the biooxidative phase, one of the two composting piles was inoculated with a microbial consortium formed by the strains, Bacillus licheniformis 1374 and Bacillus aerophilus 2310, belonging to the BIO-175 group of the University of Almería, to obtain a final concentration of 107 CFU g-1 in the pile. After inoculation, from the cooling phase in both composting piles (inoculated and non-inoculated), the presence of mesophilic aerobic bacteria, phosphate-solubilizing microorganisms, and siderophore-producing microorganisms was quantified by counting plated in specific culture media (Pikovskaya, 1948; Schwyn and Neilands, 1986). In parallel, the phytostimulant capacity of the pre-mature and final product was evaluated by assays germination in cress seeds.

### Results and discussion

With regard to the physical-chemical parameters, both piles evolved adequately. The results derived from the phosphorus analysis revealed the influence of the inoculation of the composting piles on the dynamics of the phosphorus fractions in the maturation and final product phases. It should be noted that the load of Bacillus spp. added to the inoculated pile caused the phosphate solubiliser counts to remain stable throughout the process, unlike what happened in the non-inoculated pile, where a progressive decrease of this group was observed as the process progressed. Regarding the germination indices, the samples from the inoculated pile were free of phytotoxicity.

### Conclusion

Therefore, the application of phosphate solubilizing microbial consortia in the cooling and maturation phase of a composting process could provide added value to the final product thanks to the mobilization of phosphorus fractions that are more readily available to plants, as well as other bioactive substances involved in plant development.

### Acknowledgements

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## Characterization of alternate P-sources and evaluation of their potential application

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### Introduction

Dairy industries generate vast volumes of wastewater, and the resulting dairy processing sludge (DPS) is spread on agricultural lands in the EU. However, as DPS composition varies significantly among dairy industries, there are difficulties (transport costs, nutrient oversupply) associated with its land application. Meat and Bone Meal (MBM) of Category 1 is currently banned in feed applications in the EU and is disposed by incineration/ landfill. Due to the challenges associated with their land application and disposal, alternative means of reutilizing these P-rich sources are necessary. Ashes generated from the fluidized bed incineration of dairy processing sludge (DPS) and MBM contain high concentration of phosphorus (13-17% P) and low concentration of heavy metals (HM). This study investigates and compares the properties of the 2 ashes with a phosphate rock for their effective management and utilization. The process routes to convert these ashes into STRUBIAS fertilizer products will also be discussed.

### Methodology

Meat and Bone Meal ash (MBMA) was obtained from fluidized bed incineration at a temperature of 850oC for 2 seconds in an industrial scale process whereas dairy ash (DA) was obtained from fluidized bed incineration on laboratory scale at different temperatures and flow rates. MBMA particle size reduction was achieved in a rod mill and DA particle size was reduced using a motor and pestle apparatus.

The particle size distribution was determined in a vibratory sieve shaker. To assess their properties, several characterization techniques viz., XRD, SEM, SEM-EDX, XPS and ICP-OES were used.

### Results and discussion

The reduction in particle size of MBMA causes bone particles to stick together that do not flow well. XRD identified the presence of the main crystalline phases viz., hydroxyapatite and whitlockite in MBMA and DA. MBMA and DA had a minor element ratio (MER) of 0.042 and 0.99 with HM concentrations lower than the required EU limits. SEM-EDX and XRD results confirmed that P is mainly bound to Al- and Ca-phosphates in DA and Ca-phosphates in MBMA. XPS results showed that P in DA and MBMA exists mainly in the form of PO4 and other P-O compounds, and it was found that P is less oxidized in MBMA than in DA.

### Conclusion

The low MER, organics, and HMs in MBMA makes it an attractive option for phosphoric acid (PA) production using a conventional Dihydrate (DH) route. DA, due to their low CaO/P2O5 ratio and high MER majorly because of the use of Al/Fe salts for P precipitation during wastewater treatment, cannot be directly used in a conventional process for PA production and require upgradation. GetmoreP process developed by Prayon is one such route where DA can be upgraded and converted to obtain Dicalcium Phosphate (DCP) as the main product.

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## Evaluating efficacy and storage of carbon capture based organo-mineral fertilisers to improve soil health and grain quality

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### Introduction

As global agriculture pushes towards carbon neutrality, a change in the production methods of mineral fertilisers to reduce their greenhouse gas (GHG) emissions or carbon neutral alternatives will be a necessity. The increasing price of nitrogen has also driven the need for alternatives to mineral fertilisers. The carbon capture based organo-mineral fertilisers (OMF), fertilisers composing of both mineral and organic components, produced by CCm, are developed by capturing carbon dioxide ($CO^2$) from the source and integrated with organic waste products to produce a dry pelletised OMF (Lake et al. 2019). By locking atmospheric carbon dioxide into the fertiliser, there is the potential to sequester carbon stocks within agricultural soils. The reduction in soil carbon and organic matter could be partly helped with the use of OMF's, utilising both the quick release aspects of mineral fertilisers and the soil health benefits of organic fertilisers. The aim of this work is to identify whether OMF's produced from waste products could become a viable or even better replacement for mineral fertilisers in both producing high yields and improving soil quality.

### Methodology

Two trials were setup in 2020 across two separate fields, one with winter oilseed rape and the other with spring barley in the second season, in the first season the fields were drilled with winter wheat and winter barley. The soil types of the fields are silty clay and silty clay loam. The efficacy of CCm OMF's was tested against no nitrogen controls and chemical fertilisers, to assess impacts on yield, grain N in spring barley and oil content in oilseed rape. The trials include three OMF formulations at 5%, 10% and 15% nitrogen content, a commercial fertiliser regime using chemical fertilisers and a no nitrogen control group. All treatments also included 4 dose rates at 50%, 100%, 150% and 200% recommended nitrogen input. 80 plots of 6m x 2m on each site arranged in a randomised complete block were used. Fertilisers were applied in spring, post drilling of both crops. Both trials were harvested, and the yields calculated. Grain samples were taken from both sites for all plots and analysed for grain N and oil content dependent on the crop.

### Results and discussion

The 10%N CCm OMF performed the best at the recommended dose rate applied to spring barley producing yields at 4.65T ha-$^1$ compared to 3.48T ha-$^1$ produced by the chemical treatment. 15%N CCm OMF produced the highest yield of oilseed rape at recommended dose rate at 3.39T ha-$^1$, compared to the 2.38T ha-1 produced by the chemical treatment. At the recommended nitrogen rate, 10%N and 15%N CCm OMF produced significantly higher spring barley grain N%, at 1.61% and 1.59% respectively, than the no nitrogen control at 1.38%, and comparable grain N% than the chemical fertiliser, at 1.64%. The results showed that CCm's OMF's can produce yields and grain nitrogen values which are significantly higher than no nitrogen controls and comparable yields to commercial chemical fertiliser alternatives, in spring barley. The OMF's also produced comparable oil yields, in oilseed rape, when compared to commercial chemical fertilisers.

### Conclusion

The results produced indicate that OMF's perform as well as chemical products and could become a reliable alternative in the future. Further study into the bioavailability and environmental fate of the nutrients released by the carbon capture based OMF will add more insight into their future usage.

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## Nutrient composition and fibre contents of slurry from different feeding systems in NW Spain

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### Introduction

Nutrient composition of slurry depends on the animal species, feeding practices and the animal production system (including housing and manure management). On farms, appropriate recycling of nutrients by using slurry as fertilizer is important in order to reduce an extra mineral fertilizer input and prevent surplus that pollute the environment. In Galicia (NW Spain), the main dairy producing region in Spain, there is a lack of information about the influence of representative feeding systems on nutrient composition and organic matter of slurries, and the aim of this study is to explore those differences.

### Methodology

Nineteen dairy commercial farms were selected to represent the different feeding systems in the region according to the main type of fodder supplied: pasture grass (PS, n=5), grass silage (GS, n=4), grass and corn silage (GCS, n=5) and corn silage (CS, n=5) (Botana et al., 2019). Between April 2018 and April 2019, every season, samples of slurry from pits (which store slurry from lactating cows) were collected. Samples of slurry were classified according to feeding systems: 21 samples from PS, 10 from GS, 24 from GCS and 16 from CS and analysed to determine dry matter (DM), organic matter (OM), carbon (C), pH, total soluble salts measured as electric conductivity (EC), total nitrogen (N), total ammonia N, organic N and macronutrients (P, K, Ca, Mg). Neutral and acid detergent fibre of organic matter (NDF and ADF), acid digested lignin (ACL), hemicellulose, cellulose and ash were also analysed.

### Results and discussion

The lowest values for DM and EC were found in the PS system. The highest values of pH, MO, C, P and K were found in the PS and GCS systems. With respect to N contents, the highest values of total N and ammoniacal N were found in the GCS system. Although there were no differences in total N and organic N between GCS and PS, there were differences in ammoniacal N, which was higher in GCS than in PS. This means that the highest ammonia N/total N ratio was found in the GCS system and the lowest in the PS system. This ratio is decisive in the processes of N transformation, losses due to NH3 volatilisation and N assimilation by the crops once the slurry is applied in the field.

Slurry from PS and GCS feeding systems have higher organic N contents than slurry from GS and CS systems. This may be related to diets with high levels of NDF and ADF, especially in the PS system (Santiago et al., 2022). The highest values of ADF contents of slurry were found in PS and GCS systems. It seems that the FAD in GCS contains higher cellulose content, whereas there were not significant differences between systems fed with grass (PS, GS and GCS) in the lignin contents. Higher ash contents in GS and CS were especially related to the presence of silica from the sand used in the bedding, and higher Ca and Mg contents in GCS were due to substances applied in the animal bedding.

### Conclusion

Slurry from typical feeding systems in the region have different nutrient value, different ammonia N/total N and type of fibre which could be decisive in the processes of N transformation and C fixation in the soil once the slurry is applied in the field. C. Santiago was the recipient of an INIA Predoctoral Fellowship.

### Acknowledgements

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## Paper mill biosolids as soil amendments and plant nutrient sources in Eastern Canada

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### Introduction

Paper mill biosolids (PMBs) pose both significant challenges and interesting opportunities. Used efficiency as soil amendment, these residues can decrease the need for synthetic fertilizers and thus reduce production costs and negative environmental impacts. . Indeed, 420 x 103 Mg of PMBs from treated effluents and liming by-products such as wood ash and lime mud are generated annually from the forest industry in Canada. The objectives of our study were to assess the effect of continuous (9 yr: 2000-2008) and residual applications (13 yr: 2009-2021) of PMBs on crop yields and soil fertility.

### Methodology

A field study was initiated in 2000 in eastern Canada (Quebec) in a Chaloupe loamy soil. During the first nine years, treatments including different PMBs rates were manually applied to the same plots at sidedress, about four to five weeks after crop seeding. Since 2009, no PMBs were applied. For all these years, dry matter yields were estimated and plants were analysed for different parameters. Soils were sampled after harvest and characterized for mineral and heavy metals contents.

### Results and discussion

Crop yields were significantly increased by the applications of fresh PMBs at 90 Mg wet ha$^{-1}$ relative to the unamended control. The PMBs addition increased soil organic matter and metal concentrations during the years of repeated applications. However, the plant metal concentrations remained below critical threshold values indicating the low risk of the potential of metal contamination using such by-produces. Positive effects of PMBs on crop yields were detected 3-5 years after their cessation. Previous PMBs addition also continued to improve soil organic matter but the effect was declining to stabilize at 15% of total added organic carbon after six residual years. Meanwhile, addition of lime mud raised soil pH to the level obtained by calcitic lime, and this effect lasted over the period of application even though a constant decrease was observed in residual years.

We concluded that PMBs can be successfully applied to agricultural soils over many years when their rate does not exceed 60 Mg wet ha$^{-1}$ yr$^{-1}$. Repeated PMBs application improved soil fertility and this improvement can be sustained for years after cessation.

## Field study of pelletised compost-based biofertiliser distribution with a pendulum spreader

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### Introduction

The proper handling and application of agricultural fertilisers is very important to increase crop yield, reduce costs and minimise environmental pollution (Aphale et al., 2003). The solid fertiliser spreading machines must be calibrated according to the type of fertilizer. Pellets can be an alternative for the application of compost, and can be applied with conventional machinery (Ferrari et al., 2022). The performance of pendulum spreaders has been widely investigated, however there are few information about the distribution of novel biofertilizers compost-based. The aim of this study is to validate the use of conventional fertilizers spreaders to the distribution of the developed pellets.

### Methodology

The trial was carried out in a field plot in UPC-Agropolis (Viladecans, Spain) using a pendulum fertilizer spreader (Vicon, Kverneland group, Denmark). Three different fertilizers were used: two pelletised compost-based biofertiliser (6 mm caliber): organic pellet (P1) and organic-mineral pellet (P2); and urea (U) granular fertilizer as reference. The application was performed in triplicate, at 6 km $h^{-1}$ speed each. Previous to application the spreader was calibrated to 300 kg $ha^{-1}$ for U and to 600 kg $ha^{-1}$ for P1 and P2, corresponding to the same dose of nitrogen per hectare. The distributed fertilizers were collected in boxes (0.25 m2) placed along the distribution width with 1 m separation (10 m) in both sides and a central box (UNE-EN 13739-2:2012). The fertilizer on each box was weighed to analyse the uniformity of the distribution. The coefficient of variation was calculated by overlapping the transverse distribution curve pattern at a certain working width; the mean and standard deviation of the overlapped application rate (Lawrence et al, 2006). A one-way analysis of variance (ANOVA) and the least significant difference (LSD) test at $P<0.05$ were used to assess the significance of differences among the treatments.

### Results and discussion

On the comparison of the distribution curve obtained with different fertilizers, no statistical differences were identified ($p>0,05$; F anova 1.37), showing similar triangular patterns of distribution. On the other hand, the analysis of the uniformity of the distribution, indicates as well, no differences among fertilizer type ($p>0,05$; F anova 1.52) expressed as uniformity of the overlapped curves.

### Conclusion

The distribution of the pellet presents similar trends to urea (as a reference) on transverse profile and homogeneity of the distribution. These results lead to promote this promising fertilizer proposed in this research as an alternative to reduce the amount of synthetic fertilizer used, accomplishing from farm to fork strategy goals.

### Acknowledgements

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## Producing tailored organomineral fertilizer pellets from composted slaughterhouse wastes

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### Introduction

Utilization of nutrient rich biomasses and organic fertilizers have great potential in increasing security of supply and self-sufficiency of nutrients as well as mitigation of greenhouse gas emissions of agriculture. However, these alternative nutrient sources have faced difficulties to compete with the usability of mineral fertilizers. In this study organo-mineral fertilizer pellet was developed to produce a predominantly recycling based fertilizer product that meets the high nutrient content and physical attributes of mineral fertilizer granules.

### Methodology

Pelletizing experiments were carried out utilizing a thermophilic compost, which composed of a mixture of slaughterhouse waste fractions and other organic components (Biopallo Systems Oy, Kuopio, Finland). To boost the nutrient, especially nitrogen content, of the compost, mineral additives, crystallized ammonium sulphate ($(NH4)^2SO4$) and urea ($CH4N^2O$), were blended to produce desired pellet mixtures. Ammonium sulphate was a side-product from industrial process, while urea originated from mineral fertilizer production. The goal was to reach similar nitrogen content with mineral fertilizers (20%) using at least 50% of compost in the mixture. Pellets were produced with Amandus Kahl 14-175 Laboratory Press, which operates with 175 mm flat dies with 3 kW min-1 power. Four different dies were used with 4 mm diameter holes and compression ratios between 4:1 and 8:1. Low compression ratio was prioritised; higher compression ratios were used in trial runs that failed to form hard pellets lower compression ratios. In total 53 trial runs were carried out; 20 runs to study the composts pelletization abilities; 21 trials to determine the effects of adding mineral additives to the pellet mixture and 12 trials to fine-tune the proportions of mineral additives. Target size of pellet was set to 2–6 mm from which the fines content was sieved with 2 mm test sieve and the oversized with 6.3 mm test sieve. Size guide number (SGN) was determined graphically from the particle size distribution data gathered with 6.3 mm, 4 mm and 2 mm sieves. For other physical qualities pellet hardness was analysed with Amandus Kahl Hercules M pellet tester and bulk density was measured according to ISO 17828. For the nutrient content total and soluble nitrogen were analysed using Kjeldahl method. Total phosphorus, potassium and sulphur were analysed after wet digestion with ICP-OES (Inductively Coupled Plasma Optical Emission Spectrometry).

### Results and discussion

Pelletization of the thermophilic compost in question was successful with or without mineral additives. Both ammonium sulphate and urea notably increased the nitrogen content of the pellet but lowered pellet's physical quality when added in larger amounts. In case of ammonium sulphate the issue was significantly increasing pellet strength which ultimately led to clogging of the pellet matrixes and increasing fines content. With urea, larger amounts increased moisture content of pellet and weakened the pellet strength. Combining additions of ammonium sulphate and urea resulted to most favourable nutrient content and physical quality. The most suitable recipe to be utilized with 4:1 compression ratio was 50% compost, 30% urea and 20% ammonium sulphate (by weight). This recipe produced pellets with 18.8% of total nitrogen, 18.7% of soluble nitrogen, 2.4% of phosphorus, 0.2% potassium and 4.8% of sulphur. Physical attributes of the pellet were moisture content 9.7 ± 1.0%, fines content 9.3± 0.1%, oversized content 0.6 ± 0.2 %, SGN 380, bulk density 600 ± 7 kg m-3 and hardness 12.8 ± 2.1 kg.

Physically the produced pellet compared well with mineral products not only by size (SGN 380) but also from endurance perspective. Its hardness exceeds 10 kg, what indicates a good durability in transport and spreading and its bulk density is high enough, that even spreading outcome can be expected. From production point of view producing this pellet can be considered efficient as only low compression ratio is needed and fines content stays under 10%.

### Conclusion

This study demonstrated that adding mineral components to organic biomass pelletization has great potential in production of an organomineral fertilizer that has similar usability as mineral fertilizers considering both nutrient value and physical quality. The pellet had high nitrogen content (18.8%), which originated almost completely from mineral sources, while one fourth was from ammonium sulphate, which was considered as a by-product increasing circularity. On the other hand, the phosphorus content of the pellet (2.4%) originated completely from bio-based origins. Overall, the tailoring of bio-based compost material with mineral fertilizers, could increase the use and attractiveness of bio-based fertilizer products and support in the transition towards bio-based and circular economy and fertilizer markets.

## Crop yield and quality improvement by using natural resources

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### Introduction

Sustainable agriculture development aims to improve crop quality and productivity (Helepciuc and Todor, 2022). To achieve this, it is very important to use plant protection and fertilizers properly (Römer et al., 2019). However, as climate change increases, it is encouraged to reduce the use of synthetic pesticides and fertilizers. Efforts are being made to do this according to the "Green Deal" strategy announced by the European Commission. Which includes a commitment to reduce the use of synthetic fertilizers and pesticides. To achieve these goals, we are looking for ways to replace synthetic fertilizers and pesticides. It is proposed to look for alternatives, such as replacing synthetic pesticides with biological pesticides. One option is to use allelopathic plants that contain allelochemicals. Plants enriched with these substances can suppress the growth of weeds, and increase resistance to diseases or pests (Arias-Estévez et al., 2008). To reduce the use of synthetic fertilizers, it is possible to change to organic fertilizers. Organic fertilisers effect on productivity is slow, so a combination of synthetic and organic fertilizers is recommended (Pincus et al., 2016).

The study aims to assess the potential of natural resources for crop yield and quality.

### Methodology

Field experiment were performed at the Institute of Agriculture (55° 23'50" N, 23 ° 51'40" E), Lithuanian Research Centre for Agriculture and Forestry in 2021. Two different factors were included – fertilizer and plant protection. Mineral fertilizer - ammonium nitrate and organic fertilizer – pig manure digestate were prepared for fertilizing of winter wheat. To find an alternative to synthetic pesticides was chosen of allelopathic plants-Artemisia dubia Wall biomass mulch and strips planted like intercrop. After using all these measures, were evaluated winter wheat productivity and quality (weight of 1000 grains proteins, glute, etc.).

### Results and discussion

Data from the field experiment of the first year showed that the highest grain yield of winter wheat was obtained using pig manure digestate and synthetic pesticides. However, it was only 3.62 % higher yield than used synthetic fertilizers and pesticides. The weight of 1000 grains stood out the most when determining the quality parameters of the harvest. After using Artemisia dubia Wall biomass mulch with different fertilizers, the weight of 1000 grains varied from 45.6 to 47.3 grams. And the smallest weight when growing Artemisia dubia Wall strips – 42.0 g. The amount of protein and gluten differed the most when using fertilizers compared to other treatments.

### Conclusion

Comparing the data obtained from the first year, it can be said that there is an opportunity to reduce the use of synthetic fertilizers and pesticides. This can be achieved by the use of synthetic and organic compositions and the inclusion of natural resources for plant protection. Because of this, to make sure these tools work, a repetition of the field experiment for another year is necessary.

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**Humic-like substances extraction from digestates: towards an agronomical biostimulation evaluation**

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## Introduction

Digestate management is a key concern and it still a challenge for the full-development of Anaerobic Digestion (AD). Digestate landspreading is a typical option but, in some cases, it is not always possible from regulatory and transport (cost)-point of view. Moreover, a non-optimized digestate management can provoke environmental problems such as nutrient leaching and greenhouse gases emission (Nkoa, 2014). In recent years, some products have been developed to improve soil and plant development as the biostimulants. They lead to have positive effects on plant growth, germination rate, shoot and root growth, root architecture, among others parameters (Guilayn et al., 2020). These products include humic-like substances (HLS) extracted from natural fossil sources or organic residues. The biostimulation potential of HLS has been demonstrated using hydroponic systems and the application of HSL from both fossil sources and organic material. However, few studies have reported results on digestate-extracted HLS use in biostimulation tests (Fascella et al., 2018; Massa et al., 2018). Recently, Guilayn et al., (2020) filled the gap by using HLS extracted from two digestates for the lettuce biostimulation grown in hydroponic condition. Authors showed that the biostimulation potential of these products was similar than a commercial reference. However, results obtained cannot be dissociated to the nutrient amount provided by the different extracts. In addition, no comparison was done between non-extracted HSL and extracted HSL digestates. Moreover, the feedstock nature influences the digestate composition quality (both organic matter and nutrients) (Guilayn et al., 2019; Fernández-Domínguez et al., 2021). In this context, the objectives of this study are to (i) evaluate and validate the biostimulant potential of the different HLS digestates extracts by using pot plant trials (wheat and lettuce culture), (ii) dissociate the effects observed between biostimulation and nutrient content provided by HLS extracts and (iii) evaluate the impact of feedstock type on HLS extracts characterization and biostimulation potential.

## Methodology

Three digestates were used for HLS extraction: biowaste feedstock (BioW), organic fraction of municipal waste (OFMSW) and centralised co-digestion (Terr). HLS extraction was performed through alkaline extraction described by Guilayn et al., (2020) using dry pellets of potassium hydroxide at pH 12 for 24h at room temperature. A phase separation was applied on the treated and non-treated digestates with a Russel Finex 22" industrial sieve (250µm mesh). Dry matter, volatile solids, nitrogen and ammonia and dissolved organic carbon were also measured on total and extracts from treated and not treated digestates according to Guilayn et al., (2020). Furthermore, 3D fluorescence spectra were obtained with a Perkin Elmer LS55 after 0.45µm filtration and dilution to evaluate organic matter quality and HSL quantity indicator. Randomised biostimulation assays were carried out using plant pot trial with a growth medium consisting of sand, clay and peat (water pH of 7.4 and 4.5% organic matter content). As crop models, wheat and lettuce were cultivated using two applications of biostimulant products. Treated and untreated digestates were tested at two or three doses. Mineral fertilization was carried out in parallel taking into account the nutrient inputs generated by the products. The addition of mineral controls and a commercial reference (Humifirst) brought the trials to 27 modalities for each crop. Crop performance parameters were monitored including aerial and roots dried weight, phytotoxicity assessments, crop height, relative vigor, normalized difference vegetation index and chlorophyll index.

## Results and discussion

The HLS extraction step provided different degrees of particulate organic matter solubilisation (from 5% to 22%). This value depended on the type of digestate. In addition, the HSL quantity evaluated by 3D fluorescence spectra indicators showed a significant increase of HLS in the final extract in comparison to the untreated digestate (from 2.42 to 3.03 times higher). Agronomical tests are ongoing and will be finalized by July 2023. Results will be statistically compared considering the monitored plant parameters and the biostimulation potential.

## Conclusion

The results from the ongoing research will address the following items: (i) validate the biostimulant potential of the different digestates (independently of their nutritional content), (ii) evaluate the impact of the HLS extraction on biostimulation potential and (iii) evaluate the correlation between organic matter-associated characterization with the digestate type (i.e. feedstock), with the biostimulation potential.

## Acknowledgements

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## The influence of biochar and manure-derived composts on soil properties and plant biomass growth

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### Introduction

In Poland, poultry manure is used mainly in an unprocessed form, directly spread on agricultural fields as a rich nitrogen source. Processing methods allowing poultry manure conversion to value-added products with high fertilizing potential can include composting and pyrolysis. These methods will enable the conversion of raw poultry manure into stable materials which can be easily stored, transported, mixed with soil, and distributed in the agricultural fields. With the introduction of new legislation on fertilizing products (i.e., Fertilizing Product Directive from July 16, 2022) it is expected that the interest in such resources as poultry manure to be used as substrates to obtain e.g., soil organic enhancers will increase. Poultry manure-based soil enhancers could after fulfilling the conformity assessment become available on the EU market [FPD, 2022]. This opens more possibilities for the countries with high poultry production, and thus significant quantities of poultry manure to be managed. The overall goal of this work was to investigate the potential of poultry manure as a source to produce organic soil enhancers such as poultry manure-derived biochar and poultry manure-derived compost and to determine their physicochemical properties and effects on soil properties and growth of cherry tomatoes.

### Methodology

The research work carried out on a laboratory scale was to show the fertilizing potential of the produced poultry manure products, i.e., compost and biochar. The scope of work included (a) Performing physical and chemical analysis using fresh poultry manure from cage farming; (b) Preparation of compost mixture from fresh poultry manure and wheat straw; (c) Composting under laboratory conditions; (d) Pyrolysis of poultry manure under laboratory conditions; (d) Analysis of the physicochemical characteristics of manufactured products (compare the biochars obtained from pyrolysis temperatures 475, 575, 675, 775°C and compost from poultry manure); (e) Selection of biochar with the highest fertilizer potential; (f) Preparation of soil mixtures using compost and biochar from poultry manure; (g) Preparation of a pot experiment and evaluation of plant growth using poultry manure products.

### Results and discussion

The composting temperature above 60°C enabled hygienization and reduced the growth of microorganisms, i.e., Salmonella and Escherichia coli. This research confirmed that the hygienization of the composts was performed properly and that temperatures above 60°C were sufficient for the reduction of pathogenic microorganisms [Czekała et al., 2016]. The biochar obtained from 475°C (compare to biochar from pyrolysis temperatures 575, 675, and 775°C) was characterized by the relatively high organic matter content of 39.47% and nitrogen content of 3.73%, while it had the lowest C/N ratio of 8.18. According to the recommendations of the European Biochar Certificate (EBC), biochar obtained at 475°C has the most beneficial parameters in terms of fertilizing potential [EBC, 2022].

### Conclusion

Poultry manure-derived biochars and composts are microbiologically safe, environmentally safe in terms of heavy metals, and with no significant emissions, especially of ammonia and carbon dioxide. The effect of soil additives, i.e. compost and biochar from poultry manure, had a beneficial effect on the growth of cherry tomatoes. Further research on the potential of poultry manure to produce soil enhancers should include an overall assessment of the environmental and economic impact of applying poultry manure-derived soil enhancers to close the C, N, and P cycle as well as the effects on different types of soils under various climatic conditions and selected plants.

### Acknowledgements

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**Bioremediation of drought through the application of organic fertilisers enriched with bacteria stimulating crop resistance to water scarcity – INNO-MIK project**

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## Introduction

More frequent and intense droughts in agriculture affect the crop yields, but also the biological life in the soil. Long-term drought causes significant yield losses for sensitive plants, and may also have a significant impact on the activity and structure of the microbial populations in the soil, affecting carbon and nutrient cycling processes. The Polish national INNO-MIK project is aimed at developing technology of biofertiliser production based on biodegradable waste and microorganisms, in order to support sustainable crop production, circular biowaste management and adaptation of agriculture to climate change. The technologies for producing three types of biofertilizers based on liquid digestate, compost and biochar and containing high level of phytohormones will be developed. Biofertilizers will be carriers of microorganisms supporting plant growth in drought conditions.

## Methodology

The project work plan consists with the following stages: (i) Selection of bacteria most effective in processes supporting plants in drought conditions will be selected. They are used to develop the optimal composition of a consortium of microorganisms supporting crops under precipitation deficiency; (ii) Production of biomaterials maximally rich in phytohormones using reactors faithfully reflecting the conditions of fermentation, composting and torrification on an industrial scale. These biofertilisers will serve as carriers of selected microorganisms; (iii) Development of digestate, compost and biochar inoculation technologies taking into account their physical form; (iv) Testing effectiveness of the developed innovative bio-fertilizers in supporting drought resistance of plants in greenhouse and plot experiments simulating real conditions.

## Results and discussion

So far, the following specific objectives of the project have been achieved: (i) assessment of the effectiveness of pre-selected bacteria in supporting plant development in drought conditions, together with the determination of plant support mechanisms, (ii) selection of the optimal inoculum composition to be used for inoculation of organic carriers. The project team conducted numerous laboratory tests of bacterial strains to qualify them to the PGPB (Plant Growth Promoting Bacteria) group. The ability of bacteria to biostimulate plant growth and resistance was assessed, among others, based on: the ability to synthesize phytohormones; the ability to produce siderophores; ability to solubilize phosphates and/or fix atmospheric nitrogen, produce ACC deaminase, biofilm and exopolysaccharides. The metabolic profile of selected strains potentially promoting plant growth was also determined, which was made on the basis of BIOLOG GEN III MicroPlates (assessing the ability to metabolize carbon sources and chemical sensitivity). For example, the analysis showed that the bacteria have a diverse ability to solubilize phosphates, which allowed the selection of strains for further tests.

## Conclusion

It seems that the use of phosphate solubilizing bacteria is an attractive method of increasing the effectiveness of drought bioremediation and more sustainable crop production, especially when combined with organic fertilisers. This is due to their potential to promote plant growth and resistance to abiotic stress and their ability to activate poorly soluble phosphorus. These bacteria very often also exhibit valuable mechanisms for promoting plant growth.

## Acknowledgements

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## Suitability of sugar kelp (Saccharina latissima) as organic fertiliser or soil amendment

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### Introduction

Aquacultural production of macroalgae in the world is on the rise (FAO, 2020). Sugar kelp (Saccharina latissima) or components extracted from kelp show potential, among others as ingredient for animal feeds. Any production involving kelp will also leave some residues that could potentially be used as a source of nutrients in agriculture. However, macroalgae and especially kelp may be high in iodine (I) and arsenic (As), as well as other potentially harmful elements. The main objective of this study is to obtain knowledge about the content and fate of iodine and arsenic from kelp or kelp residues that could be used in agricultural production.

### Methodology

A pot experiment was conducted to investigate the suitability of kelp and residues after chemical digestion of kelp for recycling of nutrients and/or as a soil amendment in agricultural production. The kelp treatments were compared to cattle slurry, mineral fertiliser, and a control without nutrients. Barley was grown until maturity in a loamy and a sandy soil. After harvest, biomass and grain yield, as well as grain and straw concentrations of nutrients, As, I and selected trace metals were determined.

### Results and discussion

Initially, plant development was delayed in the kelp treatment in the loam soil compared to other treatments, and the plants were clearly stressed, but visual symptoms disappeared with time. The final yield in the kelp treatment was equivalent to that in the mineral fertiliser treatment in both soils. The added kelp contained very high amounts of I (11 g $kg^{-1}$) and As (65 mg $kg^{-1}$). However, there was little difference in As or I content in barley grain between treatments. On the other hand, kelp addition resulted in much higher I content in barley straw compared to the other treatments, especially in the loamy soil.

### Conclusion

Under controlled growing conditions, a single fertilisation/soil amendment with kelp containing high amounts of As did not lead to high As concentrations in aboveground plant parts. Large concentrations of I in kelp added to the soil led to a very high straw concentration, but no increase in grain I concentration. An extremely high I content that is often found in sugar kelp may limit its potential in agriculture.

### Acknowledgements

Financial support was provided by the Norwegian Research Council (Project no. 320687).

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## Potentials of poultry manure-derived biochar as an alternative to peat

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### Introduction

One of the most popular growing media used in growing plants is peat. This is due to such properties of peat as high water holding capacity, has low pH, low content of nutrients and low number of pathogens. It is estimated that in Europe peat accounts for up to 80% of the growing media [Escuer et al. 2021; NORSØK REPORT, 2022]. To avoid excessive use of peat, one promising alternative is the use of poultry manure-derived biochar. Biochar can be an alternative for the use of peat because the parameters of biochar can be easily modified, in terms of substrate and pyrolysis temperature and time. Biochar is also more resistant to microbial activity, so it can have longer viability as a growing medium or as an addition to peat [Esceur et al., 2021]. Thus, poultry manure-derived biochar can be considered a peat alternative to phase out peat from horticulture [Drózdz et al., 2020; Drózdz, 2022]. This study aimed at determining the properties of PMBs obtained through pyrolysis at selected temperatures and assessing their potentials to substitute peat in growing media. The scope included: laboratory scale pyrolysis of poultry manure at the temperatures of 425-725°C, determination of selected physical and chemical properties of the obtained biochars, including contaminants, and assessment of the potentials of produced biochars to be used as peat substitutes.

### Methodology

Poultry manure was sampled from a local poultry farm in the Southern Poland and tested for pH, moisture content, ash, total carbon, total nitrogen and phosphorus. The properties of the poultry manure used for our studies on poultry manure varied slightly. On average, the moisture content was about 80%, organic matter – 75% (d.m.), organic carbon – 43% (d.m.), nitrogen – 8% (d.m.) and pH – 7.5. Bulk density (wet) was about 910 kg $m^{-3}$ whereas air-filled porosity was 20% . Poultry manure was pyrolyzed in a laboratory pyrolysis reactor (PRW-S100x780/11) in nitrogen atmosphere (5 L min-1) at selected temperatures: 425°C, 525°C, 625°C, 725 °C. Biochars were tested for physico-chemical and chemical properties, including heavy metals, dioxins and furans, PAHs and PCBs. In addition, sorption properties towards N and P ions were determined.

### Results and discussion

PMBs contained less than 36% of TOC. The content of P and K was about 2.03%-3.91% and 2.74%-5.13%, respectively. PMBs did not retain N and P. They can be safely used as the concentrations of heavy metals, PAHs, PCBs, dioxins and furans are within the permissible values (except for Cr). Due to high pH (9.24-12.35) they can have a liming effect. High WHC in the range of 158-232 % w/w could allow maintaining moisture in the growing media. PMBs obtained at 525°C, 625°C and 725°C showed stability (H/Corg <0.7). The biochars produced from poultry manure do not pose the risk related to the contents of heavy metals (except for Cr), dioxins and furans, and PAHs and PCBs.

### Conclusion

PMBs demonstrated potentials as alternatives to phase out peat in growing media. More research work is needed to learn how the addition of poultry manure-derived biochar for peat replacement will affect selected parameters such as pH and water holding capacity, the content of nutrients in growing media as well as have the impact on seed germination and plant growth.

### Acknowledgements

This work was performed within the Nutri2Cycle project which has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No [773682].

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**Biofertilising and oxidative stress protective effect of aqueous compost extracts on cucumber (Cucumis sativus) and lettuce (Lactuca sativa) crops.**

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## Introduction

Chemical fertilizers are widely used in agriculture to increase crop yields by providing essential nutrients. However, their excessive and indiscriminate use has resulted in negative environmental and economic consequences. Thus, sustainable and eco-friendly alternatives are needed, such as compost and its derivatives. These include aqueous compost extracts, that not only maintain but also improve compost properties (Lerma-Moliz R et al., 2023).

## Methodology

With the aim of studying the biofertilising effect of aqueous compost extracts and their role in the protection against oxidative stress, a collection of extracts was obtained by applying four different extraction protocols (CEP): CEP1 (48 h, Room Temperature (RT), 200 rpm), CEP2 (24 h, 40 °C, 200 rpm), CEP3 (12 h, 70 °C, 200 rpm), CEP4 (14 days, RT, static). The raw materials used were Agri-food Waste (AW-1, AW-3), Sewage Sludge (SS-1, SS-2), Vegetable Waste (VW-1, VW-3) and Olive Mill Waste (OMW-1, OMW-2). The extracts were characterised in terms of pH, Electrical Conductivity (EC), Total Organic Carbon (TOC) and their ability to promote radicle germination in lettuce and cucumber seeds. Finally, the oxidative stress of the radicles resulting from the previous test was evaluated by the quantification of malondialdehyde (MDA), Total Phenolic Compounds (TPC) and ascorbate-glutathione cycle enzymes (Murshed et al., 2008; López-Hidalgo et al., 2022).

## Results & Discussion

The pH and EC results of the extracts were adequate from an agronomic point of view, but the TOC levels in the extracts obtained from CEP3 were notably high due to its extraction conditions. Regarding the GI values, lettuce was highly sensitive to compost extract application due to its salt sensitivity, regardless of the extraction protocol used. Cucumber seeds were more tolerant to compost extracts showing less phytotoxicity problems. In any case, both types of seeds showed GI values above 80% after application of CEP4 and CEP1 extracts from sewage sludge and agri-food waste composts. In general, these data correlated indirectly with the results related to oxidative stress, which could be related to a possible protective effect of this type of extracts. On the contrary, CEP3 extracts, coming from a more aggressive extraction protocol, caused more oxidative stress in the germinated radicles.

## Conclusion

In conclusion, aqueous compost extracts obtained with CEP1 and CEP4 protocols proved to be a sustainable and economical alternative to mitigate oxidative stress in early stages of plant development, especially in salinity-resistant horticultural crops.

## Acknowledgements

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## Evaluation of renure material in a greenhouse trial with spinach and barley

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### Introduction

The aim of this work was to test the agronomic behaviour of the by-product obtained from a gas-permeable membrane pilot-scale processing manure. This by-product is considered a top priority RENURE material as it comes from the recovery of volatile $NH^3$ from manure and captured into soluble NH4+ using an acidic trapping solution (scrubbing salt according to Huygens et al., 2020). In this case this salt is ammonium sulphate.

### Methodology

Greenhouse experiments were conducted to examine the response of spinach crop (Spinacea oleracea L.) and barley (Hordeum vulgare L.) to RENURE comparing to a commercial fertiliser in three types of soils: clay soil, sand soil and sandy-clay soil. RENURE was mainly composed of N (2.8%) and some other minerals in a very low concentration. Fertilizers were applied in four doses throughout the crop-cycle. The response of the crops was assessed in terms of seeds germination in both crops, flag leaf length (barley) and fresh yield in spinach (root and aerial biomass) after the harvest. Data obtained was the mean of three replicates per treatment and two replicates per soil.

### Results and discussion

RENURE pot plants had better germination results for barley than for spinach. In the case of the flag leaf, RENURE treatment produced plants with higher flag leaf length than the commercial fertiliser in the three types of soils, although the difference with the commercial fertiliser was reduced in the sandy-clay soil. Regarding spinach, RENURE treatment produced higher fresh yield results in clay soil and sandy-clay soil.

### Conclusion

RENURE material is an excellent fertiliser for barley as high germination rates and optimal development of the crop were observed, between 22-32% higher germination rate than for the commercial fertilizer depending on soil type. Flag leaf length also increased between 31-75% depending on soil type. In the case of spinach, although germination rates were low using RENURE, fresh yield increased a 30% regarding commercial fertiliser in clay and clay-sandy soils, which means that RENURE was more suitable for the development stage than for the germination stage.

### Acknowledgements

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## Comparison of different fertilising scenarios for spinach production in intensive conditions II: effects on the soil biological status

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### Introduction

The application of organic amendments, such as fresh or composted materials is an effective strategy to keep the quality of soils, and thus, restore the ecosystem function and services. At first, the increment in organic matter in soils boots the soil fertility, and in the long-term soil structure and stability are improved, together with water holding capacity and infiltration, hence reducing the risk of erosion (García-Orenes et al., 2016). The organic amendments stimulate soil microbial growth and activity, with the subsequent mineralization nutrients, and consequently, promoting the growing of crops and improving soil properties related with the soil quality. This work compares the use of different organic amendments in an agricultural soil for the intensive spinach production versus inorganic fertilization to evaluate the effect on soil microbial properties.

### Methodology

A field experiment was conducted to study the effects on different soil biological properties of different fertilising treatments for the cultivation of a horticultural crop (Spinacia oleracea var. Shrike RZ) under intensive conditions in a Mediterranean area. A randomised block design with three replications per treatment and a single application dose (150 kg N/ha) was established. The treatments considered were the following: i) two inorganic treatments, inorganic NPK fertilizer 15-15-15 (IN); inorganic NPK slow release fertilizer with ENTEC Nitrofoska® plus the nitrification inhibitor 3,4-dimethylpyrazole phosphate (LI); ii) three organic amendments, cattle manure (EV) and two composts from agri-food wastes, C2 (76 % tomato soap waste + 24 % vine shoot pruning with coffee ground as additive) and C4 (57 % leek waste + 28 % olive mill waste + 15 % vine shoot pruning); iii) control soil without treatment (B); and iv) a compost tea obtained from compost C4, which was added to plots without treatment and with the inorganic treatments (IN, LI), respectively. The effects of the different treatments on the microbial soil properties as basal soil respiration, microbial biomass and enzymatic activities were measured following the methods described by Garcia-Orenes et al. (2016). The soil basal respiration (BR) was measured in an automated impedance-meter (BacTrac 4200 Microbiological Analyser, Sylab), based on $CO^2$ emission by soil microorganisms at 30°C for 24h. Microbial biomass carbon (Cmic) was determined by the fumigation-extraction methods; urease activity was measured using urea as substrate and alkaline phosphatase and B-glucosidase activities were determined by the use of p-nitrophenyl phosphatedisodium and p-nitrophenyl-B-D-glucopyranoside, respectively, as substrates, both methods being based on the release and detection of p-nitrophenol.

### Results and discussion

The results have showed an increment of microbial populations measured as their activity in the soils with organic amendment application. In general, the level of carbon biomass, basal soil respiration and the different enzymatic activities have been higher in the soils samples from cattle manure (EV) and two composts from agri-food wastes, C2 (76 % tomato soap waste + 24 % vine shoot pruning) and C4 (57 % leek waste + 28 % olive mill waste + 15 % vine shoot pruning) treatments, this is according with other previous work (Garcia-Orenes et al., 2016).

### Conclusion

The use of organic compost could be an effective solution to keep the productivity of agricultural intensive soil, keeping the soil quality, due the improvement of microbial properties.

### Acknowledgements

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Organic fertilization in traditional Mediterranean grapevine orchards mediate changes in soil microbial community structure and enhances soil fertility. Land Degradation and Development 27, 1622-1628.

## Comparison of different fertilising scenarios for spinach production in intensive conditions I: an agronomic perspective

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### Introduction

In Mediterranean areas, the increasing use of intensive agriculture practices, together with adverse climatic conditions, are among the main causes of soil degradation and loss of organic matter (Bustamante et al., 2011). The incorporation of organic materials increases soil organic matter contents, improve soil properties and imply a significant supply of plant nutrients, which results in a reduction in the amount of inorganic fertilisers used. This work aims to study the effect of different fertilising scenarios on the crop and soil characteristics under intensive management conditions.

### Methodology

The treatments established in the field experiment were the following: control soil without amendment (B); inorganic NPK fertilizer 15-15-15 (IN); inorganic NPK slow release fertilizer with ENTEC Nitrofoska® plus the nitrification inhibitor 3,4-dimethylpyrazole phosphate (LI); cattle manure (EV) and two composts from agri-food wastes (C2 and C4). Also, a compost tea obtained from compost C4 was incorporated in plots without treatment and in plots with theinorganic treatments (IN, LI). The composts consisted of different agri-food wastes, at the following rates (on a fresh weight basis): compost C2, 76 % tomato soap waste + 24 % vine shoot pruning with also and additive incorporated at the maturity phase (8 % coffee grounds, fresh weight basis); compost C4, 57 % leek waste + 28 % olive mill waste + 15 % vine shoot pruning. The treatments were incorporated as a single application dose of 150 kg N/ha in small plots arranged in a randomised complete block design with three replicates per treatment. After the incorporation of the treatments, spinach (Spinacia oleracea var. Shrike RZ) was sown in all plots and harvested after 80 days. The effects of the different treatments on the chemical properties of the soil were studied at the beginning and end (after harvest) of the experiment. Crop yield and chemical composition were also studied.

### Results and discussion

In general, the organic treatments improved in the short-term the concentrations of organic C and of the organic N in the soil (Bustamante et al., 2011), while the mineral treatments and the fresh organic material (cattle manure-EV) increased to a greater extent the nitrate soil contents. At the beginning of the experiment, compost C2 induced the lowest concentration of nitrates in the soil. However, this fact did not suppose a reduction in the crop yield, showing this treatment the highest values among the organic treatments, and similar to those obtained with the inorganic treatments. This shows a release of N balanced to the crop requirements, fact also reported by Bustamante et al. (2011) in a study of application of winery-distillery compost on a vineyard during three growing seasons.

### Conclusion

The results obtained showed that despite obtaining the highest crop yields with the mineral treatments, the use of this type of fertilization also increased the levels of nitrates in the soil at the end of the experiment. On the contrary, the organic fertilization based on the use of compost, especially compost C2, improved soil organic matter and produced similar crop yields than the inorganic fertilizing scenarios without producing an excess of nitrates in the soil at the end of the cropping cycle.

### Acknowledgements

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## Evaluation of different fertilization management strategies on golf courses by combined use of drone and multispectral camera

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### Introduction

Currently, the management of the turfgrass used in recreational and sport activities, such as football and golf, are reaching a high level of sophistication, in order to have an optimal appearance throughout the year. The testing of new management strategies in these scenarios is complex due to the continuous use of the facilities and the inability to perform destructive monitoring techniques. In addition, due to the specific properties in water management and the type of medium used (anthrosoils) that is implanted under the mat, the use of organic-derived biofertilizers has not been very common until now. In this sense, in this work we have two objectives: (i) to test and compare 5 fertilization treatments (compost of vegetable pruning (C1), olive mill waste compost (C2), vegetable pruning vermicompost (V), and two commercial treatments, one of inorganic type (I) and another of organic type (N) applied at a dose of 4 kgm-2 equivalent to an average of 70 gTN m-² using as a reference unfertilized areas (B); (ii) to correlate the production of plant biomass and the mineral content in the clipping yield with different vegetative indices obtained by using a multispectral chamber installed in a drone device.

### Methodology

36 subplots (280 x 400 cm each) were established at Font del Llop golf course (Monforte del Cid, Alicante, Spain), on the fairways 5 and 6, where the treatments were applied by six-fold over bermudagrass (Cynodon dactylon, Riviera cultivar). The biomass generated throughout the experiment has been quantified and the clipping yield corresponding to days 0, 64, 92 and 155 after the application of the treatments have been analysed (chlorophyll content and the total C, N, P, K, Ca, Mg, Fe, Cu, Mn and Zn). Periodic flights have been made on these subplots using a DJI Inspire drone equipped with an RGB camera and a multispectral camera (©MicaSense 5-band RedEdge): Red (R), Green (G), Blue (B), Infrared (NIR) and Near Red (RE), obtaining a multispectral footprint of each subplot (with GDS resolution of 8 cm/pixel and 1,700 points per subplot and flight). The relationship between spectral bands and their spatial relationship was then analysed at the statistical level using correlations. Spectral variables were also correlated with agronomic data using Bayesian hierarchical spatial models that consider the space-time component. A multivariate analysis has been carried out considering together several of the indices using a corrected model to do a better study of the behaviour of the values of the indices than using a univariate analysis.

### Results and discussion

It was observed that the most suitable treatments have been the vegetal compost (C1) and vermicompost (V), with productions even higher than that of the inorganic treatment commonly used in the golf course. The use of olive mill waste compost (C2) has generated problems of production and general appearance, probably due to the inadequate maturity of the material and the existence of polyphenolic phytotoxic compounds. Mineral contents were affected by the fertilizing scenarios and time. The estimation of the mineral contents by spectral bands and indices varied depending on the element; C was better estimated by Green and Near Red bands (82 and 74% of variability explained respectively); total N by Blue and Red band (65 and 55% of variability explained respectively).

### Conclusion

High-quality (balanced and well-stabilized) biofertilizers as compost or vermicompost can be used in substitution of inorganic commercial fertilizers, obtaining a regular biomass production without any turfgrass visual quality loss (colour, texture, density and uniformity) and keeping its playability characteristics (rigidity, elasticity, resiliency and recuperative capacity). The combined use of drone-multispectral camera systems and in situ properties (e.g. clipping yield measurements, chlorophyll content, and mineral contents) may produce a significant improvement in the treatment assessment, allowing a quicker detection of under-quality areas to be managed.

### Acknowledgements

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**Agroentool: Insects as a biotechnological tool for obtaining compounds of agricultural interest.**

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## Introduction

Currently, the increasing cost and environmental impact of some chemical fertilisers has led to the search for new, more economical, and efficient fertiliser alternatives. In this context, the growing interest in agricultural biostimulants, which aim to improve the biological functionality of the plant as well as plant-soil interactions, should be highlighted. Thus, the use of edible insects as a natural source of compounds such as chitin is considered an innovative line of research and is fully in line with current European sustainability policies. A derivative of chitin is chitosan, which is an attractive biocomponent both for its biodegradable polymer content and for its insolubility, which prevents contamination of the natural environment and allows it to be used in smaller quantities as it is not lost through evaporation (Son et al., 2021). For all these reasons, the main objective of AGROENTOOL is to rear insects to produce chitosan from the chitin contained in their exoskeleton and to produce agricultural inputs based on insect chitosan which will induce defence mechanisms and thus improve crop protection. In this sense, the project is based on the concept of a new, more sustainable, and efficient agricultural model and is in line with two of the 17 SDGs, as it will not only promote the food supply of the population through the development of environmentally friendly inputs, but also provide a sustainable alternative to the use of traditional chemical fertilisers, with the consequent impact on the resilience of agricultural systems.

## Methodology

The project has been divided into three phases: i) selection of insects with the highest chitin content according to the bibliography and rearing them with different feed treatments to improve mass production; ii) design of a protocol to obtain chitin as well as its derivative chitosan. For this activity, the chitin/chitosan extraction protocol will be optimised according to an organo-mineral acid-base treatment at laboratory scale, with the aim of obtaining a scalable method at industrial level for obtaining high quality chitosan and its subsequent use in the formulation of prototype inputs with commercial properties. In addition, according to Cárdenas et al. (2004), useful chitosan is obtained when the degree of deacetylation (GD) is greater than 50%. For this purpose, the GD of each method studied was determined; iii) Finally, the formulation of products with field application and their final validation in a horticultural crop will be carried out.

## Results and discussion

This project is currently in development, but, one of the first activities to be completed was the selection of insects. Among the insects with a higher content of chitin of the exoskeleton, the individuals of the order Orthoptera (the most common for mass production are Acheta domestica, Gryllodes sigillatus and Gryllus assimilis) were deeply investigated. Initially, G. assimilis was chosen because of the larger size of the adult and the chitin content. However, subsequent activities will also be carried out on A. domesticus to obtain a comparison of the chitin extract obtained. On the other hand, the effect of 3 different diets based on greenhouse plant by-products was evaluated. Experimental diets containing 50%, 70% and 90% of the plant by-products (or a mixture of several) together with a mixture of wheat or other alternative protein source were studied. On the other hand, different extraction methods were tested on the targeted individuals to select the one with the highest yield. The GD of extraction method was 50-60% which determine to the suitability of them to obtain chitosan.

## Conclusion

In summary, no definitive conclusions can be drawn due to the lack of current data at a developmental stage. However, it is expected that a sustainable product with biostimulant capacity will be obtained as an alternative to conventional synthetic chemicals and fertilizers.

## Acknowledgements

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## Use of microbiome from olive-mill wastewater sludge as biotech tool for sustainable development

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### Introduction

The number of oil mill wastewater (OMW) evaporation ponds throughout the Mediterranean basin has been increasing (>3000 in Spain, 30-50% abandoned), and although most are in disuse (30-50%), they cause serious pollution problems in the soil and surrounding waters (Kavvadias et al., 2017). Despite its highly polluting nature, mainly due to the high content of phenolic compounds, the study of the microbiota that inhabits this type of sample deserves special attention, since it is highly adapted to specific and extreme conditions. This fact makes this microbial group a very interesting biotechnological tool for its application in a wide range of agri-food and environmental fields. Although the microbial communities of OMW sludge and their functionality are almost unknown, they are considered key agents of a sustainable bioeconomy. Therefore, the objective of this work was to obtain the microbiome profile of a catalog of abandoned OMW ponds to determine their capabilities based on their origin and state of maturation, and to identify their associated functionality and potential applicability.

### Methodology

To meet the objectives of this work, microbial groups of special environmental and agronomic relevance were quantified from a catalog of OMW sludge samples from abandoned ponds. Thus, microorganisms that degrade polyphenols, phosphate and potassium solubilisers, nitrogen fixers, cellulolytics, amylolytics, proteolytics, chitinolytics and other producers of siderophores (Machuca and Milagres, 2003; Jurado et al., 2014; Phillip et al., 2020) were quantified. After the quantification, the best strains were identified, according to their agronomic and environmental capacities, through genetic sequencing. On the other hand, the suppressive capacity of the OMW sludge samples against phytopathogenic bacteria and fungi was evaluated, as well as their ecotoxic and phytostimulant character in watercress seeds. In parallel, a functional and biodiversity metagenomic analysis was carried out in the most representative samples of OMW sludge.

### Results and discussion

All microbial groups were represented in the OMW sludge analysed depending on the seasonality and maturity of the sample. The OMW sludge presented a variable degree of ecotoxicity and phytotoxicity, although in some cases it was mitigated after the dilution of the sample. As a result, a collection of 30 strains (bacteria and fungi) was obtained, to which a high functional diversity could be attributed. Among the most representative fungi, the genera Aspergillus, Scedosporium and Fusarium were identified, while Bacillus and Rhodococcus were some of the most widely distributed bacterial genera in the samples. All these microorganisms present management properties suitable for their production, transport and joint application in the field on a large scale for biofertilization and bioremediation strategies in situ. Finally, the metagenomic profiles showed less fungal than bacterial diversity, highly dependent on the maturity of the samples.

### Conclusion

Despite their potential toxicological risk, OMW sludge present a very diverse fungal and bacterial microbiota in terms of their potential agronomic and environmental application. The microbiome of such samples can be highly variable and depend on seasonal factors as well as the age of the ponds.

### Acknowledgements

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## Wood residues amendment: A sustainable approach to improve soil quality for agriculture in the boreal region of Canada

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### Introduction

Climate change has resulted in warmer temperatures and the potential for boreal regions of Canada to become more suitable for agricultural production (Government of Canada, 2021). However, challenges from climate change induced weather variability and the poor quality of soils need to be overcome (FAO, 2018). The application of organic material rich in carbon and lignin content, such as wood residues (WR), could be a sustainable approach to rapidly improve soil properties (Lalande et al., 1998; N'Dayegamiye and Angers, 1993). The objective of this field study was to evaluate the effect of wood residues co-applied with liquid dairy manure (LDM) amendment, as a source of nitrogen, on soil quality for agricultural production.

### Methodology

Five treatments were compared: (i) unamended soil; (ii) inorganic fertilized; (iii) liquid dairy manure (LDM); (iv) LDM + 24 t C ha-¹ as WR; and (v) LDM + 48 t C ha-¹ as WR in a poor structured clay soil. Each treatment was replicated four times for a total of 20 experimental units. The plots were sowed with barley under seeded with a grass-legume crop mixture in spring 2021.

### Results & Discussion

Results indicated that the addition of WR had a positive effect on soil properties, such as aggregate stability, organic carbon content and soil respiration, at the end of the first season in 2021. Our preliminary results confirm those observed in a sandy loam of a previous field study of Lalande et al. (1998). The beneficial effect of WR on these parameters was also maintained in the second year, especially with the addition of 48 t C ha-¹ as WR.

### Conclusion

The preliminary results suggest that the addition of 48 t C ha-1 WR combined with manure could be a sustainable and economic alternative to improve the soil quality for agriculture in boreal regions. Long-term studies by testing different wood materials in different soil textures will confirm this beneficial effect.

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## Soil quality effects of different compost types applied in cereal-legume rotations on calcareous soil

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### Introduction

Long-term and unbalanced application of inorganic fertilizers has degraded soil quality in many areas. For a more sustainable crop production, the application of organic fertilizers both alone and combined with mineral fertilizer is recommended. The objective of this study was to determine the rehabilitation potential of different types of compost for degraded cropland soils by quantifying soil quality parameters.

### Methodology

We investigated the impact of different compost types in a field experiment on calcareous soil in Tigray, Northern Ethiopia, after two years with faba bean (Vicia faba L) wheat (Triticum aestivum) rotation or continuous wheat, respectively. The experiment consisted of eight treatments: no fertilizer, mineral fertilizer, traditional compost, vermicompost, and compost with effective microorganisms (EM), as well as a combination of each compost with mineral fertilizer. After the harvest of the second season, the following soil parameters were determined: soil respiration, biomass carbon, active carbon, organic carbon, wet aggregate stability, bulk density, available phosphorus, total nitrogen, and pH.

### Results & Discussion

Application of EM and vermicompost, both alone and combined with mineral fertilizer, increased soil respiration, biomass carbon, active carbon, organic carbon, wet aggregate stability, available phosphorus and total nitrogen compared to mineral fertilizer and traditional compost in both crop rotations. In addition, EM and vermicompost decreased pH and bulk density. However, both traditional compost and mineral fertilizer showed better results than the control without fertilizer in both rotations. Compared to continuous wheat cultivation, rotation with faba bean improved all soil quality parameters.

### Conclusion

In this field experiment on calcareous soil, EM compost and vermicompost were more efficient in improving soil quality than traditional compost. Including legumes in the rotation further improved properties related to soil quality.

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## Certifying Compost and Digestate as Consistently Safe and Good Quality for Use as Products

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### Introduction

Renewable Energy Assurance Limited (REAL) carries out a range of certification and consumer protection activities in the fields of renewable energy, electric vehicles, organics recycling, biomethane-to-grid, and compostable materials. REAL operates the Compost Certification Scheme (CCS) and Biofertiliser Certification Scheme (BCS).

The Schemes are the only schemes in the UK providing an 'end of waste' framework for waste-derived compost and digestate, allowing compost and digestate to be spread and used as a product. This means that compost and digestate can be spread to land without waste regulatory controls and supplied to professional markets, as the environmental regulators are assured in the consistent quality and safety of the product.

There are 175 certified composting processes on the CCS; 135 of which are located in England, 21 in Scotland, 11 in Wales, 5 in Northern Ireland and 1 in the Republic of Ireland. In total, these sites are processing ~4.0 million tonnes of input per annum and producing ~1.8 million tonnes of output per annum. On BCS, there are 106 certified AD processes in total; 78 of which are located in England, 13 in Scotland, 8 in Wales, and 7 in Northern Ireland, collectively processing ~5.0 million tonnes of input per annum (correct as of 30/03/2023).

Through the Schemes, REAL seeks to promote a circular economy and provide assurance to consumers, farmers, food producers, and retailers that **quality composts and biofertilisers** are safe for human, animal, and plant health.

### Scheme Operation

The CCS and BCS certify to the relevant Quality Protocol, PAS, and Scheme Rules. Sites are audited annually by appointed certification bodies and samples are tested regularly according to the requirements of PAS 100 or PAS 110 by appointed laboratories (and the results of these tests are stored in REAL's central database).

During the audits, the operator's QMS, sampling process, and various other aspects of the process are reviewed. Sites can also be subject to any necessary spot checks after a non-compliance.

### Quality Management

As part of compliance with PAS 100 or PAS 110, operators must implement a QMS and a HACCP plan. A QMS is a system of procedures, documents and records for planning, achieving, and demonstrating effective control of all operations and management activities necessary to achieve compost or digestate that is fit for purpose, while HACCP ensures identification and management of hazards to make sure the compost or digestate is safe and of good consistent quality. Hazards are managed throughout the process and the HACCP plan is specific to the intended end use of the product.

### Evidence of Quality

In 2022, REAL conducted an analysis of Scheme data held on plastic contamination in certified compost and digestate produced in England; this analysis shows 98.5% of compost samples and 98.1% of digestate samples tested were within the required quality limits for physical contaminants.

Additionally, REAL's 2021 annual report presents information on the NPK content of compost and digestate, demonstrating the value of quality compost and digestate as organic fertilisers.

(Also see the REAL Research Hub Digestate Data Pack; this comprehensively reports key positive and negative characteristics of UK digestates produced from different feedstock types. Specialist laboratory analysis was carried out, focussing on microplastic analysis and dewaterability of digestates derived from food waste processes).

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## The effect of bio-based fertilisers on soil chemical, physical and biological properties

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### Introduction

The transition to circular and bio-based economy requires recycling of nutrients from agricultural, industrial and societal by-products and waste. In addition to nutrient supply in crop production, bio-based fertilisers have the potential to improve soil fertility due to the organic matter content and may consequently lead to soil that is more resilient to extreme weather events. However, as wide range of different bio-based fertilisers will be available, the major challenge for implementation is the variability in the quality. Therefore, the aim of this study was to examine effect of diverse biobased fertilisers with contrasting properties on soil fertility properties.

### Methodology

In long-term incubation study (330 days), we studied the effect of 11 different bio-based fertilisers (digestates, composts, insect frass, meat and bone meal, Fertigro and Maltaflor) on soil fertility parameters by performing chemical (nutrient release of N, P and S, pH, electrical conductivity and cation exchange capacity), biological (microbial biomass carbon) and physical (clay dispersibility) analyses.

### Results and discussion

Nutrient release varied greatly among the different bio-based fertilisers and depended on feedstock source, processing technology and nutrient content of the final product. Release of N and S was highest in meat and bone meal whereas P was highest in soil amended with insect frass and cattle manure digestate. Compost amendments resulted in almost no release of N and S and low release of P. Compost amendments increased the soil pH, while all fertilisers except the composts increased electrical conductivity. The lowest content of microbial biomass carbon was achieved in soil amended with meat and bone meal and the highest content was in soil amended with household waste digestate and insect frass.

### Conclusion

Bio-based fertilisers studied in this experiment showed the potential to substitute mineral fertilisers or/and to improve soil fertility parameters. This, however, depends on the chemical composition of the fertilisers. Results from this study also suggests the potential of development of tailor-made bio-based fertiliser mixtures with improved nutrient composition. Nevertheless, research on interactions between bio-based fertilisers and soil properties under variable growth conditions is still needed.

### Acknowledgements

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## Crop production potential and soil health benefit of organo-mineral fertiliser in the UK: A review

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### Introduction

Production of mineral fertilisers (MFs) involves costly and energy intensive processes. Organo-mineral fertilisers (OMFs) can be produced with organic waste materials, such as sewage sludge or manure. Reusing organic waste reduces the amount of mineral fertiliser needed, while also promoting a sustainable circular economy. If OMFs can provide benefits comparative to MFs, they offer a more sustainable method of fertilising crops. OMFs have also been observed to improve soil fertility, increasing soil organic matter (SOM) by 1% over 3 years as opposed to an increase of 0.42% in unfertilised control (Ayalew and Dejene, 2012). SOM is an important factor in multiple soil health traits. However, the impact of OMFs have not been well studied in a soil health framework despite their potential to improve soil health while providing similar crop yields to MFs. This review identifies the current knowledge gaps and suggests potential mechanisms affecting OMF efficacy and effects on soil health.

### Methodology

The literature was searched using key terms '("organo-mineral fert*" OR "organomineral fert*") in combination with other terms, such as "yield" or "soil organic matter" to refine results. Papers were excluded if they were only comparing organic inputs to mineral inputs. This review focuses on crops with significance to UK agriculture, although some studies with exotic crops were included to add further support to the efficacy of OMFs and to show the full scope of current knowledge on how OMFs affect soil characteristics. This resulted in more than 150 papers being included in the review.

### Results and discussion

Most studies found OMF to be comparable to MFs in terms of yield for a variety of crops. Studies that found OMF to not provide comparable yields to MFs highlighted the lack of knowledge surrounding the mechanism of nutrient release from OMF, as well as the wider effects of OMF on soil traits such as microbial activity. Current literature also suggests that the combination of organic and mineral nutrients in OMF affects crop nutrient use efficiency as well as nutrient quality.

OMFs have the potential to affect multiple soil health traits. A greenhouse study found OMF to increase the field capacity of soil from 18% to 26%, via the introduction of organic matter (Semida et al., 2015). However, these results may not be reflective of OMF effects on soil water holding capacity in the field. OMFs appear to benefit the production of SOM, although there are some examples where this was not the case (Antille et al., 2017; Ayalew and Dejene, 2012). These examples highlight how SOM formation is affected by both inputs and land management decisions, such as fallowing and cover crops. However, there is a deficit of evidence for OMF carbon sequestration and whether addition of mineral nutrients alters microbial carbon cycling differently from pure organic matter inputs. This could be a key area of future study, as soil may be an important carbon store for greenhouse gas offsetting. Nutrient mineralisation is of interest for new OMFs, with formulation affecting nutrient availability and cycling. Further studies into factors affecting nutrient release from the OMF would benefit our understanding of the mineralisation of the organic nutrients. OMF has also been observed to promote biological soil health traits, such as microbial diversity and colonisation. Understanding how OMF nutrient release is affected by and effects microbial activity is a key area of future study.

### Conclusion

OMFs are a viable alternative to MFs in terms of maintaining current yields. Key gaps in current knowledge include the mechanisms underlying nutrient release from OMF products, confounding factors that affect release and the potential effects on crop quality. Understanding these factors could inform changes in OMFs to maximise effects. More investigation is also needed into the effects of OMF on soil health characteristics, particularly carbon sequestration.

### Acknowledgements

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## Agronomic effects of adding fibrous pulp mill sludge to two soils in Sweden

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### Introduction

There are large quantities of organic fibres as side streams from forest industries. These fibres has the potential to improve soil physical properties of agricultural soils which could have positive yields effects (Chow et al., 2003; Sippola et al., 2003; Gallardo et al., 2012). The effects may vary between soils, climate and crops. In this study, we investigated the effect on two soil types in Sweden with grain production.

### Methodology

Two field experiments were established in 2021 in the west part of Sweden within a region with rather intensive grain production. One experiment was on silty clay (42 % clay, 3.9 % topsoil SOM) and the other on sandy loam (12 % clay, 3.6 % topsoil SOM). Two treatments with different fibrous sludge from the forest industry (CPMS = composted pulp mill sludge, LPMS = lime-stabilized pulp mill sludge) was compared with an untreated control. Both had a C/N-ratio around 17-19. The experiments were two factorial with the fibre treatments in large plots (24 x 12 m) in four replicates and four nitrogen fertilization treatments tested in small plots (6 x 12 m) in each larger plot in a split-block design. The fibres were applied in October (42 tons per ha CPMS and 60 tons per ha LMPS, corresponding to 5 tons TOC per ha) and incorporated to about 10 cm depth with a tine cultivator with spreader discs. In April, spring oats was sown and nitrogen fertilizer applied in rates of 0, 60, 120 and 180 kg N per ha, of which 120 kg N/ha represents a normal recommended rate for the area. Biomass and nitrogen uptake was estimated from drone images taken in beginning of June shortly before panicle emergence. Grain yield was measured plot wise and grain quality and nutrient contents were analysed. Soil samples were taken in October 2021 before application of fibres and then again after harvest in 2022. The samples from 2021 was used for determination of soil bulk density and soil organic matter content. In 2022, the soil was also analysed for porosity and water holding capacity.

### Results and discussion

At the site with sandy loam, NDVI was higher in both treatments with fibre additions compared to the control in all nitrogen treatments. At the site with silty clay, it was only the LMPS treated plots without any nitrogen fertilizer that differed, with lower NDVI than the other treatments. Grain yield at the site with sandy loam was on average 580 kg ha-¹ and 730 kg ha-¹ higher in treatments with CPMS and LPMS respectively ($p<0.0001$) reaching yields around 5 500 kg ha-¹. At the site with silty clay, grain yield was significantly elevated with 840 kg ha-¹ in the treatments with LPMS reaching 6 900 kg ha-¹, but not significantly and only with 390 kg ha-¹ in the treatment with CMPS. These differences were consistent for all nitrogen treatments, also above optimum rates, indicating that the yield elevation was not a nitrogen fertilization effect from the fibres. In autumn 2022, the carbon content was on average 2.0% in the untreated plot compared to 2.2% in the treatments receiving fibres. The results on soil physical properties and grain P and K uptake are not yet available, but will be presented at the conference.

### Conclusion

Adding fibres to the soil can promote crop yield and is not related to nitrogen addition.

### Acknowledgements

This study was financed by Soilfood and performed by field technicians at Lanna field station (Swedish University of agricultural Sciences).

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## Evaluation framework to predict the fate of organic fertilisers

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### Introduction

In December 2015, the European Union introduced the Circular Economy Package for the transition towards a circular economy that aims to reuse waste streams such as sewage sludge, surplus of manure, and organic household waste. Treatment and reuse of these waste streams will lead to new organic fertilisation products, but there is no framework available to evaluate the potential agronomic, environmental, health, and economic impacts of the organic products that would enter the market as fertilising products. To fill this gap, Wageningen Research developed a toolbox that can be used by various stakeholders, including government, farmers, and producers, to assess the impact of these products. The framework is currently being validated and tested in a follow-up project. This abstract focusses on a part of the evaluation framework dealing on the agricultural impact of organic fertilising products in terms of carbon and nitrogen turnover.

### Methodology

The model RothC has been used to assess C mineralisation and sequestration from organic fertilising products. The C/N ratio of the individual organic pools of RothC was used to assess the N-mineralisation and immobilisation. The model was calibrated based on incubation studies in which C and N mineralisation of 16 different organic fertilisers was measured, both in a sandy soil and a clay soil. The measured C-mineralisation was used to determine in each fertilising product the fraction of easily decomposable plant material (fDPM) and the complementary fraction of recalcitrant plant material (fRPM = 1 - fDPM). Furthermore, the influence of soil type on mineralisation/immobilisation was quantified. With regression analysis, a connection was made between the fraction of easily decomposable plant material and a large palette of laboratory analyses performed on the organic fertilisers in order to derive a simplified method the estimate C- en N mineralisation of organic products in soils.

### Results and discussion

A new simplified innovative methodology has been developed to predict the fate of an organic product in terms of C- and N-mineralization and immobilisation. Simple laboratory analyses (total nitrogen content, a pyrolysis parameter and a MicroResp. parameter) could predict the size of the RothC parameter for the easily decomposable fraction of carbon (fDPM) of an organic fertilising product, enabling the prediction of carbon dynamics. The model results were quite similar to what was measured with incubation experiments. For N mineralisation, an overestimation was found, meaning that just using a fixed C-N ratios of each of organic pools in RothC is a too simple approach. However, this approach is a first step from the conventional long-term and costly incubation experiments or field studies that are typically required to assess the impact of organic fertilisers, at least for carbon turnover. The model assessment of N mineralisation will be further investigated.

### Conclusion

The evaluation framework tool can, with a simplified method, help to predict the expected effects of an organic fertiliser on carbon storage in soils and in the future possibly nitrogen mineralisation as well.

### Acknowledgements

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## Temporal effect of exogenous organic inputs on soil microbial communities under conservation agriculture practices

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### Introduction

Facing the depletion of agricultural soil fertility and the loss of its biodiversity (FAO et al., 2020), developing new methods to manage agricultural soils in a more sustainable approach becomes a priority. The implementation of agro-ecological practices, namely conservation agriculture, including no-till, permanent cover crops, long and diversified rotations, contributes to improve long-term soil productivity by supporting biological activity and nutrient turnover and availability for plants. Indeed, soil biodiversity contributes to soil fertility and plant health (Modal et al., 2020). The objective of our study is to evaluate, through a multi-year approach, the impact of the addition of different exogenous organic matter on soil microbial biodiversity in a plot managed under conservation agriculture.

### Methodology

The plot, located in Normandy (France), have been managed under conservation agriculture for 16 years, with superficial tillage and direct sowing. During the current year, the crop was predominantly fodder grasses. This field experiment has been setted-up in 2020 with a regular organic matter input (OMI), from 2021 onwards: 40T/ha for Green waste compost (GWC), 40T/ha for cattle manure (CM) and a control without exogeneous input (C). Four auger soil samples were collected at a depth of 20 cm in March 2020, 2021 and 2022 for current physico-chemical analysis (pH, Total C and N, organic C and N, …). In parallel, rhizospheric soil samples with an intact root system were collected with four replicates per treatment, for microbial analysis (arbuscular mycorrhizal spores density, fungal and bacterial biomass, enzymatic activities).

### Results and discussion

The originality of our study consists in the long-term observation of microbial and physico-chemical parameters dynamic in the soil with different organic carbon amendment. Whatever the OMI, the enzymatic activities such as N-Acetyl-Glucosaminidase and alkaline phosphatase, and also arbuscular mycorrhizal spores density increased steadily over the 3 years of study. No significant differences were observed on the other variables. After 2 years of organic inputs, we found a significant increase on spores abundance with GWC and CM treatments. More, bacterial biomass was higher in GWC treatment, while no effect of organic inputs was found on enzymatic activities. Concerning the physico-chemical variables, only oxidizable organic carbon and total nitrogen increased with the CM treatment compared to other treatments.

Our results show that some biological indicators can reveal changes in soil functioning more quickly than physicochemical indicators. They also show that differentiating the effects of organic matter composition takes time. Finally, they suggest that the addition of CM could increase the mycorrhizal potential of the soil. This field experiment will be continued in the long term with the aim of identifying biological or physicochemical indicators able to provide early information on changes in soil conditions.

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## Sown forage mixtures boost organic matter cycling and soil biological activity with concomitant productivity gains

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### Introduction

Belowground allocation of net primary productivity reaches values up to 60% in grassland ecosystems (Jackson et al., 2017). However, different management schemes could lead to varied resource allocation and utilisation. Notably, species-enriched grasslands have been found to store more organic carbon due to increased root-derived carbon and steering of microbial necromass and associated by-products (Bai & Cotrufo, 2022). Furthermore, not only the quantity of organic inputs is altered but also their quality. Nevertheless, the role of microbes when it comes to processing those organic matter inputs is not clearly dilucidated.

### Methodology

In order to elucidate the effects of sown forage diversity on soil processes influencing soil quality, two biodiversity-ecosystem function (BEF) experiments were established. One of them was set up in Solsona (Spain) following the LegacyNet network protocol (LegacyNet, 2023), whereas the other one included different regions within the Mediterranean basin (Spain, France, Slovenia, Jordan and Lebanon; SUSFORAGE, 2023). Both studies shared a similar experimental design which manipulates the richness and evenness of sown species belonging to three different functional groups: grasses, legumes and non-legume forbs. The selected parameters, monitored throughout 2021 and 2022, included: biomass production, soil organic carbon content (SOC), total Kjeldahl nitrogen (TKN), microbial decomposition following the Tea Bag index method, and microbial functional diversity according to the MicroRespTM method; and were analysed through the Diversity-Interaction modelling approach by Kirwan et al. (2009).

### Results and discussion

Preliminary results point to higher productivity, SOC and TKN in mixed swards compared to monocultures. At the same time, the most diverse swards also present greater microbial functional diversity in the use of different carbon substrates (especially true for amino acids in most of the studied countries) and a higher rate of decomposition. Our results seem to partly confirm the findings of Bongiorno et al. (2020) who found a higher utilisation of amino acids related to conservation agriculture practices, to which increasing sown diversity could subscribe.

### Conclusion

Overall, although being short-term results, it can be concluded that in mixed swards there is a more efficient cycling of organic matter that would allow an enhanced productivity (aboveground compartment) as well as an improved SOC and TKN accrual (belowground compartment).

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## Evaluation of bioremediation technologies for arable soils degraded by intensive management: bioremediation strategies facilitated by the application of biochar (BIORECHAR)

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### Introduction

Since the middle of the 20th century, an agricultural model has been established and characterised by intensive crop production through the excessive use of agrochemicals, due to the increasing food demand of the world's population (Stagnari et al., 2009). In addition, in agricultural areas with intensive irrigated crop production and semi-arid climates, the use of desalinated water of marine origin and reclaimed water of residual origin has been imposed. These intensive management practices cause soil and water contamination by inorganic and organic compounds, which leads to a deterioration in the quality of them, unproductivity and the unsustainability of agricultural activity (Kopittke et al., 2019). On this basis, soil bioremediation technologies and solutions based on the circular economy, such as the reuse of organic waste, have become a viable approach that favours the transition from conventional intensive production to agroecosystems, as they are more sustainable in terms of resource management (water and soil). In this sense, the project BIORECHAR aims to study the feasibility of new bioremediation technologies, facilitated by biochar and other plant extracts, of chemically degraded (contaminated) soils due to: a) boron (B) contamination because of the use of desalinated seawater or regenerated wastewater, and b) contamination with the herbicide pendimethalin. These are the most common causes of agricultural soil degradation in the targeted semi-arid areas of south-eastern Spain.

### Methodology

In BIORECHAR project two different soils were selected from Spanish agronomic zones (Murcia and Almeria), and two compounds (B and pendimethalin) were chosen as case-bioremediation studies. Physicochemical and fertility parameters were analysed. Murcia soil had a high B concentration but Almeria was contaminated with pendimethalin (1,5 mg a.i. kg-1). Both soils (200 g) were then incubated, at 25°C and RH of 60%, with different doses and types of biochar in order to determine the most effective application to improve soil health. After 7 and 120 days of incubation soils were sampled and analysed to determine parameters such as pH, EC, TOC, total N, N-nitric, N-ammonium and enzymatic activities. Subsequently, compost and plant bioactive extracts were collected and subjected to biochemical analysis. Morphological analyses were also carried out using FTIR spectroscopy to determine the polysaccharide fraction. Once the plant extracts have been obtained, a new soil bioremediation experiment will be carried out using both degraded soils amended with these plant extract together with the biochar and compost to check their efficacy in remediating B and pendimethalin.

### Results and discussion

Both targeted soils showed high levels of degradation, as expected. The soil in Almeria, taken from a greenhouse with intensive horticultural production, had low organic matter, low fertility, and high salinity. The Murcia soil has a lower OM and nutrient content and higher content of B than Almeria soil. On the other hand, following the plant extraction procedures, three different raw materials (persimmon fruits, Opuntia and Borago officinalis) were studied as potential raw materials with bioremediation activity.

Opuntia extracts were found to have a protein content of 5.8%, a fat content of 0.40% and an organic matter content of up to 70%. FTIR showed the presence of different saccharides and pectin, which opened new lines of research to continue the second soil remediation test with biochar and compost.

### Conclusion

No definitive conclusions can be drawn, but, it is expected to get knowledge on novel bioremediation technologies for soils contaminated, contributing to the transition from intensive agricultural model to more sustainable management practices from an environmental and socio-economic point of view. In addition, soil amendment with biochar will allow the use of materials rich in C and N compounds and other nutrients needed to support microbial activity and plant growth.

### Acknowledgements

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## Long-term soil quality changes under paddock trails for horses at the regional scale

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### Introduction

Paddock trails offer horses the possibility to follow their natural urge to move and to behave interactively in a group association (Hildebrandt et al., 2020). This type of horse husbandry has however inevitably consequences for physical, chemical and biological properties of soil, potentially affecting soil quality in a negative way (Romero-Ruiz et al., 2023). The aim of this study is to quantify long-term changes in soil quality under covered and uncovered paddock trails for horses. Specifically, we ask if soil covers prevent the soil from degradation of critical soil functions due to soil compaction, loss of fertility and microbial activity. We hypothesize that soils are better protected when covered and remain in better condition compared to unprotected paddock trails in the long-term.

### Methodology

To test the long-term changes, 17 horse farm estates with covered and uncovered paddock trails with varying soil properties and paddock trail age have been selected across Switzerland, Germany and Luxembourg. A range of physico-chemical soil properties (bulk density (gcm-3), total soil organic carbon and nitrogen (CN), pH and microbial biomass (BM-C (FE)) were measured in a depth explicit way in spring 2022 and compared to nearby unstressed control sites.

### Results & Discussion

The lowest mean value of soil bulk density was found in the unstressed control area (1.04 gcm-3) with values ranging from 0.55 - 1.52 gcm-3. Covered trails showed a slightly higher mean bulk density value (1.13 gcm-3) with high ranging values of 0.58 - 1.75 gcm-3. The uncovered trails showed the highest mean soil bulk density (1.21 gcm-3) with a range of 0.79 - 1.62 gcm-3. Microbial biomass was highest in unstressed control areas (899 mgBM-C (FE) kgsoil), followed by uncovered trails (653 mgBM-C (FE) kgsoil) and covered trails (547 mgBM-C (FE) kgsoil).

Preliminary results indicate a protective effect of soil covers on soil structure, revealed by lower bulk densities compared to uncovered paddock trails. Results of microbial biomass show no definite influence of the protection of soil covers, indicating that farm management, soil type and climate may have an essential influence on this parameter. This influence is currently analysed and will be considered in the final conclusion.

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## Effectiveness of amendments in the restoration of grassland soil physical properties under different compaction and soil moisture conditions

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### Introduction

Soil compaction resulting from heavy machinery traffic is a major concern in grassland management (Keller et al., 2022), with 68 million ha of land globally estimated to have suffered from soil compaction, including 33 million ha in Europe (Hamza and Anderson, 2003; Nawaz et al., 2013). Soil compaction impacts other soil properties and plant growth (Hamza and Anderson, 2005; Batey, 2009) and the degree of soil physical change due to compaction is influenced by soil moisture content at the time of trafficking. Despite efforts to improve physical properties of compacted soils with organic and inorganic amendments, their effectiveness under different compaction and moisture conditions is not well understood. This study aimed to assess the effects of slurry, farmyard manure, and agricultural gypsum on soil physical properties in a compacted grassland site.

### Methodology

One year before soil amendment, plots (7 x 3 m) were compacted during one year of grassland management, involving four machinery passes under different soil moisture deficit (SMD) targets of 10 (dry (D)), 0 (moist (M)), and -10 (wet (W)) mm. Plots were treated with slurry (SL, 33 $m^3$ ha), farmyard manure (FYM, 50 ton $ha^{-1}$), or agricultural gypsum (GY, 1 ton $ha^{-1}$) and compared to non-compacted amended plots (NC) and a control (C) without compaction or amendment. Six months after amendment application, bulk density (BD) samples were taken under the compacted area (as evidenced by tyre marks) at different depths (0-10, 10-20 and 20-30 cm). Additional soil cores (10 cm height, 5 cm diameter) were taken from the topsoil to measure pore size, shape and connectivity using X-ray Computed Tomography (CT). Dry matter yield (DMY) samples were taken every four months to determine short-term effects of the treatments.

### Results and discussion

The study is ongoing; hence, additional details will be given as the results become available. Findings from this study can provide new insights into the effectiveness of different amendments for helping soil restoration from compacted grassland soils. This research can contribute to the development of sustainable soil management practices, which can lead to improved soil health and productivity in grassland management.

### Acknowledgements

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## Eisenia foetida gut microbiota with potential to degrade linear low-density polyethylene

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### Introduction

Annually, the agri-food industry generates millions of tonnes of plastic waste, especially associated with primary agriculture production. In this sector, synthetic plastics are used due to its main characteristic of durability in turn related to its low biodegradability. The limited availability and effectiveness of technologies for its treatment has led to their accumulation in the natural environment, causing serious imbalances in ecosystems (Ahmed et al., 2018). In previous studies, earthworms, in combination with their intestinal microbiota, have shown the ability to partially degrade certain types of plastics (Yang et al., 2018). The aim of this work was to analyse the plastic degrading potential of the gut microbiota of earthworm Eisenia foetida after being fed with different doses of the plastic polymer linear-low density polyethylene (LLDPE).

### Methodology

The study was divided into three main phases. In the first one, the protocol for extracting the microbiota from the digestive tract of earthworms was optimised, ensuring the non-intervention of the superficial microbiota of the individuals studied. In addition, the the number of specimens needed to obtain microbiologically representative results was determined. In the second phase, the general (total bacteria and fungi) and specific (potential degraders of plastics) microbiota of earthworms exposed to different doses of plastics (LLDPE at 2.5% and 5% w/w) was studied and compared with control samples (worms fed without plastics). For this, Petri dishes with Nutrient Agar (NA), Rose Bengal (RB), and Remazol Brilliant Blue Reactive (RBBR) were used to count bacteria, fungi and yeasts, and microorganisms degrading recalcitrant compounds, respectively. Finally, the strains found in greater abundance were isolated in pure culture for subsequent morphological and molecular identification.

### Results and discussion

The results obtained showed the importance of the sample size used, as well as the need for intensive sterilisation of the individuals studied for the acquisition of representative data. The bacterial load was shown independent of the dose of plastic incorporated into the diet. Contrary to what was observed for the total fungal count. Regarding the specific microbiota, an increase in the load of microorganisms capable of growing in selective media (RBBR), mainly bacteria, was observed among individuals subjected to the lowest dose of plastic (LLDPE at 2.55) (Liu et al., 2018). Finally, molecular identification results revealed a higher abundance of bacteria associated with the genera Pseudomonas and Bacillus.

### Conclusion

These results highlight the potential of the Eisenia foetida gut microbiota for the biodegradation of plastic, as a source of microbial inoculants or, directly, during vermicomposting where these animals, together with their microbiota, are the main tools of the process. This work lays the foundation for the development of bioremediation technologies for polluted environments with plastics or other recalcitrant waste.

### Acknowledgements

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## Evaluation of compost effectiveness on soil agrochemical properties using fractional extraction

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### Introduction

Concentrations of total macronutrients and heavy metals are often insufficient to determine the value of compost. It is very important to determine the mobility and plant availability of the macroelements in the compost, because these properties have the greatest influence on the agrochemical properties of the soil - the concentrations of mobile phosphorus, potassium, and mineral nitrogen- which determine the size of the harvest. The purpose of our research is to perform fractional extraction of compost using different extractants, and to determine what part of the macroelements is mobile. The size of the mobile fraction influences the value of the compost and its impact on plant nutrition.

### Methodology

The extractants used are: water, 1M KCl, 0.1 M Na4P2O7, 1M NaOH. Compost is separated into 5 fractions: soluble in water, soluble in salt solutions, fraction bound with complexing agents, fraction bound with organic matter, insoluble - residual fraction. Green waste, food industry waste, manure composts and digestate after processing manure into biogas are used for research. For composts, the proportion of nitrogen, phosphorus and potassium in the mobile water-soluble fraction was determined and the mobility coefficients of macroelements were calculated.

### Results and discussion

Every input waste has different nutrient contents, in turn, suggesting that every compost has different fertiliser and/or soil improvement values. (Grigatti M. at all 2015, Lanno M. at all 2021) Sequential extraction, with increasing strength extractants, was successfully applied to compost from many different origins, aiming to determine the pattern of P solubility, i.e. labile, non-labile; inorganic–organic (Jakubus M.2016). Composts made from manure contain the highest proportion of water-soluble nitrogen, phosphorus and potassium. The concentration of mineral nitrogen in this compost reached as much as 20 percent of the total nitrogen content when other types of compost contained only a few percent. Green waste compost has the smallest amounts of soluble macroelements, so its role as a fertilizer for the agrochemical properties of the soil is small, it plays a more important role in improving the soil structure and increasing the amount of organic matter.

### Conclusion

Thus, comprehensive analyses are required, assessing resources of available macroelements both in composts and in soils fertilized with these composts, to ensure that such supplementation is consistent with the principles of sustainable fertilization and environmental protection. A brief conclusion is recommended; or exclude if your results are not yet known.

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## Deploying green technology to Improve soil health in African countries by using vermicomposting technology: A Review

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### Introduction

Various studies in African countries have revealed that the disposal of about 90% of municipal solid waste (MSW) is uncontrolled. Thiswaste is dumped in open areas and landfill sites, creating problems for public health and the environment. In addition, the harsh environment (hot weather and acidic soil) led to a decline in the soil quality of the region. This situation has increased the need for long-term green strategies in agricultural engineering and sustainable waste management. Among different biological treatments, vermicomposting (VC) is an environmentally friendly process that meets sustainability goal 7 of the UN Millennium Development Goals (MDG7) and is consistent with the ecological sanitation concept. To date, there are more than 10,000 publications related to earthworms. Sub-Saharan African countries suffer from soil degradation and a significant decline in soil fertility that adversely affects crop yield and food production (Gebrehana et al., 2022). Vermicompost, the end product of a VC process, is sometimes called "black gold", because of its valuable properties concerning plant health and growth. Vermicompost is an excellent plant growth promoter, with demonstrated positive effects on various aspects of agricultural and horticultural development (Gómez-Brandón et al., 2015). Vermicompost can balance the entire soil environment while providing a desirable habitat for soil microbes (Saha et al., 2022). Hence, the present work highlights VC as a sustainable, economical approach to waste management in African countries and evaluates technologies for improving agricultural practices and soil bioremediation.

### Vermicomposting practice in African countries and its challenges

A few studies have been conducted in Africa on vermicomposting with various substrates, including sludge, paper waste, agricultural waste (rice straw, leaf litter, sawdust, banana peel, etc.), and winery wastes. Katakula et al. (2021) applied Eisenia fetida for the vermicomposting of goat manure mixed with vegetables. The authors reported that after 12 weeks of vermicomposting, total phosphorus was significantly increased to about 60%. A significant increase in NPK levels after vermicomposting was continuously reported by different authors, such as Gardefors (2015) and Manyuchi et al. (2018) from South Africa, and Gichaba et al. (2020) from Kenya. In general, vermicompost can balance the entire soil environment while providing a desirable habitat for soil microbes (Saha et al., 2022). Ijah et al. (2021) studied the growth of Nigerian native plants Melissa officinalis L (lemon balm) and Sida acuta (stubborn weed) using vermicompost as an amendment soil. The authors reported a high potential for phytoremediation and phytostabilization. In addition, a few other scholars reported that the application of vermicompost on African countries' contaminated soils successfully decreased contaminants' bioavailability. For instance, Lukashe et al. (2020) noted that the uptake of Fe, Mn, Zn and Cr in Chloris gayana (Rhodes grass) was significantly reduced by adding vermicompost. Although vermicomposting is promoted as a sustainable solution to soil fertility in Africa, there remain challenges regarding the successful application of this technology. According to Hengel (2021), diverse soil types are found in Africa, making them a suitable niche for various earthworm species such as Keffia penetrabilis n. sp. and K. proxipora n. sp. However, hot climate and dry soil properties are not a favourable conditions for earthworm growth. In addition, a lack of general awareness of earthworm biology, optimal growth temperature requirement, substrate quality, etc., discourages smallholders from using the vermicomposting technique as a sustainable solution.

### Conclusion

The simple methodology and the low investment required make vermicomposting applications possible in low-income areas, mainly tropical countries. However, increasing awareness among the farmers and stakeholders will contribute to a successful, efficient vermicomposting strategy. There is, therefore, an excellent opportunity to initiate specific initiatives involving people, private companies, and governments to develop sustainable waste management solutions. Public-private partnerships (PPPs) seem to solve waste management issues (particularly in developing and underdeveloped countries).

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## Recycled fertilizer for organic farming – assessing the effect on soil fertility and associated risks with potentially toxic elements

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### Introduction

There is a large political motivation goal in the EU to increase organic farming area to 25%. However, for this, additional nutrients, preferably from recycled sources are needed. Before their wide use in organic farming concerns about contamination with potentially toxic elements (PTEs) and their influence on soil fertility must be assessed. In this study, the effect of recycled fertilizers from urban waste on crop yield, nutrient balances, soil fertility (especially soil nitrogen and carbon), and risk of contamination with PTEs were examined. Therefore, data from three long-term (>20 years) were analysed and combined with a model simulation exercise to gain more insight into the nitrogen (N) and carbon (C) cycle.

### Methodology

Data from three long-term field trials using different recycled fertilizers, including compost from household and green waste, human urine, and sewage sludge was analysed. The first trial investigates different compost application rates in combination with mineral fertilization and was established in 1997 at the research station Heidfeldhof, South Germany. The second trial compares different application rates of sewage sludge and was established 1981 in Speyer, Germany. The third trial is called CRUCIAL and was established in 2002 at the station Taarstrup, Denmark. It compares compost from household and green waste, human urine, and sewage sludge to mineral fertilization and cattle manures. Crop yield, and soil parameters like soil carbon, soil N, phosphorus, potassium, and PTE content were collected and analysed. The results of the CRUCIAL trial were used to calibrate the soil-plant-atmosphere model DAISY which in turn was used to estimate water, C and N flows.

### Results and discussion

Recycling urban waste into fertilizers can serve as a viable source of nutrients. In terms of nitrogen recovery rates, sewage sludge and human urine performed similarly to cattle slurry with N recovery rates of about 0.5 – 0.6, while household waste compost showed similar values to straw-rich animal manures with N recovery rates of about 0.3. After field application, the model simulation estimated nitrogen losses ranging from 34-55% with nitrate leaching being the primary loss pathway. Compost and cattle manure resulted in slightly smaller total nitrogen losses. Further, higher soil nitrogen accumulation of about 25% of the applied nitrogen were associated with compost and manure application. Compost also had the highest soil carbon sequestration of about 0.36, while cattle manure showed 0.12, sewage sludge 0.09, and cattle slurry 0.02. Concerns about contaminants, such as PTEs, exist, particularly with compost and sewage sludge fertilization, which can increase PTE levels in the soil. Yet, not above the precautionary threshold levels. Additionally, significant changes in crop PTE uptake were rare probably due to low PTE bioavailability.

### Conclusion

The organic nutrient management in Europe requires more external nutrient inputs, and recycled fertilizers from urban wastes are an adequate source to close the nutrient gap and substitute animal manures from conventional origin. They additionally can increase soil carbon and nitrogen levels. Overall, the use of recycled fertilizers from urban waste is a promising solution, with negligible risks associated with PTEs to human health and the soil environment.

### Acknowledgements

This study was conducted within the RELACS project 'Replacement of Contentious Inputs in Organic Farming Systems', which has received funding from the European Union's Horizon 2020 research and innovation program under grant agreement No 773431.

## Application of pig slurry as a phosphorus fertiliser at different application rates: impact on potential leaching of nutrients

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### Introduction

Animal manure application is mostly applied based on its nitrogen (N) content and it is applied uniformly across a field, without accounting for the phosphorus (P) provided. Underapplication of P can limit plant growth and crop productivity, whereas overapplication of P can result in nutrient loss through runoff or leaching, and if it reaches freshwaters can stimulate algae growth, which is a major contributing factor to water eutrophication (Kang et al., 2011). As such, taking into consideration soil spatial variability when applying animal manures is a strategy to increase crop productivity in poor-fertility areas and to reduce P losses in high-fertility areas within a field. A leaching experiment was conducted to understand the potential loss of nutrients from the soil following the application of pig slurry as a P fertiliser and to meet different soil P requirements.

### Methodology

The leaching experiment was conducted on PVC columns, each containing 1 kg of soil and the fertiliser to study the effects of three different application rates of pig slurry in three different sandy soils. Each soil had different concentrations of extractable soil P: very low (VL, <25 ppm), low (L, 26-50 ppm) and medium (M, 51-100 ppm). The application rates used were 200, 300 and 400 kg P2O5 ha-1 and were based on the recommendation for vineyard installation for M, L and VL content of extractable P in soils, respectively. For each soil, four treatments were established: a control with no fertiliser, and the three different application rates of pig slurry, with four replicates each. Following the application of pig slurry, irrigation events (IE) were simulated (3, 10, 17, 24, 31, 38, and 45 days after slurry incorporation) as described in Fangueiro et al. (2014).

### Results and discussion

The preliminary results showed a peak of leached P in the pig slurry treatments on day 17 after the incorporation of the slurry, and afterwards, the amount leached decreased over time, remaining higher than the control. There were only significant differences between the application rates, regardless of the soil, at day 17, with the highest application rates losing more P. Taking soil into consideration, higher P losses were observed in the treatment with soil M and the 400-application rate. Most of the ammonium (NH4+-N) was lost in the first two IEs, which was the NH4+-N present in the pig slurry. In the controls of each soil, the loss of NH4+-N was negligible. Nitrate (NO3--N) losses occurred immediately in the first IEs in all treatments, indicating that indigenous soil NO3--N was being lost. In the second and third IE, NO3--N losses were higher in the control treatments and, afterwards, the amount of NO3--N lost was higher in the pig slurry treatments, with little significant difference between the application rates. The electrical conductivity (EC) of leachates was higher in the first IEs in the slurry treatments, due to the amount of nutrients that were leached from the columns, but then gradually decreased until reaching the values of the ctrl at the end of the experiment.

### Conclusion

Further analyses are still being conducted, however, the preliminary results show that applying pig slurry, without taking into consideration the soil spatial variability, led to higher amounts of nutrients lost.

### Acknowledgements

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**Future water pollution reduction requires accounting for multiple pollutants** Li Yanan [a,b], Wang Mengru [a.d], Zhang Qi [a,b], Kroeze Carolien [a.d] , Xu Wen [a], Ma Lin [c], Zhang Fusuo [a] & Strokal Maryna [b]

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## Introduction

Agriculture and urbanization are often the common sources of multiple pollutants in rivers. These pollutants include nitrogen, phosphorus, pathogen (Cryptosporidium), and plastics, chemicals. Multiple pollutant pollution challenged global clean water availability and affect the ecosystems and public health. However, existing studies focus on individual groups of pollutants, but hardly on multiple pollutants. Furthermore, existing studies are limited in quantifying inputs of multiple pollutants to rivers from both urban and agricultural sources. To better understand the future multiple pollutant pollution in rivers, we select 395 Chinese sub-basins as a case study. We integrated existing MARINA (Model to Assess River inputs of pollutaNts to seAs) models to explore future trends in river pollution with multiple pollutants under a scenario with high socioeconomic developments and global warming with limited environmental policies.

## Methodology

MARINA is a large-scale water quality model. Many versions of MARINA have been developed and applied across the world for different purposes. We integrated three versions of the MARINA models (e.g., MARINA-Multi (Global 1.0), MARINA-Multi (Global 2.0), and MARINA-Plastics (China-1.0)) to estimate multiple pollutant pollution in China for 2050. We account for Dissolved Organic Nitrogen (DON), Dissolved Inorganic Nitrogen (DIN), Dissolved Inorganic Phosphorus (DIP), Dissolved Organic Phosphorus (DOP), Macro-and microplastics, Cryptosporidium inputs to rivers from urban, rural, and agricultural sources.

## Results and discussion

Inputs of pollutants to all Chinese rivers are projected to increase during 2010-2050. Plastics in Chinese rivers are expected to increase by 80% as a result of future urbanization in the year 2050. Cryptosporidium in Chinese rivers is expected to increase by over 90 % as a result of future agricultural activities in the year 2050. Nutrients in Chinese rivers are expected to increase by 57%-70% as a result of future urbanization and agricultural activities in the year 2050. In general, over 50% of the national population is projected to live in sub-basins where rivers may be affected by at least two types of pollutants. We argue that future water pollution reduction options need to account for multiple pollutants. Pollutant reduction needs to associate with specific sources. Our study can inspire policymakers for designing water pollution management strategies in China.

## Conclusion

Our research is original in two aspects. First, our research integrates knowledge of urban, rural, agriculture, and water pollution from a multiple-pollutant perspective. Second, our research highlights the dominate pollutants in urban and agriculture, respectively. This provides insights into future water pollution management for urban and agriculture.

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**Phosphorus Loss in Sub-Surface Runoff Water Differed with Manure Forms in the Lake Erie Basin, Canada**

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## Introduction

Amid growing concerns of rising phosphorus (P) losses from soil to water resource, nutrient management regulations encourage P-based manure application to alleviate soil P build-up and loss risk resulted from conventional N-based approach. Effect of manure addition on soil P loss can vary depending on types, forms, and handling processes. In addition, sub-surface runoff (i.e., tile drainage) has been deemed a predominate pathway for soil P loss in the Great Lakes region (Zhang, et al., 2002). We conducted a 4-year study to evaluate the effects of P-based application of various forms of cattle manure and chemical fertilizer on soil P loss in sub-surface runoff water in the Lake Erie basin, Canada.

## Methodology

A four-year study was conducted in a Brookston clay loam soil located on the Harrow RDC research farm, Agriculture & Agri-Food Canada, ON, Canada. Treatments included liquid cattle manure (LCM), solid cattle manure (SCM), and chemical fertilizer as triple superphosphate (IP). Each treatment received 50 kg P ha-1 in the corn phase of corn-soybean rotation. There were two replicates for the study, with each plot dimensioned at 15m by 67 m. In each plot, three drainage tiles were installed. Tile drainage water from each full plot was delivered to a single collection sump. Drainage flow volumes were monitored with water samples collected using on-site equipped auto-systems that ran continuously year-round. Water samples were analyzed for dissolved reactive P (DRP), particulate P (PP), and total P (TP). DRP flow-weighted mean (FWM) concentrations were calculated on an annual basis or for the 4-yr study period.

## Results & Discussion

Ranging between 345 and 420 mm yr-1, mean tile drainage flow accounted for 37 to 45% of mean annual precipitation over the four year. Compared with IP, the SCM amendment had significantly lower flow volume of tile drainage over the period of the study (420 vs. 345 mm yr-1). No significant difference in tile drainage flow volume was observed between LCM and either IP or SCM amendment regimes.

Over the four years, the FWM DRP concentration in sub-surface runoff water was greater under SCM than either IP or LCM fertilization. Notwithstanding its lower value on an annual basis, FWM DRP concentration rose dramatically immediately after LCM application. However, the differences in FWM DRP concentration did not result in detectable differences in DRP loads, due to compensating tile drainage flow volumes. Compared with IP applications, those of SCM decreased PP and TP loss in sub-surface water over the four years by 68% and 47%, respectively, whereas LCM applications had no such effect. Overall, the P contained in SCM was less prone to P loss after land application.

Regarding to P form distribution and loss in tile drainage water, during the first year, the ratio of DRP/TP loads declined from 88 to 25% for the IP plots, and from 61 to 21% for the LCM plots, whereas for SCM plots, it dropped from 63 to 35% and then rose back up to 50%. The peak DRP/TP ratio in tile drainage water occurred in the 1st 2.5 months of the 1st year, showing the substantial effect of surface P application on promoting DRP loss within a short period of time after application. Starting at the end of the 1st year, the % of cumulative DRP/TP loads remained relatively stable: SCM (53–56%) > IP (26–34%) > LCM (22–32%). Overall, DRP loss represented a smaller fraction of TP loss from both IP-and LCM plots. The main reason for higher DRP/ TP ratios with SCM was that this treatment, while having similar DRP loads to the IP and LCM treatments, had significantly lower PP loads in tile drainage water.

## Conclusion

Inorganic P, LCM, and SCM had different effects on P losses in tile drainage water after land application. Although LCM resulted in dramatically higher DRP FWMC soon after application, on an annual basis, SCM addition resulted in higher DRP FWMC. Over the 4-yr, annual DRP loads were similar among the three P sources due to flow volume compensating the DRP concentration. However, it might be reasonable to expect a reduction in DRP loss if LCM can be arranged to avoid rainfall events immediately after application. In contrast with annual DRP FWMC, annual PP FWMC was lower with SCM than either with IP or LCM. This may indicate that even if one selects appropriate P source for land addition, it will remain challenging to simultaneously reduce both DRP and PP losses. Along with reduced tile drainage flow volume, SCM reduced PP FWMC and consequently the PP and TP loads in sub-surface water. Solid cattle manure can be a more environmentally friendly source than the LCM to provide P for crop growth.

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## Nature of Phosphorus in Canada-Wide Animal Manures and Implications for Sustainable Management

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### Introduction

Canadian livestock produces annually over 146 million tonne of manure, containing 889 and 245 Gg of nitrogen (N) and phosphorus (P), respectively, equivalent to 43% and 67% of fertilizer N and P consumption in the country (Zhang, 2018). Due to the significant cost of commercial fertilizers and rapid depletion of global phosphate rock reserves, land application of manures has come to be viewed less as waste disposal and more for fertilizer replacement and soil improvement (Gilbert, 2009). However, manure applications, commonly based on N requirements for crop growth, often result in over-application of P due to the discrepancy in N:P ratio between manure and field crops. Accumulation of P in soils would increase potentials for losses in both surface and sub-surface runoff water into water resources. Farm land application of animal manure has been deemed a predominate factor contributing to eutrophication of many lakes and rivers in the world, such as Lake Erie (GLWQANAS, 2019). A comprehensive understanding on manure P chemistry in association with its availability to plants and runoff water loss is prerequisite to improve manure management in an environmentally sustainable manner.

### Methodology

Representative manure samples were collected from farms of major intensive livestock areas of Canada. Manure samples were stored and transported under controlled environment, and ground freshly at -80oC using a free mill. Phosphorus in manures was sequentially fractionated with H2O, 0.5 M NaHCO3, 0.1 M NaOH, and 1.0 M HCl, respectively, into various inorganic (Pi) and organic P (Po).

### Results and discussion

Across the manures, total P (TP) ranged from 3.71 to 17.3 g kg-1, with total Pi and available P (i.e., the sum of H2O-Pi and NaHCO3-Pi) accounting for 67.0-92.4% and 35.6-67.3% of TP, respectively. Available P varied with manure type, form, and the handling process, following the order of liquid dairy > solid dairy > liquid swine > solid beef > solid dairy compost > solid poultry > solid beef compost > solid poultry compost, in percentage of TP. Composting reduced the percentages of available P and Po in TP, and meanwhile increased the percentages of moderately stable HCl-Pi. Compared to other P fractions, manure available P increased more rapidly with increases in TP; once manure TP reached 7.8-9.6 g kg-1, further TP increase enhanced transformation to more recalcitrant P (i.e., NaOH-Pi and HCl-Pi). Under Canadian conditions, manure application to meet the demand of crops for N would lead to P build-up in the soil at rates of 6.1-41.6 kg P kg-1yr-1, increasing runoff P loss risk.

### Conclusion

Manure P content varied remarkably in Canada, with up to 97.3% in inorganic forms and 67.3% in available forms. Organic P accounted for 2.7-17.4% of manure TP and would not contribute much to available P after land application. Composting promoted formation of recalcitrant Pi at the cost of Po and available P. There were positive relationships between manure available P and TP, but just up to a certain point, above which further TP increase enhanced the formation of recalcitrant P. For both manure compost and poultry manure, current land application protocol often based on manure TP may provide insufficient available P for crop growth in the season and meanwhile generate less incidental dissolved P losses if a runoff event occurs immediately after application. However, they may cause rapid P buildup in the soil due to large additions of moderately stable P and become a long-term P source for runoff losses. This needs to be taken into consideration in the future when BMPs and policies are amended and/or new ones are developed to achieve the goals of real profitable and sustainable crop production with cleaner environment.

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## Reducing N leaching in semi-arid winter conditions through cover crops, tillage dates and irrigation on demand in Austria's Marchfeld region

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### Introduction

Cover crops (CC) have shown promise in reducing nitrogen (N) leaching, but in semi-arid regions, they might compete with subsequent field culture for water availability (Liebig et al. 2015; Reese et al. 2014). In Austria's Marchfeld region, which is intensively used for agriculture, nitrate levels in groundwater exceed threshold values due to limited dilution of seepage water caused by low annual precipitation. Since most of the precipitation in this region falls in winter when plants do not need much N, the N mineralized in autumn leaches down to groundwater. Early sown CC with sufficient emergence and N uptake might reduce such groundwater pollution. However, CC induced changes in soil water availability could impact the follow-up crop. To investigate the impact of cover crops (CC) on nitrogen (N) leaching, water availability, and competition with subsequent field culture, we conducted two field trials. To optimize CC development, we also implemented irrigation on demand. We used CC varieties with different seed compositions (frosting, winter hardy, none/fallow) and tillage dates (autumn, spring).

### Methodology

A field trial was set up twice in two consecutive years but at different agricultural fields. The randomized block trial consisted of following CC varieties: frosting CC – autumn conversion, frosting CC – spring conversion, mixture of winter hardy and frosting CC – spring conversion and fallow plots. CC irrigation on demand was performed with same varieties. Within each plot soil moisture sensors and suction cups were installed. Soil moisture sensors were installed at the soil surface and as well in 30 cm, 60 cm and 90 cm below soil surface. Two suction cups per plot were installed in 90 cm. The soil water collected with suction cups were analysed for NO3-, NH4+, Cl-, pH and electrical conductivity. Within some plots matrix potential sensors were installed in 3 depth to gain more data on water availability and for irrigation scheduling. Mineralized N samples were taken monthly at 0-30 cm, 30-60 cm, and 60-90 cm depths in each plot to document the dynamics of N mineralization. Plant samples were taken in autumn and spring before the CC conversion and at harvest of the subsequent crop to monitor any effect on yield in relation to N, water availability and weed pressure. All plant samples were analysed for fresh and dry matter and C/N content. Evaporation was measured using four Mini-Lysimeters, one for each CC mixture, but only for the plots without irrigation and the first year of investigation. We used STOTRASIM, which is a soil water and mass transport model to model amount of seepage water of each plot (Feichtinger 1998).

### Results and discussion

Data from the first year of the trial indicate that CC conversion in spring resulted in a lower amount of N leaching to groundwater compared to conversions in autumn and fallow fields. Because of the relatively dry winter of the first year, most N leaching occurred under irrigated follow-up crops. CC + spring conversion reduced N leaching by four times compared to the fallow variety. The data on mineralized N levels are consistent with the N leaching data.

The soil water content did not show any significant differences between plots when comparing water content at the CC seeding with the time of seed of the follow-up crop. However, the data from the Mini-Lysimeter indicated that evaporation was higher (30 mm) in the CC plot compared to the fallow plot. Moderate weed pressure due to thistles was observed, which was mainly induced by limited tillage prior to CC seeding and limited CC development, resulting in modest ground cover. The yield of the follow up crop was not affected by the different CC varieties. To further support the results from the first trial year, data from the second trial year (autumn 2022 - autumn 2023) should be considered.

To fully understand the practical implications of the field trial, several factors need to be considered. These include issues related to phyto-sanitation, seedbed preparation, tillage methods, crop rotation, and choice of follow-up culture.

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## Phosphorus filters as a mitigation tool to achieve the Danish climate goals for agriculture

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### Introduction

Denmark aims to reduce agricultural greenhouse gas (GHG) emissions with 1,9 mil tons of CO2e by 2030 (Ministry of Finance, 2021). Emissions from cultivated peatlands are recognized as one of the major GHG contributors in the Danish agricultural sector, though carbon-rich peatlands represent less than 7% of all cultivated areas in Denmark (Klimarådet, 2020). It is estimated that the annual GHG emission from Danish peatlands is roughly 5,7 mil tons CO2e, corresponding to approximately 40% of all GHG emissions from the Danish agricultural sector (DCA, 2023). Thus, one of the Danish strategies to meet the climate goals is to rewet 50.500 ha of peatland soil (Ministry of Finance, 2021). However, rewetting can remobilize phosphorus (P) which can cause loss of aquatic biodiversity due to eutrophication. Therefore, all rewetting projects must undergo a nationally P-risk evaluation. So far, this evaluation has resulted in the rejection of 33% of all submitted rewetting projects due to the risk of substantial P-losses (Filsø S.S, 2019). Consequently, Denmark needs new P-mitigation strategies to reach the current climate goals for the agricultural sector. The GUDP FosLav project (2022-2025) aims at developing highly efficient P filters by utilizing and combining existing filter components. Hereby developing new P-mitigation tools, which can increase the acceptance rate of rewetting projects and thus accelerate the green transition of the Danish agricultural sector.

### Methodology

The project entails three study sites across Denmark. Two of the areas are peatlands and one area consists of drained mineral soil. According to an initial analysis of soil and water chemistry different combinations of sediment filters from WaterCare Aps, electro-flocculation devices from Bio-Aqua A/S, and reactive filters from DiaPure AB will be tested and evaluated in relation to the retention of both particulate and dissolved P. Water samples will be collected at the inlet and after each filter component to determine the effectiveness of the individual filter components and of the whole filter system.

### Results and discussion

The FosLav project has yet to produce results of the filter's effectiveness. However previous results from small-scale experiments have shown a monthly removal rate for TP varying between -33 to 88%, with an average removal of 61%, indicating an acceptable average efficiency. However, in the previous study only 10% of the drainage water from a 25-ha catchment was directed through the reactive filter component (Pugliese and Heckrath, 2022). Consequently, full-scale field experiments are necessary to evaluate the true potential of the filter systems, and this is the purpose of the GUDP FosLav project, which is currently collecting data from the first two active P-filter systems.

### Acknowledgments

The FosLav project is funded by the Green Development and Demonstration Program and Promilleafgiftsfonden for Landbrug.

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## Prediction of the mobility and persistence of eight antibiotics based on soil characteristics

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### Introduction

Closing nutrient cycles is one of the basic pillars supporting the circular economy. To ensure food production over time, the recycling of crucial nutrients into agro-food complex is most relevant. In today's western lifestyle human excreta are considered as waste and treated accordingly. As a result approximately 30 % of the phosphorus input in food production is leaving the agro-food circle, either ending up in the ash after incineration or finding its way towards the oceans. It is expected that recycling will result into new organic and organo-mineral fertilizers becoming available in the near future. These products should meet criteria on nutrients, but should also be checked for the presence of unwanted substances. A limited number of substances are (inter)nationally regulated, but still a large number of substances is not and this number is still increasing. Examples of (emerging) contaminants are: PFAS, nanoparticles, personal care products, medicinal compounds used by humans, veterinary drugs and endocrine disrupting compounds. In order to evaluate the risks related to these (new) substances it is important to know where (soil/water/product), to what extent and when (time) risks occur. To be able to predict these risks, it is essential that information is available on the mobility and persistence of these potentially harmful substances. In the Netherlands antibiotics are widely used in intensive animal husbandry and subsequently emitted to soil via manure. Most prediction models are, however, based on limited number of soils and have been not validated for arable soils in the Netherlands. To improve model predictions, we have investigated behaviour of 8 commonly used antibiotics in 29 typical Dutch arable soils, to assess to what extent soil characteristics affect sorption and degradation.

### Methodology

Laboratory experiments have been performed to investigate the behaviour of antibiotics in Dutch soils. Both the mobility (log Kd) and degradation (DT50) of 8 commonly used antibiotics in 29 well characterised Dutch soils were determined using a recently developed experimental approach (Berendsen et al. 2021). Soils were spiked with antibiotics and added to columns and extracted with 0.01 M CaCl2 to assess their mobility. Persistence was evaluated by spiking the soils and measuring at the start and after a month. The acquired data were evaluated to extract the model parameters to describe the sorption and degradation.

### Results and discussion

The obtained results show that the range of DT50 for any given antibiotic is large across different soils (Rietra et al., 2023, in prep). For almost all antibiotics DT50 and Kd are correlated to individual soil properties. Some antibiotics show strong sorption to all soils. The modelling test show that the range in DT50 and Kd can be predicted reasonably well based on the soil characteristics and sampling depth.

### Conclusion

Organic matter, iron oxides, pH and clay content appear to be important factors that explain the variation in DT50 and Kd. The effect of sampling depth on DT50 and Kd is limited. This information in combination with local data on soil type can be used to more accurately predict the potential risk of antibiotics in soil and transport to ground- and nearby surface waters.

### Acknowledgements

This project was funded by the Dutch KB programme Circular & Climate Neutral Society of Wageningen University and Research.

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## Effect of liming on phosphorus leaching

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### Introduction

In agricultural areas phosphorus in surface waters often exceeds limits values due to leaching and surface runoff. Although P-surpluses in Dutch agricultural soils have decreased considerably since 1986 (Dutch Fertilizer Law), the agricultural soils still contain the legacy from using excessive amounts of P-rich animal manure in the past; in 2013 the surpluses in the Netherlands was still one of the highest in Europe1. To reduce P leaching in this context new measures are needed. For 2020, modelled surface runoff and leaching of P from agricultural soils to Dutch surface waters varied from 0.4 to 4.9 kg P ha-2, in which leaching gives the highest contribution. Long-term scientific field experiments to validate modelled P-leaching and surface runoff are scarce and the distinction between leaching and surface runoff is uncertain. Consequently, the effectiveness of several measures to reduce P-leaching and surface runoff is also uncertain. Therefore, we set up several experiments to investigate surface runoff and the effect of measures that can reduce surface runoff and leaching of P to surface waters, including 1) barriers in ridge cultivation in potato fields, and 2) liming of sandy soils.

### Methodology

Surface runoff and the effect of barriers: Surface runoff due to heavy summer rains has been determined within 8 potato fields and 1 maize field in 2020 and 2021. Slopes vary from 0.6 to 6.5%. In these fields, the runoff was captured in 6 metal V-shaped funnels and connected 90-L vessels that were buried in the soil. Each vessel gathered the runoff from a plot of 2.25 m by 9.5 m, three plots with and three plots without the barriers. The barriers, about 1 inch high, were created automatically with the tillage for ridge cultivation. Rainfall was determined on-site. Besides the field experiment, in a catchment of 38 hectares with loss soils and an average slope of 6%, the discharge and sediment was measured during 18 months using an automatic water sampler (ISCO). Together, it resulted in resp. 324 and 177 runoff samples in which the P concentration was determined, and it resulted in resp. 138 sediment samples from the fields and 32 from the catchment in which oxalate extractable P, Fe, and Al content was determined. Liming of sandy soils: international literature2 shows that the effect of lime on P equilibrium concentration is very divers, also in Dutch soils. In the laboratory, the pH dependency of the P concentration in CaCl2 has been determined for soils in all 8 investigated fields. A selection of three soils have been limed in the laboratory a three rates (0-10-20 gram lime per 7 kg soil) to assess the effect of agricultural lime on P in soil solution after one year, using sampling by Rhizon samplers, centrifugation, and 0.01 M CaCl2 extractable P.

### Results and discussion

Average P concentrations in surface run-off samples per potato field varied between 0.3 to 2.4 mg P-PO4 L-1, and the average P concentration in the catchment was 0.7 mg P-PO4 L-1. Note: the WFD-targets for average P-concentrations are 0.11 mg P/l in most Dutch surface waters bodies. The captured water volume was limited to 6-78 mm of water, the corresponding dissolved loads were 0.01 to 0.16 kg P ha-1 and via sediment load was 0.9 to 8.6 kg P ha-1 in the surface runoff. The barriers resulted in a limited lower P surface runoff. The P-loads from the sloping catchment, due to 9 events within 18 months, was in total 0.17 kg P ha-1 via water and 2.2 kg P ha-1 via sediment. This corresponds well with the European average: app. 2 kg P ha-1 is lost via erosion3. All studied soils show a strong pH dependency of P: higher P concentration at lower pH values, and lower P concentrations at higher pH values. The effect of using agricultural lime on soil solution shows that the P concentration in acid sandy soils can be decreased approximately to 1/3 of the original P concentration by increasing the soil pH from 5.5 to 6.5. This part of the research is continued in the period 2023-2025.

### Conclusion

The catchment and surface plot measurements show that P runoff via water (<0.2 kg P ha-1) is relatively small, while the P transport via sediment-bound P was app. 13 times higher. As the runoff was limited, also efforts to decrease P transport using barriers in potato field resulted in a limited effect. The effect of increasing the soil pH from 5.5 to 6.5 using lime resulted in a 66% decrease of P concentrations in acid sandy soils.

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## Influence of manure management on $NH_3$, $N_2O$, $CH_4$ emission from fattening piggeries

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### Introduction

In France, in the foreseeable future, for different reasons (climate change, social expectations…), the contribution of pig production (NH3 : 8% - N2O :4% - CH4 : 9% - Citepa, 2022) will have to be drastically reduced. Housing is the first step in the emission process and building design and practices can effectively affect emissions from storage and land application. The aim of this study is to make an inventory of knowledge published in the literature concerning NH3, N2O and CH4 emission factors for fattening pigs in relation with manure management.

### Methodology

This work is based on the use of the database called ELFE (ELevage et Facteurs d'Emission, i.e., Livestock and Emission Factors) described by Vigan et al. (2019). This database gathers emission factors available on articles published between 1964 and 2022 but also metadata concerning breeding conditions and measurement methodology. Each publication has been carefully read to extract relevant data and adding it to the database. After this data collection work, the second step was the conversion of raw data to reference units. For the need of the present study, only the conversion to kg per place per year is presented. When the raw emission data was not expressed into the reference unit, additional data concerning breeding techniques for example were used for the conversion. A statistical analysis was conducted to identify the main factors of influence on NH3, N2O and CH4 emissions in relation with manure management.

### Results and discussion

In December 2022, 1 073 articles from 22 countries are collected in the database ELFE with a total of 2 116 emissions factors concerning emissions from pig buildings. Around 50 % of data concerns ammonia emission (N2O: 11%; CH4: 13% - CO2: 10% - Odour and particles: 16 %) and 82% is devoted to fattening pigs (sows: 9%; post-weaning piglet: 9%). The statistical analysis led to identify two main ways of reducing gaseous emissions: the nutritional strategy and especially the crude protein content of the food and the manure management inside the building. For fattening pigs bred on fully slatted floor and with storage of slurry in the pit during the whole presence of animal, the median emission factor for ammonia is 3.1 kg NH3_N.place-1. year-1 when one-phase-feeding strategy (average crude protein : 16.7 % - calculation made with 18 data from 7 publications) is applied vs 2.9 kg NH3_N.place-1. year-1 with a multiphase feeding strategy (average crude protein : 15.3 % - calculation made with 131 data from 29 publications). Concerning the effect of manure management, the implementation of manure collection in water lead to a reduction to close to 2 kg kg NH3_N. place-1.year-1 (calculations made with 14 data from 4 publications) and around 1.4 kg NH3_N.place-1.year-1 for pigs bred in building equipped with V-Scraper (calculations made with 10 data from 4 publications). Comparisons between emission factors obtained with ELFE data and other references such as EMEP (2019) and Bittman et al. (2014) for the UNECE TFRN have been made and discussed. The same analysis has been made for N2O and CH4 in relation with different ways of manure management.

### Conclusion

Much data is available in the literature on the influence of manure management on ammonia emitted by piggeries. Nevertheless, additional studies are necessary to obtain enough data for the calculation of N2O and CH4 emission factors.

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## A tool to reduce workers exposure from ammonia and particles in swine and poultry housing

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### Introduction

In France, more than 30 000 people work daily in swine buildings or poultry houses. Air quality inside pig and poultry housing is already known to be concentrated in several gases – ammonia is the most studied – but also particles (Lagadec et al., 2020). Regular exposure is associated with a high prevalence of respiratory dysfunctions and pathologies such as chronic bronchitis or asthma. This prevalence is multiplied by 2-3 for farmers in comparison to the general population (Iversen et al., 2000). The principal aim of this project called QualiAir is to develop an assessment tool to (1) allow workers to evaluate the air quality inside buildings, (2) promote the implantation of techniques to prevent the risk of ammonia and particles exposure and (3) advise workers on the existence and the use of personal protective equipment (PPE).

### Methodology

The first step of the project is the building of the self-diagnostic tool to assess the air quality inside a building. This will be elaborated on data collected from farmers organisations (pig and poultry) and the previous expertise of partners in air quality. The next steps are the elaboration of fact sheets highlighting (1) the different ways of reduction of gas and particles inside building and (2) the different type of personal protective equipment with a focus on strengths and weaknesses of each. After having collected data on PPE available in the market, a study will be conducted on their assessment on the ground directly by farmers and people working in the experimental farms of Chamber of Agriculture and Ifip. Results of the study will be the base of exchange between partners and manufacturers for the improvement of one or two PPE.

### Results and discussion

For the first step of the project, a questionnaire grouping technical aspects (type of floor, manure management, kind of ventilation…), working organisation (duration and type of work, previous works, …) and health history (specific pathology, medical therapy…) has been elaborated by the partners of the project. A group of 12 pig farmers and 12 poultry farmers essentially located in Western France has been formed to be directly implicated in the test of the self-diagnostic tool. Visits and collection of data will be completed in summer 2023. In relation with a previous work done on best practices to reduce ammonia and particles (Guingand et al., 2019), a multi-criteria evaluation grid on mitigation techniques to reduce gas and particles has been built. The writing of fact sheets in progress and contacts have been already taken with manufacturers of PPE.

### Conclusions

The different steps of the project have been started and first results of the project are available on the following web site: www.qualiair.chambres-agriculture.fr.

### Acknowledgements

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## A new tool for the comparison of emission factors of pig and poultry housing

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### Introduction

Livestock systems are responsible of a major part of gaseous emissions all over the world. Numerous research teams achieved studies on this topic but with various aims: methodology assessment, emission factors, improvement of knowledge on mitigation techniques. Comparison of data published in the literature is often a delicate matter due to many obstacles such as unit of expression, age and weight of animals but also rearing conditions. The aim of the project was to build a database including data concerning gaseous emissions but also metadata about production conditions and the methods used to acquire emission values.

### Methodology

A consortium of French research organizations (INRAe) and agricultural technical institutes (Ifip-Institut du Porc, Itavi, Idele, Chambre d'Agriculture de Bretagne) was established to build and feed a database called ELFE (ELevages et Facteurs d'Emission; i.e., Livestock and Emission Factors). Three files are developed in Microsoft Excel 2019 corresponding to animal housing (pig, poultry and cattle -Vigan et al., 2019). For each file, experts of the consortium have identified specific parameters which are relevant in the whole process of emission of NH3, N2O, CH4. To standardize data entry, drop-down lists were created for most variables in each group. The identification of relevant publications on gaseous emissions from livestock have been done by using keywords series on The Web of Science. Only raw data are entered in the database. To compare emission data, additional tabs were created to convert, when it's possible, the unit of the publication into 3 units of reference chosen by the experts of the consortium.

### Results and discussion

The structure of the database is divided into three main groups of variables: the first one is dedicated to the emission factors itself (gas, values, units, min, max), the second one to the characteristic of the animal housing with 5 subgroups (production and technical parameters, manure composition, manure management, building and equipment, resource consumption). The last one focuses on metrology with seven subgroups concerning measurement protocol, sampling, measurement of airflow rate, mass balance and calculation. This paper focuses only on gas emitted by buildings housing pigs or poultry. In December 2022, 2 116 emissions factors from 22 countries over the period 1966- 2022 were collected in the database concerning emissions from pig buildings. Around 50 % of data concerns ammonia emission (N2O: 11%; CH4: 13%, CO2: 10%, Odour and particles: 16 %) and 82% is devoted to fattening pigs (sows: 9%; post-weaning piglet: 9%). For the same period, 1 027 emissions factors from 106 articles concerning poultry housing published from 18 countries were collected. Such as for pig, 54% of data concerns ammonia emission (N2O: 7.8%; CH4: 9.3%, CO2: 7.2%, Odour and particles: 15 %). Broilers are the most concerned production in poultry with 52.4% of emission factors (laying hens: 45.8 % - turkeys and ducks: 3%).

### Conclusion

The ELFE database is a useful tool to define emission factors for national inventories and to study the effect of key variables such as manure management or nutritional strategies linked to specific technical itineraries. Regular updating makes it possible to integrate the latest publications into the database and thus to establish emission factors for new practices developed in pig and poultry production.

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Development of a database to collect emission values for livestock systems. J.Environ.Qual. 48: 1899-1906. doi:10.2134/jeq2019.01.0007

**Reducing ambient temperature to lower $NH_3$, $N_2O$ and $CH_4$ emissions from pig fattening housing** Guingand, N.[a]*, Rousseliere, Y.[a], Thomas, J.[a] & Colin, A.[a]

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## Introduction

At the European level, France is committed to reducing its emission of ammonia by 13% by 2030 compared to 2005 and emissions of Green House Gases by 40% by 2030 compared to 1990. Compliance with this commitment is based on a global reduction of the agriculture contribution and of the pig sector contribution even if it is a minor one. A project led by Ifip in collaboration with Inrae has been developed to study the influence of cold temperature on growing performance and gaseous emissions.

## Methodology

The study was conducted in a special unit of the Ifip experimental farm based in Western France where the ambient temperature can be lowered and maintained during the whole fattening period. Two identical rooms each housing 20 fattening pigs between 30 and 110 kg were compared with a set temperature of 16 and 18°C respectively for rooms 1 and 2. Pigs were individually weighted at the entry and just before slaughtering. Feed and water consumptions were daily recorded per room. During the whole fattening period, ambient temperature was recorded each hour. Ammonia (NH3), nitrous oxide (N2O) and methane (CH4) concentrations were semi-continuously measured into both rooms by using an IR photoacoustic analyser (Innova 1512, LumaSens Technologies Inc.). The day of slaughtering, slurry volume per room was measured and samples were taken for analysis.

## Results and discussion

During the 80-day fattening period, the average ambient temperature was 16.4±1.0 °C for room 1 (set point: 16°C) and 18.1±0.8 °C for room 2 (set point: 18°C). The reduction of ambient temperature led to a drastic reduction of NH3, N2O and CH4 emissions per pig place compared with those obtained under 22-24°C which is the normal farming conditions in France. NH3 emission was reduced by more than 60%, N2O emission by 50% and CH4 emission by 44%. Nevertheless, the difference between 16°C and 18°C on gaseous emissions was not significant. For pigs of both rooms, feed conversion ratio (FCR) increased in comparison with reference value (2.44 and 2.66 kg.kg-1respectively for room 1 and 2 vs 2.40 kg.kg-1 for the reference – Quiniou et al., 2021). Average Daily Gain (ADG) were lower for both rooms (926 and 1002 g.d-1 respectively for room 1 and 2 and 1034 g.d-1 for the reference – Quiniou et al., 2021). Carcass performance were lower for pigs bred under low temperatures than reference values especially with an increase of fat content. All those parameters illustrated the energy mobilisation by pigs to struggle against cold ambient temperatures. With lower temperatures, water consumption by animals was also drastically reduced (-40%) in comparison with the average value generally adopted of 7 liters per fattening pig per day under 22-24°C ambient temperature (Massabie et al., 2014).

## Conclusion

The reduction of the ambient temperature is a great way to reduce NH3, N2O and CH4 emitted by the building. Nevertheless, the reduction of the ambient temperature had negative effect on pig performance (FCR, ADG and carcass performance) which could be perhaps partially compensated by new nutritional strategies.

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## Occurrence of hydrogen sulphide in a fattening pig barn equipped with inhouse acidification

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### Introduction

In-house acidification, the pH value of slurry is reduced to a target level of approximately 5.5. It is a promising option for ammonia emission abatement since emission reduction can be achieved over the entire manure cascade housing, manure storage, manure application. Acidification is done through addition of sulfuric acid to slurry in a reactor outside of the livestock housing. The acidified slurry is then returned to the channels. The excretions of the animals immediately end up in an acidified environment where the equilibrium between NH4+ and NH3,l is shifted towards NH4+. Through the addition of sulfuric acid, further sulphur is available which can be potentially converted to H2S. This induces concerns for enhanced formation of H2S. H2S is highly toxic to humans and animals. Long-term workplace exposure limit given as 8-h time weighted average is 5 ppm with a 15 min exposure threshold of 10 ppm in the EU (European Commission, 2009). The aim of this study is to present data from H2S concentration measurements in a fattening pig housing with 400 places in 16 pens littered with straw pellets with partly slatted floor before and after installation of an in-house acidification.

### Methodology

In 2021, H2S concentrations were measured in the barn using portable gas detectors "PAC 6500 and Multiwarn II" from Dräger and with electrochemical sensors (range of 0.1 - 100 ppm). Four measurement campaigns were conducted. One of them were conducted before the acidification was operative and three campaigns with acidification in summer and winter and with and without extraction of the air above the slurry channels. The number of measurement periods was 5 for the reference measurement and 6 to 14 for the measurement with acidification. The duration of a measurement period was 10 to 104 min, with less than 20 min occurring only in the summer campaign with 14 measurement periods.

### Results and discussion

H2S was exclusively detected when channels were flushed. Outside of periods with flushing, H2S concentrations were below the detection limit of 0.1 ppm. The maximum average over 15 minutes value was 20.2 ppm which was obtained without acidification. With slurry acidification, no exceedance of the 15 Min threshold of 10 ppm occurred, the maximum H2S concentration was 4.8 ppm. Overall, the H2S concentrations with slurry acidification (0.14 ppm) were lower than without acidification (1.44 ppm). The mean values of measured H2S concentrations in winter (0.16 ppm) were higher than in summer (0.06 ppm) due to higher ventilation rate in summer. The use of the exhaust air system in slurry channels reduced H2S concentrations to 0.16 ppm compared to 0.30 ppm without air extraction. The lower H2S

with Eriksen et al. (2008) and Ottosen et al. (2009) who did not find elevated sulfide levels in acidified pig manure compared to untreated slurry. This can be explained by the inhibition of sulfate reduction by microorganisms at a pH of 5.5 (Eriksen et al., 2012). Also, Overmeyer et al. (2023) found lower H2S formation with inhouse acidification in a pig barn.

### Conclusion

Slurry acidification did not enhance H2S concentrations in the investigated pig barn. This complies with actual studies and the response microbial processes to a low pH in the slurry.

### Acknowledgements

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## Reduction of gas emissions by addition of humic acid to the bedding material in broiler chicken housing

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### Introduction

The aim of this study was to investigate the effect of the addition of humic substances to litter in experimental broiler chicken rearing on the reduction of gases emissions (ammonia, carbon dioxide, hydrogen sulphide). It is estimated that about 27% of total atmospheric NH3 emissions from animal husbandry come from poultry litter (USEPA, 2004). It is possible to reduce the concentration of harmful gases in animal housing environment by application of humic substances or other organic materials as zeolite to the litter, which are characterized by a significant adsorption capacity (Ondruška et al., 2012). They also have antimicrobial, detoxifying, immune-stimulating, health- and production-promoting properties (Aristimunha et al., 2019).

### Methodology

In the experiment, we used two flocks of 40 one-day-old broiler chickens of the ROSS 308 breed. They were reared on the litter of wood shavings for 42 days in an environment with a controlled microclimate. Into the bedding material of experimental group of chickens was added a preparation (in three doses) based on basic humic acids. The control group of chickens had bedding without the addition of humic acids. CO2 and ammonia and hydrogen sulfide gas emissions were measured using a plastic chamber and a measuring device with an infrared gas analyzer uniTOX.CO2 G/IR/S and an electrochemical gas analyzer uniTOX NH3 were connected. The litter was analyzed for moisture, pH, and concentrations of total and ammoniacal nitrogen.

### Results and discussion

Concentration of ammonia in air during the rearing was slightly higher in the control group compared to group wit addition of humic substances in bedding material (5ppm vs 5.6ppm). The concentration of hydrogen sulphide in the air was in both group 0 ppm. Also the concentration of carbon dioxide in air was lower in the environment with the addition of humic substances to the litter (2500 ppm vs 2200ppm). The humic substances are good absorbent material in animal litter and decreased the moisture content which could influenced emitted concentration of evaluated gasses in the air.

### Conclusion

Reducing of moisture content can positively affect cleanliness of the body, health and welfare of the poultry and slightly decreased the concentration of some gasses.

### Acknowledgements

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## Assessing TEOM and portable particle counters for animal barn PM concentration measurement

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### Introduction

Livestock and poultry production generates a large amount of particulate matter (PM) that can be related to respiratory health issues in farm workers and animals. Measurement of livestock and poultry farm PM concentrations, which are typically high and dynamic, is technically challenging. Commercially available instruments were not designed for measuring PM on livestock and poultry farms and can introduce significant errors. New approaches are needed for objective and reliable PM measurements on these farms. This study was conducted to characterise two commercially available devices and assess the feasibility of the devices for PM measurement in animal buildings.

### Methodology

Two Tapered Element Oscillating Microbalance (TEOM) Ambient Particulate Monitors (Model 1400a, Thermo Fisher Scientific, Waltham, MA, USA), one equipped with a PM10 sampling inlet and another equipped with a PM2.5 sampling inlet, were set up in a laboratory test chamber. The TEOM is a U.S. EPA designated automated equivalent method. The two TEOM monitors were within the valid period after the manufacturer's calibrations.

Six Dylos PM2.5/PM10 Air Quality Monitors (Model DC1700-PM, Dylos Co., Riverside, CA, USA) were set up close to and at the same height of the TEOM sampling inlets. The DC1700-PM is based on a laser particle counter and responds to changes in particle concentration within 6 seconds according to the product manual. The price of a Dylos monitor is roughly 2.5% that of a TEOM monitor.

A custom-built agitator was used to generate and release organic hay dust into the test chamber. The PM was generated at different concentrations by varying the amount of hay in the agitator and the agitation speed. An Optical Particle Sizer (Model 3330, TSI Inc., Shoreview, MN, USA) in the test chamber determined that the PM mode diameter was 0.337 µm. Assessments of the TEOM and Dylos monitors were conducted by creating pulse inputs and quasi-steady state inputs of PM concentrations in the test chamber and analysing the responses of the TEOMs and Dylos monitors.

### Results and discussion

The pulse input experiment results showed slower responses of the two TEOM monitors for PM10 and PM2.5 measurement compared with the Dylos monitors. The responses of the TEOM monitors had 4 – 10 min delays. Due to the slow responses, the TEOM monitors could not detect the fast variations in dynamic PM concentrations compared with the faster-response Dylos monitors.

The quasi-steady state experiment results demonstrated high coefficients of determination (R2) between the TEOM monitors and the Dylos monitors for PM10 at concentrations from 0 to 2800 µg m-3 (R2 = 0.985) and PM2.5 at concentrations from 0 to 160 µg m-3 (R2 = 0.988). The correlations between the TEOM and Dylos monitors results were even better at concentrations of PM10 < 130 µg m-3 and PM2.5 < 50 µg m-3. However, Dylos monitors under-reported PM10 but over-reported PM2.5 concentrations compared with the TEOMs.

The study demonstrated the advantages of using laser PM counters for objective and reliable PM measurement in animal buildings. However, improvements in laser PM monitor design and calibrations of the monitors are needed to satisfy the requirements specific to PM monitoring in animal buildings.

### Conclusions

Although TEOM is a U.S. EPA designated automated equivalent method, its slow responses to PM concentrations present a technical limitation to measuring dynamic PM generated in animal buildings. While offering faster response and lower cost, the measurements of Dylos monitors were highly correlated with those of the TEOMs, demonstrating the feasibility of using laser PM counters for dynamic PM monitoring in animal buildings and the surrounding areas.

### Acknowledgements

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## Various management of fines from wood biomass screening as an alternative to spelt straw as litter for young bulls: agronomic and environmental performances

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### Introduction

Wood biomass are potential alternative to cereal straw as litter for rearing cattle. Indeed, alternatives to straw have to be identified notably for economic but also potentially for environmental reasons (e.g. greenhouse gas emissions when transported on long distances). Wood biomasses, products or by products, can be produced locally, in forest or from agroforestry systems where they potentially contribute to carbon storage. Nevertheless, their use as litter have to be economically competitive, feasible and healthy for farmers, cattle and soils and their environmental consequences have to be investigated (ex: greenhouse gas and ammonia emissions during manure storage, etc.)

### Methodology

With four small deep litter experimental barns, each for two heads of cattle, and manure storage devices (Belgium, Libramont, Mathot et al., 2016), we compared fully strawed (spelt) litter to its partial or complete substitution by fines, refusal of screening for pellet production (F).

During two asynchronous repetition, 2 young Belgian Bleu bulls were raised for c.a. 65 days on four litter types : (1) (100Straw) straw supply at about 3 kg FM (fresh matter) per m² on day one followed by an initial daily supply of 1 kg FM of straw per 100 kg cattle liveweight (CLW) , (2) (F-Straw) an initial supply of about 10 cm of fines (size 0-15 mm) followed by an initial daily supply of about1 kg FM of straw per 100 kg CLW, (3) (Alt-F-Straw) an initial supply of 10 cm of fines before to alternate, on a daily basis, the supply of straw or F (size 0-8 mm) at an initial rate of 1kg fresh matter (FM) per 100 kg of CLW and (4) (100F) an initial supply of about 10 cm of F (size 0-15 mm) followed by, a supply of about 7 cm F (size of 0-8 mm) when required.

These managements were derived from Moreau et al., 2020. The treatment 100Straw was the reference. F-Straw was expected to lead to well drained litter due to large fines at the basis. Alt-F-Straw allowed to substitute a of large amount of straw by F while keeping litter stability (long fibres). Finally, the 100 F treatment was expected to be less time consuming as it didn't need a daily supply of litter substrate. It allowed also a full substitution of straw by F. The initial daily supply rate programmed was adapted thereafter by the operator, on a daily basis, to maintain cattle cleanliness.

Litter supply were independently increased when cattle get dirtier and stabilized or decreased when enough or too much amount of straw was estimated to be use to keep cattle cleanliness. Litter use and quality, cattle performances, manure amount and quality removed from barn and after manure storage, and greenhouse gas emissions (CO2, CH4 and N2O) at barn and manure store were recorded.

### Results and discussion

Most of the data are still under treatment but no difference in cattle performances ((daily liveweight gain) between treatment were recorded while differences in the amount of litter supply and manure characteristics were recorded. Detailed results will be presented.

### Acknowledgements

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## A new method to calculate ammonia emission from stored animal slurry

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### Introduction

Ammonia (NH3) emissions from agriculture increased by 90% from 1970 to 2005, and agriculture is now the largest source of NH3 to the atmosphere (Behera et al. 2013; Uwizeye et al. 2020). Atmospheric NH3 is a threat to human health, and NH3 may cause eutrophication when deposited to land or water (Sutton et al. 2020, Stevens et al. 2020). Emissions from stored manure contribute to NH3 losses from livestock production systems (Leytem et al 2013). The importance of liquid manure storage as a key source of NH3 calls for valid emission estimates.

### Methodology

We have carried out an analysis of published data and based on this analysis developed a new concept for calculating emission of NH3 from untreated and uncovered stored liquid manure and including effects of mitigation measures. The model is related to physical and chemical prosses in the liquid and air surface interphase.

### Results and discussion

It is shown that with data from literature the mass transfer coefficient used to calculate emissions can be calculated for three liquid manure categories (cattle, pig, digestate) stored in either lagoons or tanks. The SD of the mass transfer coefficient estimated using data from literature is similar to the SD of the standard emission factor used in most inventory calculations. Our simple to use model contributes to more accurate calculations of NH3 emission, because it relates the calculations to surface processes (composition and temperature) and area of stored liquid manure. The model relates emission rate to the driving force of a concentration and mass transfer, and the calculations incorporates temperature, pH, total ammonical nitrogen (TAN) concentration, storage area, and effects of a cover. Values for empirical resistance terms used to calculate the mass transfer coefficient were estimated from measurements from 44 studies. Although, the calculation SD of the model parameters is high, the approach has two advantages compared to the alternative: it is not necessary to estimate TAN or nitrogen flow through the storage, and calculated values reflect management (e.g., storage area, TAN concentration, or the use of a cover) and environment (temperature) based on well-established principles.

### Conclusion

This quantitative model for calculating NH3 emission, that relate emission to the controlling chemical and physical processes has the potential to be useful for estimating emission from slurry storages. The important feature of the concept is to provide more accurate emissions related to site-specific liquid manure storage management by including effect of variation in cover, temperature, pH and TAN over time and the area of stored liquid manure.

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## Ammonia mitigation potential of acid-activated biochar as a floating cover during liquid manure storage

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### Introduction

A significant proportion of plant available nitrogen in slurry is volatilized in the form of ammonia (NH3) during storage. Emitted NH3 impacts human health, biodiversity, and air and water quality; thus NH3 emission mitigation techniques urgently need to be identified. In this study, we evaluated the NH3 emission mitigation potential of biochars derived from miscanthus (MB) and solid separated anaerobic digestate (DB), and orthophosphoric acid activated MB (AMB) and DB (ADB) as well as lightweight expanded clay aggregate (LECA).

### Methodology

Fresh dairy cattle slurry was collected below the slatted floors from the AFBI-Hillsborough farm cattle house. Twenty litre aliquots of well mixed slurry were stored in 37 L buckets and several floating covers were surface applied. The selected floating covers were miscanthus biochar (MB), activated miscanthus biochar (AMB), digestate biochar (DB), activated digestate biochar (ADB), and lightweight expanded clay aggregate (LECA) including a control (Ctrl). Digestate biochars were produced from separated solid digestate. Activated biochars were produced using orthophosphoric acid (5% H3PO4). During activation, biochar was added to H3PO4 solution at 1:2 (w/v) ratio. After 5 days of soaking, the acid was drained from the biochars. All biochars were ground and used <2 mm size biochars as floating covers maintaining 7 mm thickness. LECA was procured from a commercial supplier and applied maintaining a 2 cm layer thickness. The six treatments with three replicates were assigned randomly into three blocks during the experiment. The emissions were measured with a photoacoustic analyzer (GASERA F10, Finland) for 4 months starting from January under an open farm building.

### Results and discussion

In this experiment, significantly lower NH3 emissions were observed from acid activated biochars compared to the Ctrl, suggesting that activated biochar is an effective bio-cover for NH3 emission mitigation. It is inferred that the activation of biochar increases the surface area and porosity, and creates new functional groups which increase NH3 adsorption. In agreement with this, we observed higher NH4+-N adsorption in the activated biochar than in the non-activated biochar. Importantly, the reduction of emissions occurs for a month of storage. In this study, AMB and ADB reduced the emission by 51% and 37%, respectively, during the first month of storage. After a month of storage, the emissions returned to the same level as the other treatments. Therefore, the emission mitigation efficiency was reduced respectively to 25% and 28% in AMB and ABD in four months storage period. Application of non-activated biochar on the slurry surface did not decrease NH3 emissions compared to the Ctrl most likely due to the use of the small thickness of the biochars as the emissions reduce with increasing transfer resistance of NH3 from the slurry surface to the atmosphere. Similarly, the commercial LECA reduced NH3 emissions by 21% during the experimental period. Refer Baral et al., (2023) for the detail information.

### Conclusion

This study demonstrated that acid-activated biochars and LECA can be potential floating-covers for the reduction of NH3 emissions during outdoor slurry storage. NH3 emissions are reduced by the combined effects of an increase in the porosity, surface area and functional groups of biochar and a decrease in the slurry surface pH. Further research should focus on the impact of floating covers to reduce NH3 emissions, soil N and C cycling and microbiomes after field application.

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## Absolute emissions of methane and ammonia from small-scale slurry tank with MMB and inverse dispersion modelling

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### Introduction

Quantification of absolute emission factors for ammonia and methane from open full-scale slurry tanks can be conducted with e.g. the Integrated Horizontal Flux (IHF) method (Kupper et al., 2021),the Micrometeorological Mass Balance (MMB) method (Kariyapperuma et al., 2018; Park et al., 2010), or the backward Lagrangian Stochastic (bLS) model (Lemes et al., 2022). However, only bLS has been used to determine ammonia and methane emissions from a full-scale tank simultaneously. It can be a challenge to find suitable tank, where other sources in close vicinity do not disturb the measurements. Furthermore, it is practically impossible to measure the same slurry concurrently in several open tanks without changing the surroundings and thereby the conditions, thus repetition of emission measurements cannot be concurrent. This makes it very difficult to estimate the natural variation in emissions. Small-scale slurry tanks have been used in multiple studies as dynamic chambers (Ma et al., 2022; Petersen et al., 2009; Vanderzaag et al., 2009); however, these dynamic chambers are not suitable to determine absolute emissions from open slurry tanks because the natural surface dynamics are changed.

### Methodology

In the present work, CFD modelling was used to investigate flow patterns and emission strength from an open full-scale slurry tank and this was compared to CFD modelling of small-scale tanks to find a suitable size. The MMB method has been used for full-scale slurry tanks, but not for small-scale tanks with a limited fetch over of slurry surface, thus MMB was tested and validated for a small-scale tank by measuring simultaneously with MMB and an inverse dispersion method. Cavity ring-down spectroscopy (CRDS) analysers were used to measure the concentration of ammonia and methane.

### Results and discussion

The objective of this work was to find a practically implementable method to measure absolute emissions from small-scale tanks, thereby allowing for simultaneous semi-continuous measurements on multiple tanks. This will allow measuring different treatments to determine absolute emission factors, variation within treatment, and effect of treatment. The CFD modelling yielded similar emissions strengths for a 5 m3 tank (Ø 240 cm) and a full-scale slurry tank, thus this tank was used for later experiments. The emission strengths were depending on filling level of the tank, which is changing throughout the storing period. We expect that emissions from MMB and bLS will match over time, but it is possible that ebullition of methane can be difficult to observe with MMB. Furthermore, it can also be challenging to measure ammonia from multiple positions with sufficiently high time resolution. This is investigated in detail in this study.

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## Relevance of farm-scale emission measurement for quantification of emissions from slurry stores

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### Introduction

Slurry storage substantially contributes to ammonia (NH3) emissions from livestock production. Therefore, important efforts have been made to quantify emissions and to evaluate mitigation techniques. Most studies have been conducted at laboratory or pilot-scale (Kupper et al., 2020) to facilitate experiments, control for environmental factors, or due to budget restrictions. Emissions from slurry stores are driven by complex interactions between meteorological conditions (precipitation, temperature, wind speed), storage operations (agitation, filling and extraction of slurry), and slurry properties (Kupper et al., 2021a,b). Farm-scale measurements using non-intrusive methods are challenging due to interactions with other farm emission sources. Data obtained from individual stores cannot necessarily be extrapolated to be generally applicable e.g., for generating emission factors at a country level due to the variability of storage operations at individual farms. Alternatively, studies at laboratory or pilot-scale could be employed which allow for standardized experimental conditions, higher accuracy of experimental outputs through the inclusion of replicates. Here, we discuss outcomes of recent farm-scale studies, the validity of available data used for emission inventory reporting and possible options to generate emission factors which better reflect real-world conditions.

### Methodology

We conducted farm-scale NH3 emission measurements from an uncovered circular open storage tank with slurry from dairy cows by means of continuous measurements over two years using a non-intrusive method. After covering the tank with a semi floating cover, the emission measurements were continued for one year. The data analysis was structured according to the main influencing factors: using time after agitation and the tank filling level as proxies for the state of crusting and meteorological conditions (precipitation intensity; temperature, T; wind speed, WS; Kupper et al., 2021a,b).

### Results and discussion

We showed that a natural crust of ≥ 10 cm thickness covering the slurry surface reduced the NH3 emissions by 57% compared to the absence of a crust for the uncovered tank and was thus the most relevant factor influencing the emission level. Crusting was strongly affected by agitation of the tank and its filling level. Precipitation reduced emissions by 64% to 86% compared to dry weather conditions but was rather episodic and thus had little influence on the total emission. Higher WS and T increased emissions. An average abatement of 37 and 54% was achieved due to covering the tank with the cover during periods with and without a surface crust, respectively. The influence of meteorological conditions on NH3 emissions varied according to the state of crusting which strongly depended on slurry agitation and the filling level.

### Conclusion

NH3 emissions are driven by interactions of influencing factors occurring at farm-scale tanks but currently, they are not sufficiently considered in the determination of emission factors. These influencing factors cannot be mimicked by laboratory or pilot-scale studies and thus farm-scale measurements over periods of months or years are required. A future option could be to use real-world experimental tanks with a volume in the order of several 100 m3 allowing non-intrusive emission measurements, employing varying tank operations representative of current practises and using different types of slurry. This would allow these influencing factors to be appropriately considered and to better reflect the real-world conditions at slurry stores.

### Acknowledgements

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## Ammonia volatilisation from an uncovered pig slurry storage lagoon

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### Introduction

Ammonia (NH3) emissions have been increasing since 2015 in EU-28 mainly driven by the agriculture sector, which accounted for 93 % of the total NH3 emissions in 2018 (EEA, 2020). In particular, animals' housing and its associated manure or slurry storage system are NH3 hotspots. Uncovered lagoons tend to have a great emission potential because of their considerable surface area to volume ratio (Webb et al., 2005) and the long-term storage of products such as pig slurry. Pig slurry has a relatively large fraction of nitrogen in the form of ammonium that is rapidly lost to the atmosphere via ammonia volatilisation (UNEP, 2013).

The study aims to evaluate time-lapse differences while measuring the ammonia emission from a traditional pig slurry storage lagoon (uncovered) with simple passive samplers. This is a reference scenario to be compared to another that will incorporate different techniques to reduce $NH^3$ emissions (a prior mono-digestion system and covering of the digestate pond).

### Methodology

Net NH3 fluxes in each sampling period were estimated with the Backward Lagrangian stochastic inverse dispersion model (bLS IDM) and concentrations of NH3 captured by ALPHA® passive samplers (Adapted Low-cost Passive High Absorption). The atmospheric dispersion modelling software WindTrax was used to obtain such estimations of the NH3 flux. The $NH^3$ concentration was calculated through the measurement of the ammonium (NH4+) concentration in theaqueous extracts from the ALPHA® samplers. This concentration was determined by colourimetry following the salicylate method with nitroprusside (Searle, 1984) in a segmented flow analyser (AutoAnalyser3, Bran+Luebbe, Norderstedt, Germany).

### Methodology

Net $NH^3$ fluxes in each sampling period were estimated with the Backward Lagrangian stochastic inverse dispersion model (bLS IDM) and concentrations of NH3 captured by ALPHA® passive samplers (Adapted Low-cost Passive High Absorption). The atmospheric dispersion modelling software WindTrax was used to obtain such estimations of the NH3 flux. The NH3 concentration was calculated through the measurement of the ammonium (NH4 +) concentration in the aqueous extracts from the ALPHA® samplers. This concentration was determined by colourimetry following the salicylate method with nitroprusside (Searle, 1984) in a segmented flow analyser (AutoAnalyser3, Bran+Luebbe, Norderstedt, Germany).

### Results and discussion

For the studied period (294 days) and the lagoon surface (2,106 m2), the nitrogen released to the atmosphere as ammonia volatilisation from the pig slurry storage was estimated at 2,263 kg N, i.e., nitrogen emissions were 15.4% of N generated by sows and piglets. This percentage is similar to the one reported by Kupper et al. (2020).

The temperature was the driving factor for NH3 volatilisation and 78% of NH3-N emissions were captured when the air temperature was higher than 15 °C. However, although wind speed is another important propelling factor for NH3 emissions (Sommer et al., 2013), no relation between wind speed and ammonia fluxes was found.

### Conclusion

The studied scenario, an uncovered pig slurry storage lagoon, was a hotspot of ammonia emissions that contributed to 15% of nitrogen lost to the atmosphere. Considering the future context of global warming, ammonia emissions could have a great significance in hot and mild climate regions where the ambient temperature reaches values above 15 °C during large periods.

### Acknowledgements

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## Downstream effects of Feed Additives on Ammonia and Greenhouse Gas Emissions during Cattle Manure Storage

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### Introduction

Manure management is an important source of greenhouse gases (GHG), especially methane (CH4) and nitrous oxide (N2O) and air pollutants such as ammonia (NH3) in livestock production systems. Agriculture, specifically livestock production, accounts for over 80% and 60% of the total global NH3 emissions, respectively (Behera et al., 2013). Feeds and feed additives can determine the composition and quantity of manure produced, thereby controlling what enters the manure management chain. Additives such as seaweeds (Glasson et al., 2022; Alvarez-Hess et al., 2023) and linseed oil (Rowntree et al., 2010; Doreau et al., 2018) have reduced methane when added to cattle diets. Limited studies extend gaseous measurements from feed additives to the manure management stage. This study aimed to examine the effects of feed additives (seaweed and linseed oil) and impact of acidification on ammonia and GHG emissions from cattle manure during storage.

### Methodology

Urine and faeces were collected from the animals during a feeding trial. Briefly, 16 animals were divided into four treatments – Control (CON), Linseed oil (LIN), Seaweed (SW) and Seaweed Extract (SW Ext) of four animals each and fed a 60:40 forage to concentrate diet. The additives were added at 4% (LIN) and 2% (SW and SW Ext) of the overall diet. Ascophyllum nodosum (brown seaweed) was used as the seaweed, but the phlorotannins were condensed in the SW Ext. treatment.

The faeces and urine of each treatment were mixed and sieved to form a homogenous slurry in a ratio that produced a dry matter (DM) of 6% (Hyde et al., 2003; Bourdin et al., 2014). Sub-samples were collected before the experiment for slurry characteristics analysis. 1.6 kg of the mixed slurry was then transferred to a 2 L-capacity urine container for a laboratory-scale incubation in a temperature-controlled growth chamber. The temperature and relative humidity of the chamber was set to 15°C and 76% respectively. Each treatment was replicated five times in a randomised block design. To simulate air movements during manure storage in a slatted shed, 10 holes were drilled into the lids of the 2 L containers.

Ammonia and GHG emissions were sampled three times a week at the start of the experiment and then reduced to twice a week. Ammonia was sampled using a dynamic chamber technique with a photoacoustic gas analyser while the GHG emissions were measured with a static chamber technique as described by (Kavanagh et al., 2019; Connolly et al., 2023). pH and temperature readings were also taken every sampling day. In the second phase of the experiment, all treatments were acidified with Sulphuric acid to a pH of 5.5 to determine the effects of additive + acidification during manure storage.

### Results and discussion

This experiment is on-going, early results indicate that feed additives impact NH3 emissions from resultant manure. Final results will be presented at the conferences.

### Acknowledgements

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## A comparison of two heat transfer models for predicting temperature of stored animal slurry

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### Introduction

The temperature of stored animal slurry (liquid manure) affects chemical and biological processes that determine emission of greenhouse gases, ammonia, and other air pollutants. Stored slurry temperature is affected by weather, storage structure characteristics, and management, and widespread measurement is not practical. Instead, emission inventory compilers may use various means of estimating temperature. In this contribution, we compare two publicly-available models for estimating slurry temperature. The first is a 1-D mechanistic model based on the 3-D model presented by Rennie et al. (2017). This mechanistic model is referred to as the AAFC-1D model in this work. The second model is STM, a simpler model described by Hafner et al. (2023) and available from https://github.com/AU-BCE-EE/STM. In this contribution, the two models were compared by application to slurry tanks in three different countries (Canada, Denmark, and Sweden).

### Methodology

Model inputs included weather data, which were taken from the nearest major weather stations. Air temperature and solar radiation were used by both models, while wind speed, precipitation, and relative humidity were used only by the AAFC-1D model. Site data included tank dimensions and slurry level. For AAFC-1D, additional inputs were manure management, incoming manure temperature, and soil properties. One year of input data was used for each site, and the models were run for 3 years to eliminate any effect of the starting temperature.

Measured slurry temperature was determined using combined temperature sensors and loggers suspended from floats at the slurry surface. Model accuracy was assessed by calculating common fit statistics including root mean square error and mean bias error.

Several simplifications were also evaluated. These varied between models and included calculating weather data using the models based on sinusoidal approximations, simplified slurry level inputs, and exclusion of heat transfer in the incoming slurry to circumvent the challenge of determining its temperature.

Models were also compared with respect to the number of inputs.

Project files are publicly available from https://github.com/Chih-yuHung/STM-and-1D-model.

### Results and discussion

This work is ongoing, but preliminary results show that both models are generally able to predict annual patterns of slurry temperature without major errors in all locations. However there were clear cases where each model performed poorly. STM tended to underestimate slurry temperature in Canada, especially for the winter. AAFC-1D overestimated winter temperature in Sweden, but more closely matched summer temperatures, which are more important for emission prediction. More detailed quantitative results will be presented at the conference, along with recommendations for estimation of the temperature of stored slurry.

### Acknowledgements

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## Inhibition of Greenhouse Gases, Ammonia and Hydrogen Sulphide Generation from Cattle Slurry Storage

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### Introduction

Manure management is responsible for approx. 10% of Europe's greenhouse gas emissions (GHG) and 82% of its ammonia ($NH^3$) emissions originating from agriculture. Hydrogen sulphide ($H^2S$) is not monitored by the EPA however is a health and safety concern and contributes to the formation of sulphur dioxide. Cattle slurry, an important organic fertilizer, is held in storage when cattle are housed indoors and through anaerobic digestion generates and releases methane (CH4), carbon dioxide ($CO^2$), nitrous oxide ($N^2O$) and other potent gases such as $NH^3$ and $H^2S$. The release of these gases, as well as contributing to climate change and pollution also liberates potential nutrients, thereby decreasing slurry's fertilisation value. The additive described here by which CH4 abatement is achieved, is based on the introduction of oxygen into the slurry via hydrogen peroxide. The subsequent increase in dissolved oxygen and redox potential decreases CH4 production. $CaCl^2$ was used to abate increased emissions as a result of the oxidative additive. The short-term effects of this treatment are particularly advantageous for future use in anaerobic digestion systems in which biogas production may be increased (Thorn et al., 2022). The objective of this research is to investigate and optimize the GHG, NH3 and H2S abating potential of this treatment in cattle slurry and to eventually apply it to farm scale experiments.

### Methodology

A pilot scale mesocosm experiment was carried out, nine 1 $m^3$ tanks, filled with 660 L of cattle slurry were stored for 90 days. This trial was fully replicated (n=3) with 2 treatments and 1 control. Hydrogen peroxide and potassium iodide were pumped into each tank separately but simultaneously to investigate the effect of treatment on CH4, $CO^2$, $N^2O$, $NH^3$ and $H^2S$. This was repeated for the next treatment except a 1.06 M calcium chloride ($CaCl^2$) spray was applied to the top of the crust as often as the oxidising treatment was applied. GHG and $NH^3$ emissions were regularly using a static chamber flux method. A dynamic chamber system was used to measure $NH^3$. $H^2S$ emissions were measured post 90 days storage immediately following agitation of the slurry using a biogas a GeoTech BioGas 3000. pH, redox potential and dissolved oxygen were also measured.

### Results and discussion

The oxidising treatment abated CH4, N2O and H2S emissions by 19, 61 and 81% respectively compared to control slurry. CO2 and NH3 emissions were increased as a result of the oxidising additive by 108% and 111% respectively. CH4 inhibition potential may have been reduced due to high temperatures during slurry storage. The oxidising treatment appears to have interrupted denitrification taking place as the slurry surface and crust. Sulphate reducing bacteria may have been inhibited during storage or the introduction of oxygen into the slurry reduced dissolved sulphide to sulphate. The CaCl2 spray abated 49% of NH3 emissions compared to control slurry in first 2 days of treatment, but its efficacy appears to subside thereafter. Increased CO2 emission increased the pH, which coincided with increased NH3 emissions. CaCl2 may be of greater use therefore in a covered slurry stores. Combined with the oxidising treatment, CaCl2 abated N2O emissions by 86% during slurry storage. CaCl2 may have acted as a nitrification inhibitor on the slurry surface and crust reducing N2O production.

### Conclusion

The oxidising treatment with the inclusion of a CaCl2 spray has shown potential to abate GHG, NH3 and H2S emissions from cattle slurry. Reduced GHG emissions from slurry storage will help in reaching European GHG emission targets by 2030. The use of the oxidative additive may lead to safer working environments for farmers through reduced exposure to H2S gas. CaCl2 may be a cheap and useful way of abating NH3 emissions in the future while also maintaining the slurry's viability for anaerobic digestion (CSTR) which is not possible with sulphuric acid addition. Further research may be carried out using CaCl2 in slurry storage systems using covers or aeration to abate GHGs and NH3 emissions.

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## Effect of the management of dried laying hen droppings (aviaries, enriched cages) on ammonia emissions during storage

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### Introduction

The agricultural sector is the main source of ammonia in France, more than 70% of which comes from livestock (Citepa, 2020). The French inventory could be improved with technical data on the effect of manure management on ammonia emissions. Indeed, there are few data on ammonia emissions for the poultry sector during the storage of laying hens droppings reared in enriched cages or aviaries.

### Methodology

The objective of this study was to compare the ammonia emissions during storage, under controlled laboratory conditions (tray of 12 storage cells of 5 liters under controlled conditions of air speed and temperature, approximately 6 weeks, ammonia emissions determined by a nitrogen mass balance (total nitrogen losses) of the dried droppings of laying hens (i) reared in an aviary system with external drying and (ii) reared in enriched cages with pre-drying in building on a manure evacuation belt. Different storage conditions were tested (Dry matter content, quantity, re-humidifcation).

### Results and discussion

The results confirm that the drier the droppings, the lower the nitrogen losses. On the other hand, any re-humidification of the dried droppings relaunches the process of ammonia volatilization. In addition, the quantity of droppings in a given storage volume has an impact on nitrogen losses: at constant volume, a larger quantity of droppings reduces nitrogen losses.

### Conclusion

These results make it possible to make some operational recommendations on the management of droppings in storage such as avoiding the storage of dry droppings in an environment conducive to hydric condensation or favoring a large quantity stored with drying of the surface of the heap by avoiding repeated stacking on a same area.

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## Mitigation of methane emission from pig slurry storage with sodium dodecyl sulfate and hydrogen peroxide treatments

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### Introduction

The raising concerns about climate change have increased the focus on agricultural greenhouse gas (GHG) emissions to the atmosphere. Methane (CH4) emissions account for 96% of total GHG emissions emitted from livestock production (http://www.fao.org/faostat/en/#data/GT). And about 80% of CH4 emission from pig production is contributed by manure management (http://www.fao.org/faostat/en/#data/GT). Hence, the mitigation of CH4 emissions from the manure management chain will significantly reduce the overall impact of GHG emissions in countries with intense livestock production. Within manure treatment technologies, acidification is considered to be a benchmark technology for reducing CH4 and ammonia (NH3) emissions from stored slurry (Ma et al. 2022). However, due to difficulties such as safety issues in the application, soil sensitivity to increased sulphur loads during land application and inhibitory effects on biogas production, alternative treatments are sought out. In this study, sodium dodecyl sulfate (SDS) and hydrogen peroxide (H2O2) were studied in laboratory scale as treatments to reduce CH4 emissions from stored pig slurry. Furthermore, the treatments were conducted on residual pig slurry, which is left over under the slats after flushing to inhibit the inoculum responsible for CH4 emissions within barns.

### Methodology

The effect of slurry treatments on CH4 emission from residual slurry was studied in a headspace emission setup. In screening experiments, the slurry was stored in 1L reactors, and compressed air was allowed to flow through the headspace of the reactors. The gas composition of the outlet air was measured in a cavity ring-down spectrometry (CRDS), and the CH4 concentration (mmol) was determined. The treatments included sodium dodecyl sulfate (SDS), hydrogen peroxide (H2O2) and sulfuric acid (H2SO4). Later, the effect of treatments on residual slurry after weekly slurry removal was studied to mimic the real-time effects of defecation on CH4 emissions at pig barns. Here, faeces and urine were added to the slurry daily, and 70% of the accumulated slurry was removed at the end of the week. The remaining slurry was treated with SDS (1.5 g kg-1 slurry), H2O2 (2.5 g kg-1 slurry) and H2SO4 (pH 4.7 to 5.5). After treatment, faeces and urine were added daily as described earlier, and the cycle was repeated for 56 days. The CH4 emission (mmol) during the entire time was measured similarly to the screening experiments.

### Results and discussion

The treatment with SDS (2.5 g kg-1 slurry), H2O2 (2.5 g kg-1 slurry) and H2SO4 (pH 5.5) in the screening experiments resulted in 98%, 34% and 92% reduction in CH4 emissions, respectively after 16 days of storage. In the case of treatment with weekly slurry removal, SDS (1.5 g kg-1 slurry), H2O2 (2.5 g kg-1 slurry) and H2SO4 (pH 4.7 to 5.5) resulted in 94%, 66% and 49% reduction in CH4 emissions after 56 days of storage. In both cases, SDS treatment at a low dosage (≤ 2.5 g kg-1 slurry) resulted in > 90% reduction in CH4 emissions from pig slurry storage.

### Conclusion

In slurry treatment technologies, acidification with H2SO4 at pH 5.5 is considered a standard method to reduce CH4 and NH3 emissions from slurry storage. However, the treatment of residual slurry under the slats with H2SO4 could be inefficient in reducing CH4 emissions due to the prolonged dropping of faeces and urine on top of it. In contrast, SDS reduced emissions by > 90%, even with the prolonged addition of faeces and urine and could represent an efficient alternative to H2SO4 as observed in this study.

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## Acidification of slurry and digestate – Impacts on N recovery and fertiliser replacement value in arable crops.

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### Introduction

UK agriculture is responsible for approximately 85% of UK ammonia (NH3) loss with emissions from livestock housing, and manure storage and spreading contributing c.60% of agricultural emissions. Ammonia emissions can be harmful to human health and contribute to acid rain, and subsequent deposition can result in damage to sensitive habitats. The UK has set legally binding targets to reduce ammonia emissions by 16% of 2005 levels by 2030. Slurry acidification has the potential to reduce ammonia emissions at all stages of slurry management by altering the equilibrium between ammonia (gaseous phase) and ammonium (aqueous phase) in slurry. This paper reports results from six site years.

### Methodology

Field plot experiments were conducted at ADAS Gleadthorpe in Nottinghamshire, ADAS Terrington in Norfolk and ADAS Boxworth in Cambridgeshire to investigate the effect that acidification by sulphuric acid had on N offtakes, nitrogen use efficiency and crop yields following contrasting application methods (bandspread and surface broadcast) timings (autumn and spring) of pig slurry and food-based digestate to winter cereals and oilseeds in harvest season 2019 and 2020. There were 3 replicates of each treatment arranged in a randomised block design. Target application rates were 180 kg/ha total N.

### Results

For Autumn 2018 applications there was a higher fertiliser replacement value (FRV) on clay soil (Boxworth) in the acidified treatment compared to the unacidified, corresponding to average nitrogen use efficiencies (NUEs) of 47 % and 30 % respectively. The other sites did not show an N response. In Autumn 2019 on the light soil (Gleadthorpe) no impact was seen from acidification of digestate or slurry. On the silt soils (Terrington) ahead of OSR FRVs were higher in the acidified treatments compared to the unacidified and corresponded to an NUE of 34 % and 18 % respectively.

In Spring 2019 applications the light soils (Gleadthorpe) had much higher FRVs for acidified digestate and slurry applications compared to unacidified, which corresponded to an average NUE of 50 % and 48 % for acidified digestate and acidified slurry compared to 26 % and 25 % for the unacidified.

### Conclusion

On average across all site years there was no effect from autumn applications (silt soils ahead of OSR). For Spring applications, the average FRV was higher in the acidified treatments compared to the unacidified and corresponded to average NUEs of 34 % and 29 % for slurry respectively and 35 % and 20 % for digestate.

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**Fugitive air contaminants emissions from pig slurry spreading** Brassard, P.[a]*, Létourneau, V. b, Turgeon, N.b, Baghdadi, M.b, Leclerc, S.b, Trivino, A.M.[a, c], Mila Saavedra, L.[a], Zand Miralvand, A.[a,d], Palacios, J.H.[a], Duchaine, C.[b] & Godbout, S.[a]

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## Introduction

Manure spreading on agricultural land might emit large quantities of air contaminants such as dust, gases, odors and bioaerosols (e.g. aerosolized human and animal pathogens and antibiotic-resistant bacteria), affecting the health of workers, animals and surrounding communities (Spencer and Guan, 2004). The aim of this study was to quantify and compare fugitive emissions (gases, odors, dust and bioaerosols) from the spreading of pig slurry using different techniques and to evaluate the risks for human health associated with slurry spreading.

## Methodology

The experiment was conducted in two parts. At first, spreading tests were carried out in a large wind tunnel to calculate the fugitive emissions. A greenhouse (8 m width x 30 m length) was set up to carry out spreading experiments in a controlled environment (CANFARMSAFE, 2022). A large wooden frame was built in the greenhouse and filled with a loam soil maintained at 20% water content. Two large inlets at one extremity and ten fans at the other end were installed to insure a controlled air flowrate (41.5 changes h-1) and velocity (0.32 m s-1). Environmental conditions, including temperature, humidity, and wind speed, were monitored continuously inside and outside the greenhouse. Six spreading tests with pig slurry were carried out with two types of spreaders: a splash plate and dribble bar systems. The spreaders were pulled with a tractor and the combustion gases were evacuated outside.

A Fourier-Transform Infrared Spectroscopy (FTIR) analyzer (GT5000 Terra model, Gasmet Technologies) was used to continuously analyse $N^2O$, $CO^2$, CH4, CO and $NH^3$ concentrations at the outlet of the greenhouse, and a UV Fluorescence analyzer was used for $H^2S$. Emissions were calculated by multiplying concentrations by the air flowrate. Air bags were collected before, after and during spreading for analysis of odour intensity by a human panel. Bioaerosols were collected upstream and downstream the greenhouse with robust high-volume electret dry filter air samplers: the SASS® 3100 and the SASS® 4100 (Research International, Inc.). The bioaerosols, as well as liquid and solid manure samples, were analyzed using DNA extraction followed by qPCR assays to determine ratios of antimicrobial resistance genes (ARGs)/bacterial loads. Particle counter (DustTrak™ DRX Aerosol Monitor 8534) monitored particles emission.

In the second part of the project, spreading tests are conducted in the field to study the dispersion of contaminants and to evaluate the health risks. Three repetitions will be done with both types of spreaders on plots of 12 m x 65 m. During each test, bioaerosols are sampled with the SASS® 3100 Dry Air Sampler at one mobile point (following the tractor), and at three fixed points, 18 m away from the spreading zone. Gases, odours and particulates are also sampled at one of the fixed points, before, during and after spreading. Finally, a SASS® 4100 bioaerosols sampler is installed 36 m away from the spreading zone.

## Results and discussion

Experiments in the wind tunnel and spreading in the filed with the splash plate spreader were done until now. Preliminary results show that for both spreading techniques in the wind tunnel, as well as with the splash plate spreader in the field, CO, $N^2O$ and $H^2S$ concentrations increase was negligible. $CO^2$ and CH4 concentrations increased right after spreading and were back to the initial level after approximately five minutes. $NH^3$ was released more progressively, up to 6 hours after spreading, which was attributed to nitrogen volatilization. For all gases, emissions calculated in the wind tunnel were similar with both spreading techniques. Odour intensity during spreading reached the highest concentration with the splash plate spreading. With both spreading techniques, the concentration of total bacteria as well as the average total dust increased during spreading, before decreasing after spreading. Bacteria emission in the wind tunnel was significantly higher with the dribble bar spreader. Finally, 25 ARGs were detected in the slurry samples and are under analysis for their presence in the bioaerosols samples.

## Conclusion

Spreading in the field with the dribble bar spreader will be performed in the next few months. Moreover, slurry incorporation into soil following spreading will be tested, and results will be compared with surface application. The hypothesis is that direct incorporation will reduce the air contamination, reducing the risks for human health.

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## Reducing ammonia emissions from field applied fertilizers – comparing multi-plot approaches for ammonia measurements

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### Introduction

Ammonia ($NH^3$) emissions affect the environment, climate and human health. They stem mainly from agricultural sources and can reduce the nitrogen use efficiency of synthetic fertilizers. Such effects can be avoided by more refined fertilizer technologies and strategies. Due to uncertainties in the efficacy of such NH3 emission mitigation measures, data from valid simultaneous emission measurements on replicated small plots are of particular urgency. Several mitigation measures are actually evaluated in the national cooperative project '$NH^3$-Min' under identical environmental and management conditions. The aim of this study is the comparative assessment of two novel multi-plot methods for $NH^3$ emission measurement from field applied fertilizers.

### Methodology

The experiments were carried out across Germany during winter wheat vegetation period in 2021 and 2022, which received 3 fertilizer doses per year. Investigated measures for NH3 emission reduction include choice of synthetic nitrogen form, use of urease inhibitors (UI) and injection technique (CULTAN). In replicated square small plots with large interspaces (8 treatments, n=4, 9 m x 9 m), two types of acid samplers (sulphuric acid traps and Alpha samplers) were tested and cross-validated. Measurements with the sulphuric acid traps were scaled to absolute emissions by simultaneous measurements with the open dynamic chamber system of the 'Draeger-Tube-Method' (DTM) (Gericke et al. 2011). Alpha samplers were used for the first time in such an experimental design and tested to calculate ammonia emissions from small plots by inverse dispersion modelling ('Windtrax' software) (Loubet et al. 2018). The quantitative accuracy was checked with urea as standard fertilizer on circular plots (r=20 m) by micrometeorological measurements including Integrated Horizontal Flux Method and inverse dispersion modelling (bLs).

### Results and discussion

The sulphuric acid traps used in the small plots showed high sensitivity to treatment effect. The NH3 loss was reduced by on average 30-47% by using UI compared to urea application on two sites in central Germany. The application technique and choice of N form had an even stronger effect, e.g. the application of urea ammonium nitrate solution (UAN) with trailing hose reduced the loss by 58-68% compared to surface applied urea. The Alpha samplers were capable of significantly differentiating between NH3 emissions from treatments. The magnitude of the mitigation detected with Alpha samplers was similar to those by sulphuric acid traps, 69-72% mitigation by UAN and 24-51% by the use of UI. On the urea plots NH3 flux calculations with the Alpha sampler readings showed a promising agreement with micrometeorological measurements while the DTM showed a too low sensitivity at different application dates and an underestimation during low emission events. Use of DTM seems to be critical in particular for low / slow emitting sources.

### Conclusion

The chosen multiplot design was applicable for NH3 mitigation assessments. In this context, sulphuric acid trap sampling provided a robust and statistically sensitive method for capturing NH3 emissions. Due to a similar agreement of Alpha sampler IDM flux calculation with micro-meteorological measurements compared to DTM a scaling of sulphuric acid trap readings by this approach is suggested for future experiments. A further refinement of this approach will be discussed.

### Acknowledgements

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## Nitrous oxide emissions from manure products applied to maize and grassland

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### Introduction

Agricultural soils are an important source of the greenhouse gas nitrous oxide ($N^2O$). Reduction of $N^2O$ emission is one of the strategies of the Netherlands to meet the targets of the international climate agreement in Paris. In the Netherlands, the application of treated or separated manure products to agricultural soils is expected to increase over the coming years, as Dutch manure policy puts a growing emphasis on the use of manure-derived products, such as mineral concentrates. The composition of these products may vary strongly, however, and as a result, so may the $N^2O$ emissions following application to soil.

### Methodology

Two field experiments (one on maize land for two years, one on grassland for one year) were carried out to quantify the $N^2O$ emissions from various manure-derived products and assess the effects of manure treatment, application technique, and a nitrification inhibitor. N2O emissions were performed with the static chamber method and gas analyser. Gas measurements were measured weekly during growing season and fortnightly during winter. Furthermore, soil temperature and soil moisture content were measured continuously throughout the whole year. For the maize experiment, additional measurements were performed on total N yield and mineral nitrogen after harvest for 0-30, 30-60 and 60-90 cm layers as an indicator for the risk of nitrate leaching. In the grassland experiments, the N yield was determined for each of the six cuts.

### Results and discussion

The cumulative $N^2O$ emissions from the maize experiment ranged from 0.6% to 10.1% of the N applied in the first year and from 0.7 % to 4.6% in the second year. Application of pig slurry induced higher $N^2O$ emission than cattle slurry and $N^2O$ emissions from deep injection were significantly higher than those from shallow injection. The application of a nitrification inhibitor led to a 2% reduction of $N^2O$ emissions from mineral concentrates over the first year, but to an increase over the second year. Soil mineral N content after harvest was highest for cattle slurry and mineral concentrate, suggesting a higher risk of nitrate leaching to groundwater. Total silage maize N yield ranged from 94 to 121 kg ha-1, with highest yields for cattle slurry, CAN and mineral concentrate. The cumulative $N^2O$ emissions from the grassland experiment were much lower than those from maize and ranged from 0.1% (cattle slurry) to 0.5% (CAN) of the N applied. Results on total N yield show a higher N uptake for CAN and mineral concentrate than for cattle slurry and liquid fraction.

### Conclusion

These results suggest that choice of manure treatment product provide a management tool to mitigate fertilisationinduced $N^2O$ emissions from maize land. In addition, deep injection of cattle slurry increases $N^2O$ emission significantly and should be avoided to mitigate $N^2O$ emission. On the other hand, ammonia emissions are much lower with this application technique and therefore a more integral approach is needed to optimize N management. Moreover, the effect of a nitrification inhibitor applied on both maize and grassland is not clear and should be further investigated. Furthermore, the results indicate that application of treated or separated manure on maize has a higher risk on $N^2O$ emission in comparison has a higher risk on $N^2O$ emission in comparison to grassland. Lastly, the findings of this experiment suggest that mineral concentrate could serve as a suitable alternative CAN with limited $N^2O$ emission and high yields.

**Impact on ammonia and greenhouse gas emissions of different times of livestock manure landfill in agricultural soils of Lombardy (Italy)** Iavazzo, P.[a]*, Pelissetti, S.[b], Motta, S.[c] & Brenna, S.[a]

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## Introduction

The intensive exploitation of soils represents one of the main environmental threats of recent years with a heavy contribute by unsustainable management of agricultural practices, such as fertilization which has the greatest impact on climate-altering gas emissions, above all due to nitrogenous fertilisers. The Lombard agricultural context, which plays a key role in the regional and national economy, is largely characterized by a high use of external inputs, modest crop diversification and high manure nitrogen loaded. The high density of farms requires special attention in the livestock waste management in order to limit the risk of loss of soil fertility and contamination of soils, water and air. The aim of this study was to assess the impact of different times for livestock manure landfill on agricultural soils in order to provide useful indications for public administration decision makers to identify sustainable systems for managing organic manure in areas with a high livestock density, in compliance with the Nitrates Directive (91/676/EEC) and the national and regional regulations deriving from it.

## Methodology

In a pig farm in the Lombardy plain, three experimental plots were identified for the monitoring of the ammonia and greenhouse gas (GHGs) emission following organic fertilisation. The experimental plan consisted of carrying out 3 monitoring campaigns of ammonia emissions (following the spring - 2021 and 2022 - and the autumn - 2022 - fertilizations) and 2 of greenhouse gas emissions for the whole 2021 and 2022 crop season (second harvest maize). The organic fertilizer used was pig slurry distributed on the soil in these times and methods: a) subsurface injection with umbilical system; b) surface distribution and landfill after 4 hours; c) surface distribution and landfill after 12 hours. The quantification of ammonia emissions was carried out through the exposure of passive ALPHA samplers (Carozzi et al., 2012); GHGs emissions were monitored using closed static chambers (Bertora et al., 2018).

## Results and discussion

The distribution techniques led to an emission of ammonia ranging from 12 to 22% of the ammoniacal nitrogen distributed, demonstrating their goodness in limiting the environmental impact of the livestock manure use in agriculture. The difference between incorporation at 4 and 12 hours after distribution was not significant, as in these particular stationary conditions most of the emission occurred within 4-5 hours of distribution; the subsurface injection technique, on the other hand, showed to be able to contain the losses due to volatilization of ammonia by almost 50% compared to the more traditional techniques of surface distribution. As expected, the methane and carbon dioxide emissions were negligible and not significantly different between the theses. So, the analysis of GHGs emissions mainly focused on nitrous oxide emissions, as this parameter is closely linked to the dynamics of the nitrogen distributed in the field and consequently to its availability for the crop's growth. During the year, the persistent drought (especially in the spring-summer season) led to the recording of a total amount of rainfall of about half compared to the average for the period: this anomalous factor did not allow significant N2O emissions to be recorded in the first part of the season, due to low soil humidity. The thesis with subsurface injected slurry was the treatment with the lowest overall loss of nitrogen; all the theses showed a loss varying between 40 and 50 kg of nitrogen, equal to about 10-13% of the nitrogen distributed, demonstrating the general validity of all the methods in limiting the environmental impact of organic fertilizers.

## Conclusion

Despite the low-significant data of the N2O emissions values due to the anomalous meteorological season trend, the monitoring showed that the immediate landfill of livestock manure following surface distribution provided positive environmental effects, with ammonia emissions decreased by 50 and 40% respectively compared with landfill delayed by 4 and 12 hours after spreading. Biomass sampling also highlighted both yields improvements (with a fresh matter production increase of about 20%) and nitrogen efficiency use improvements (with an increase of about 10%).

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## Ammonia emissions after field application of anaerobically digested animal slurry: Literature review and perspectives

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### Introduction

Production of livestock manure has increased with a growing demand for animal protein. The manure can be utilized as a valuable nutrient source for crop production when applied in fields, but it also poses a serious challenge due to emission of ammonia ($NH^3$).

Emission of greenhouse gases (GHG) from manure can be significantly reduced when manure is first used as a substrate for biogas production, i.e., treated by anaerobic digestion. In countries with large livestock populations, such as Denmark, liquid animal manure (slurry) is an abundant resource that can be used as a feedstock for biogas production with the benefit of reduced GHG emissions (Møller et al., 2022).

The physical and chemical properties of the digestate vary considerable due to large variation in feedstock into the digester and management practice (Romio et al., in preparation). Changes in digestate characteristics compared to slurry feedstock can affect NH3 emission following field application. Generally, there is a scarcity of literature assessing the downstream effects of slurry digestion on emission, and both higher, lower, and comparable NH3 emission after application of digestate compared to raw slurry has been reported (Chantigny et al., 2007; Nyord et al., 2012; Rubæk et al., 1996). The main objective of the present work was to summarize current knowledge on NH3 emissions after field application of digested slurry through a literature review. Furthermore, the present work will evaluate the implications of the literature data, how it is interpretated, and how well it represents the current situation in Denmark, where the biogas industry is rapidly expanding.

### Methodology

A systematic literature review was conducted to identify studies which could be used to address either of the following: absolute NH3 emission factor for field applied digestate or effect of digestate treatments or application technique on NH3 emissions after field application. Furthermore, pH and dry matter (DM) values form the literature compilation was compared with recent Danish datasets, and the effect of these differences was evaluated with the ALFAM2 model (Hafner et al., 2019).

### Results and discussion

On average the digestion process increased pH by about 0.5 units and decreased DM by 30-50% of reference DM in the literature data. Overall, no significant difference in emissions from digestate and reference slurry was observed, which is hypothesized to be because the reduction in DM counteracts the increase in pH caused by digestion. However, due to high amounts of DM being utilized for biogas production in Denmark, the literature digestates are not representative of the current Danish conditions, where a large part of the digestates have much higher DM contents. Predictions from the AFLAM2 model show that the trend towards increasing DM contents of the digestates increases the risk of high NH3 emissions, both reducing the fertilizer value of the digestate and increasing environmental pollution.

### Conclusion

Better empirical documentation is urgently needed along with new methods to mitigate emissions from land application of digestates with high emission potential.

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## Soil pH effects on $NH_3$ emissions from pig slurry and anaerobic digestate with and without incorporation

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### Introduction

Ammonia (NH3) emission is one of the dominant pathways of N loss from liquid manure fertilization with negative effects on environment and human health. Soil properties such as pH value and CaCO3 content are generally positively correlated with NH3 emission. In contrast, clay content, organic matter and cation exchange capacity (CEC) are negatively correlated with $NH^3$ emission, due to NH4+ adsorption to clay minerals and to organic material (Duan & Xiao, 2000). In addition to soil chemistry and composition, slurry characteristics (e.g. pH, DM etc.) play also an important role for $NH^3$ emission levels from organic fertilisers (Sommer & Hutchings 2001). It is still an unanswered question, how soil and slurry factors interact in defining $NH^3$ emission processes and which of the two systems eventually dominates the other, also depending on slurry application system. A systematic incubation study was set up using soils from two long-term fertilisation trials (Jyndevad, Denmark; Bad Lauchstädt, Germany) with different base soil characteristics, in particular soil texture, and in which different soil pH levels were established by long term fertilisation practices. Two contrasting slurry types combined with two application techniques were tested. Guiding hypotheses were that from surface applied slurry emissions are mainly governed by slurry characteristics while soil effects become dominant after slurry incorporation.

### Methodology

Investigations were carried out as dynamic incubation chamber (400 g dry soil, 60% WHC, 15 °C, exchange rate 10 Vol/min) pot experiments (similar to Monaco et al. 2012) to determine the NH3 emissions after surface or incorporated application of pig slurry (PS, pH 6.6, DM 13.2%) and anaerobic digestate (AD, pH 8.1, DM 6.6%). Ammonia emissions were measured by photoacoustic gas monitor for a maximum of three to four days after fertilization. The first soil investigated was a sandy soil with low clay content from the research station Jyndevad in Denmark and the second soil was a loamy loess-chernozem with high clay content from Bad Lauchstaedt in Saxony-Anhalt, Germany. From each location several soils (4 x Jyndevad and 7 x Bad Lauchstaedt) were collected from different experimental plots. The measured soil-pH-values from different Jyndevad soils ranged between pH (CaCl2) 3.62 – 6.17 and those from Bad Lauchstaedt between 5.29 – 7.22. Soil incorporation was done manually by mixing the slurry with a tool into the upper 2-3 cm layer of the soil immediately after slurry application. Data were analysed by multi-factorial analysis of variance (ANOVA) and multiple contrast tests or multiple mean comparisons.

### Results & Discussion

A direct and general relationship between soil-pH and $NH^3$ volatilization was not observed, although statistically significant differences occurred between different soils but without clear order. Ammonia emissions for Bad Lauchstaedt were in the order surface*AD (43.58 kg $NH^3$-N/ha or %) > surface*PS (12.26 kg $NH^3$-N/ha or %) > incorporation*PS (11.01 kg $NH^3$-N/ha or %) > incorporation*AD (6.98 kg $NH^3$-N/ha or %). Ammonia emissions for the location Jyndevad followed the same order though on a higher level, the group incorporation*AD tended to rise with increasing soil-pH-value and by contrast $NH^3$ emissions for incorporation*PS at Jyndevad tended to decline with increasing soil-pH-from the lowest (3.62) to higher pH values. For PS the effect of incorporation on emissions was only marginal while being very pronounced in AD. This was probably due to comparatively shallow incorporation in this pot trial and very high DM content of PS. Sand content was positively correlated with emissions, while clay and humus content showed negative relationships.

### Conclusion

Lowest $NH^3$ emissions occurred from pig slurry compared to AD. Emissions were reduced due to factors 'incorporation' as well 'clay and humus content'. Soil pH values had only effects on ammonia emissions from incorporated slurries. The results confirm the hypotheses that soil pH only governs emissions from incorporated slurries while soil texture had a much more pronounced effect for both slurry application systems.

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## Manure, Tillage, and Winter Cover Crop Effects on Nitrous Oxide Emissions in a Semiarid Cropping System

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### Introduction

Livestock manure is commonly applied in cropping systems to improve soil fertility and quality, but it can significantly influence the amount of nitrous oxide (N2O) emitted to the atmosphere. Regardless of fertilizer source, optimal management of nitrogen (N) is necessary to maintain crop yields and minimize greenhouse gas (GHG) emissions. Other practices that can influence N availability and N2O emissions are tillage and cover crops. Compared to conventional tillage, conservation tillage has been reported to enhance soil organic carbon and reduce N2O emissions (Gregorich et al., 2015). Cover crops can be used to scavenge surplus soil N, which might lead to a decrease in substrate needed for N2O production by microbes (Behnke and Villamil, 2019). Given the potential impact of soil and crop management on GHG emissions, the objective of this study was to determine the effect of manure, tillage, and winter cover crop on N2O emissions in an irrigated cropping system. Relatively few studies have evaluated multiple management practices on GHG emissions in the semiarid western United States, especially in southern Idaho.

### Methodology

The field site was located at the USDA-ARS research farm in Kimberly, Idaho, USA. The experimental design was a split plot with four replicates, with a plot size of 12 m × 12 m. The two main experimental treatments were conventional tillage (disking) and strip tillage, which was implemented from 2017–2021. In spring 2022, the field was inversion tilled via moldboard plough. Four sub-treatments were as follows: 1) control [no winter cover crop or dairy manure], 2) winter cover crop only, 3) solid dairy manure only, and 4) winter cover crop plus solid dairy manure. The field was cropped with continuous silage corn, while triticale was used as a winter cover crop. Stockpiled dairy manure was applied at an average rate of 52 Mg ha-1 (dry wt.) in the fall after harvest from 2015–2020, but not in 2021. Nitrous oxide fluxes were measured using a vented, non-steady-state, closed chamber technique (Parkin and Venterea, 2010).

### Results & Discussion

Daily $N^2O$ flux measurements were conducted during the growing and non-growing seasons in 2021 and 2022. The fluxes were highly episodic and major $N^2O$ pulses were associated with irrigation events during the growing season. Irrigation causes the soil to become anaerobic, forcing denitrification to occur and often resulting in greater $N^2O$ emissions. In 2021, the largest pulses occurred in manured plots with maximum fluxes ranging from 89–321 g $N^2O$-N ha-1 d-1, while in non-manured plots the maximum fluxes ranged from 16–34 g $N^2O$-N ha-1 d-1. In 2022, a major emission event occurred in the wintertime on day 49, with fluxes in manured plots ranging from 29–47 g $N^2O$-N ha-1 d-1. At the same time, the fluxes in non-manured plots were substantially lower at ≤ 2.8 g $N^2O$-N ha-1 d-1. Later in the same year during the growing season, maximum fluxes ranged from 38–54 and 37–70 g $N^2O$-N ha-1 d-1 in non-manured and manured plots, respectively. Cumulative $N^2O$-N emissions were significantly greater from the manured versus non-manured plots in both years, with no significant effect of winter cover crop or tillage on emissions. The average cumulative emissions from the non-manured and manured plots were 0.6 and 5.3 kg $N^2O$-N ha-1 yr-1 in 2021 and 0.8 and 3.2 kg $N^2O$-N ha-1 yr-1 in 2022, respectively. The lower cumulative emissions in 2022 could potentially be attributed to the fact that manure was not applied in 2021 and due to the spring inversion tillage. In the latter case, burying carbon-rich topsoil deeper in the profile can slow its decomposition and increase its residence time (Lawrence-Smith et al., 2021).

### Conclusion

Nitrous oxide emissions were the highest from the manured plots and during the growing season when fields were being irrigated. Despite implementation of conservation practices, such as cover crops and conservation tillage, this study showed that they were not effective in reducing $N^2O$ emissions in manure-treated soil.

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## Assessment of GHG emissions from an apple orchard fertilized with manures

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### Introduction

The increase of the amount of animal manure produced in Europe implies to find some new soil areas apart from cereals and feed crops for its application. On the other hand, the increase of mineral fertilizers prices and the decrease of the soil organic matter content in some EU regions led to an higher interest of farmers in using animal manures. In the present work, animal manures were used to partially (50%) replace mineral fertilizers in an apple orchard and the main objective of this study was to understand if these manures are effective to substitute mineral fertilizers with no increase of greenhouse gases (GHG) emissions while maintaining apple production and trees health.

### Methodology

A trial was set up in an apple orchard with a clay loam soil, and five fertilization treatments were designed (n=4), as follow: cattle slurry (CS), acidified cattle slurry (ACS), adding 6 mL of sulfuric acid to 1 L of slurry, cattle manure (CM), poultry manure (PM) and a control (CTRL) which received only mineral fertilizers. The manure-based treatments received 50% of the crop's nitrogen (N) needs in the form of manure or slurry and the other 50% was in the form of mineral fertilizers (Fertirrigation), to fulfil the crop's need of 80 kg ha-1 of available N. Animal manure was applied in a 20 cm deep raw located close to the trees and no fertilizer was applied in the inter-row.The emissions of nitrous oxide (N2O), methane (CH4) and carbon dioxide (CO2) were measured, more frequently after manure application and then once a week until harvest, using closed chambers combined with the INNOVA 1512 photoacoustic gas monitor, as described in Fangueiro et al., 2008. The trial had a duration of 119 days, with a total of 25 measurements. Apple production was also evaluated.

### Results and discussion

The application of CS, ACS and PM led to an apple production similar to the control indicating that replacement of 50% of mineral fertilizer with these materials allows maintaining a same production level. However, CM led to a significantly lower apple production compared to the control. A methane emission was observed during the three days after application in CS and ACS only with a significantly higher emission peak (on day 2) in CS than ACS. This initial CH4 emission following CS application to soil is generally associated to the release of CH4 produced during CS storage. After this peak, CH4 emissions remained close to zero. In the other treatments, CH4 emissions remained residual during the whole experiment and negative fluxes were observed in some treatments during the last weeks of the experiment. A significant increase of N2O emissions was observed in all treatments during the first 14 days after application and the higher increases were observed in CS and ACS that peaked on day 14 and 20, respectively. It is still to refer that the N2O peak in ACS appeared later, was more intense and lasted for a longer time than in CS. A delay of nitrification has been reported in previous studies when slurry is acidificed prior to soil application. A second N2O peak was observed later (day 71) in CM, PM and CTRL. The cumulative amount of N2O released followed the order: ACS > CS > CTRL≈PM≈CM. A significant increase of CO2 emissions was observed in all manure treatments compared to CTRL during the first 20 days. The highest cumulated CO2 emissions were observed in PM and ACS while CS led to the lower total amount of CO2 released. The highest values of Global warming potential were observed in ACS and CS (ACS> CS).

### Conclusion

The use of CS and ACS for orchard fertilization increased GHG emissions when compared to CTRL but the use of solid manure led to GHG emissions similar to mineral fertilization. Furthermore, the use of ACS, CS and PM was able to keep apple production at a similar level as mineral fertilizers while all the remaining treatments led to a decrease of production.

### Acknowledgements

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## Greenhouse gas emissions from digestate application and digestate composting

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### Introduction

Composting and anaerobic digestion are the most common ways to treat organic residues. Sometimes the organic matter after anaerobic digestion (digestate) is also composted.

### Methodology

Greenhouse gas emissions were measured following the application of digestate to soil. Emissions were also measured from composting digestate over a 3 week period.

### Results & Discussion

Digestate applied to soil was found to induce relatively high greenhouse gas (GHG) emissions, mainly of nitrous oxide, but there were no emissions when composted digestate was applied to soil. Cumulative methane emissions from composting were found to be almost 12 times higher from composting digested food waste than from raw food waste. Cumulative nitrous oxide emissions were also higher when composting solid digestate was compared to composting raw food waste, but the global warming potential was mostly driven by the impact of methane emissions.

### Conclusion

It is likely that an adapted microbial community transferred from the anaerobic digestion to the compost process may be the reason for the enhanced methane emissions. We are now carrying out a study to investigate this, as well as assessing some possible mitigation option.

## Effects of relative gas diffusivity on nitrous oxide emissions from manure hotspots as modified by soil bulk density and water content

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### Introduction

Globally animal production is expanding and with that a growth in the amounts of manure to be managed, for example by recirculation for crop production (Bouwman et al., 2013). In some situations, a relatively high proportion of the nitrogen added in manure may be lost as nitrous oxide (N2O), due to coupling between nitrification and denitrification at the surface of manure hotspots (e.g. Petersen et al., 1996), which introduces a high risk for emissions of N2O, a potent greenhouse gas. Soil relative gas diffusivity (RD) has been shown to be a possible predictor of denitrification and related N2O emissions from manure hot spots (Baral et al., 2016). We contribute to this work by investigate how the complete denitrification products emitted from manure hotspots are affected by RD as modified by soil moisture and bulk density.

### Methodology

We took acryl rings (height 5 cm, diameter 8.4 cm) and packed them with partially air-dried, sieved (< 6 mm) sandy loamy soil collected from the plough layer of a long-term field experiment near Foulum, Denmark. The bulk density selected was 1.2 or 1.4 g $cm^{-3}$, and for each level the water content was adjusted to the equivalent of -100 or -30 hPa, which gave four soil relative gas diffusivity (RD) levels of 0.068, 0.029, 0.022 and 0.002, respectively. For each combination, there was a treatment with manure incorporation to 5 cm depth (100 kg N $ha^{-1}$) and a treatment without manure to serve as control. The incorporation of manure was simulated by adding cattle manure to two the surface of two soil cores and, after infiltration, combining the two cores with the manure-amended surfaces facing each other. The soils cores were incubated at 15°C for four weeks. During the four-week period, we measured fluxes of $N^2O$ and $CO^2$, the complete denitrification products by the 15N gas flux method, and sampled soil at high spatial resolution by slicing the soil cores horizontally in the intervals 0-2-6-10-14-18-30-50 mm away from the manure center. Soil from each depth interval were analysed for water content, soil organic matter, pH and content of NH4+-N, $NO^3$--N and $NO^2$--N.

### Results and discussion

Preliminary results show that soil RD affected emissions of $N^2O$ after manure incorporation, with 15 times higher emissions emission from the 0.002 treatment compared to the 0.068 treatment. Interestingly, the treatment with an RD level of 0.029 emitted twice as much $N^2O$ as the treatment with an RD level of 0.022. In addition, the treatments with RD levels of 0.068 and 0.022 had cumulated $N^2O$ in the same range. We speculate that this pattern indicates a balance between gas and solute diffusivity on the microbial activity in and around manure hot spots, as suggested for aerobic microbial activity in intact soil by Schjønning et al. (2003). Results on complete denitrification products were below the detection limit except on day 1 after manure incorporation likely due a combination of consumption of the 15N labelled $NO^3$- pool and dilution by new non-labelled $NO^3$- lowering the $15N^2O$ and 15N2 signals. One day after manure incorporation, where the highest fluxes were observed at all RD levels, there was a positive trend between $N^2O$ flux and $NO^2$- accumulation in the soil.

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## Comparison between pig slurry derived fertilization in a wheat crop

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### Introduction

The Valencian Community (Spain) has many intensive pig farms, with some problems for the correct management of slurry. On the other hand, the Mediterranean olive production generates a large amount of olive mill oil with a very high cost for its treatment and disposal. Co-composting of both wastes, generates a high quality final producto and contributes to a sustainable and effective circular economy to solve the problems generated by the direct application of organic waste to soils (Sáez-Tovar et al, 2021). Additionally, the improvement in fertiliser quality of compost through advanced pelletisation enables agricultural application in extensive crops (Pampuro et al, 2017). This research study aimed to investigate the effects of different organic fertilization strategies on methane (CH4), nitrous oxide ($N^2O$) and carbon dioxide ($CO^2$) emissions on the soil in a wheat crop.

### Methodology

The experiment was carried out in 2022/23 at the EEAD Aula Dei CSIC research station, located in Zaragoza, Spain (41°43'N, 0°48'W). The climate in the area is Mediterranean semiarid and the soil is a Typic Xerofluvent. On the experimental site, winter wheat (Triticum aestivum L. cv. Sculptur) was grown under conventional tillage and flood irrigation. The experiment evaluated three fertilization strategies at iso dose of nitrogen (150 kg $ha^{-1}$), including a non-fertilised control. The treatments were: i) conventional mineral fertilization (urea) (IN), ii) pig slurry (PS) and iii) compost pellets (PSCOP), based on pig slurry solid fraction. All fertilizers were applied broadcast: PS and PSCOP after sowing, and IN at tillering. Treatments were arranged in a randomized complete block design with three replications, and each experimental unit was 8 × 3 m. GHG fluxes were performed from 28/11/2022 to 06/03/2023 in 9 samplings every 7-20 days, using the closed chamber technique (3.5 dm3) connected to a photoacoustic infrared spectrophotometry multigas analyser (Gasera One Ltd.). Chamber bases were inserted 15 cm into the ground in the center of each experimental unit before treatment application and left in place throughout the monitoring period (Sánchez-Navarro et al., 2022). The cumulative GHG emission during the 97 days was calculated. The variables were analyzed with ANOVA and differences were determined using the LSD Fisher test at the $p<0.05$ level.

### Results and discussion

Significant differences ($p<0.001$) in the cumulative $CO^2$, CH4 $N^2O$ flux during the period evaluated were found between different fertilisation strategies. The PS treatment showed the highest GHG fluxes. In the IN and PSCOP analysis, CH4 was higher for PSCOP with 3.93 kg CH4-C $ha^{-2}$, while N2O was higher for the IN treatment with values of 1.89 kg $N^2O$-N $ha^{-2}$ during the whole period evaluated.

### Conclusion

The results of this experiment indicate that N fertilization affected soil GHG emissions. The results of the current investigation also confirmed that PSCOP was shown to be an effective fertilizer for wheat.

### Acknowledgements

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## GHG emissions linked to sustainable organic vs conventional fertilization in extensive cereal crops

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### Introduction

European Union (EU) promotes a new plan of waste management attending the Circular Economy Package of the EU (Directive EU 2018/851). One of the most important positive aspects of compost agricultural use is related to the sustainability of this cultural practice, since through agricultural use, the nutrient cycle is closed (Tittarelli et al., 2007). Also considering the compost application for agricultural purposes a strategy of high potential for carbon kidnapping in the context of climate change (Moral et al., 2009). Moreover, there is a growing interest in the study of greenhouse gases (GHG) emission even during fertilization and in the search for management practices that be able to mitigate their emission. This research study aimed to investigate the effects of different organic fertilization strategies on methane (CH4), nitrous oxide ($N^2O$) and carbon dioxide ($CO^2$) emissions on the soil in a wheat crop.

### Methodology

The experiment was carried out in 2022/23 at the EEAD Aula Dei CSIC research station, located in Zaragoza, Spain (41°43'N, 0°48'W). The climate in the area is Mediterranean semiarid and the soil is a Typic Xerofluvent. On the experimental site, winter wheat (Triticum aestivum L. cv. Sculptur) was grown under conventional tillage and flood irrigation. The experiment evaluated three fertilization strategies at iso dose of nitrogen (150 kg $ha^{-1}$), including a non-fertilised control (B). The treatments were: i) conventional mineral fertilization (urea) (IN), ii) sewage sludge (LO) and iii) compost pellets (COP). All fertilizers were applied broadcast: LO and COP after sowing, and IN at tillering. Treatments were arranged in a randomized complete block design with three replications. GHG fluxes were performed from 28/11/2022 to 06/03/2023 in 9 samplings every 7-20 days, using the closed chamber technique connected to a photoacoustic infrared spectrophotometry multigas analyser (Gasera One Ltd.). Chamber bases were inserted 15 cm into the ground in the center of each experimental unit before treatment application and left in place throughout the monitoring period (Sánchez-Navarro et al., 2022). The cumulative GHG emission during the 97 days was calculated. The variables were analyzed with ANOVA and differences were determined using the LSD Fisher test at the $p<0.05$ level.

### Results and discussion

Significant differences ($p<0.001$) in the cumulative CH4 and $N^2O$ flux during the period evaluated were found between different fertilisation strategies. The LO treatment showed the highest GHG fluxes. In the IN and COP analysis, no differences in CH4 and $CO^2$ flux were found, while $N^2O$ was higher for the IN treatment with values of 1.89 kg $N^2O$-N $ha^{-2}$ during the whole period evaluated.

### Conclusion

The results of this experiment indicate that N fertilization affected soil GHG emissions. The results obtained in this work pointed out the importance of considering the source of fertilizers to reduce soil $N^2O$ emissions in irrigated wheat systems of Mediterranean areas.

### Acknowledgements

This study forms part of the AGROALNEXT /2022/016 programme and was supported by MCIN with funding from European Union NextGenerationEU (PRTR-C17.I1) and by Generalitat Valenciana. Grant EQC2018-004170-P funded by MCIN/AEI/10.13039/501100011033 and by ERDF A way of making Europe. Grant AVI INNODOCTO INNTA3/2022/26.

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## Effect of slurry application technique, timing and acidification on nitrous oxide emissions

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### Introduction

Manure management is a significant source of greenhouse gases such as nitrous oxide ($N^2O$). Currently the Republic of Ireland uses the Intergovernmental Panel on Climate Change (IPCC) default emission factor (EF) of 2% for manure $N^2O$ emissions. This EF is very high relative to the national dung emission factor of 0.31% (Krol et al., 2016) and 0.5% for manure spread in wet climates (Beltran et al., 2021). The use of low ammonia emission slurry spreading methods have been inconsistent between studies (Bourdin et al., 2014). The objectives of this study were to (i) investigate the effect of slurry application technique, timing and acidification on nitrous oxide emissions across two application timings and (ii) refine the slurry $N^2O$ EFs.

### Methodology

A field study was conducted on a grassland site at Johnstown Castle, Co. Wexford, Ireland for two individual slurry application timings during summer (8 June) and autumn (26 September) of 2022. The soil at the experimental site is Gleyic Luvisol. Plots (1.5 m × 1.5 m) were established in a randomised block design with five blocks and nine slurry treatments for each application date. Treatments consisted of: (i) control (receiving no slurry), (ii) splash plate + acid, (iii) splash plate - acid, (iv) trailing hose + acid, (v) , trailing hose - acid, (vi) trailing shoe + acid, (vii) trailing shoe - acid, (viii) injection + acid, and (ix) injection – acid. Agitated cattle slurry for these experiments was collected from an underground storage tank. Slurry was amended with 2M sulphuric acid until a target pH of 6.5 was was attained prior application to plots. Nitrous oxide fluxes were measured using the closed static chamber technique. One 40 cm square stainless steel chamber were inserted at a minimum soil depth of 5 cm a week prior to treatment application on each replicate plot. Chamber lids were 10 cm high creating an approximately 16 L headspace. Slurry was applied at 33,000 L ha-1; application rates were 6.9 L for the plot minus chamber and 0.5 L for the chamber area. Following treatment application, $N^2O$ was sampled four times for the first two weeks, twice a week for the next two weeks, once a week for four weeks and then once a month to examine one full year. Upon sampling, chambers were closed and sampled at 0 min, 25 min and 50 min after closure. At sampling, 10 mL air sample was removed through a rubber septum using a 10 mL polypropylene syringe fitted with a hypodermic needle. Each air sample was injected into a pre-evacuated 7 mL screw-cap septum glass vials and analysed in the laboratory by gas chromatography, using an electron-capture detector. Nitrous oxide emissions were calculated based on the rate of change in $N^2O$ concentration inside the chamber during the measurement period. Volumetric water content and soil temperature was measured on each day of $N^2O$ sampling to a depth of 6 cm using a Theta probe. Rainfall and air temperature were recorded at the meteorological station located 300 m from the study site.

### Results and discussion

Soil moisture was 32.6% on date of application and rainfall was 6.3 mm post application (24 hours) for June. Soil moisture was 29.7% on date of application and rainfall was 1.8 mm post application (24 hours) for September. These experiments are on-going. Final $N^2O$ emission results will be presented at the conference.

### Acknowledgements

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## Nitrous oxide emissions and agronomic yield of four different grassland swards receiving two application levels of calcium ammonium nitrate and digestate

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### Introduction

The European Green Deal envisages to achieve climate neutrality by 2050 and Ireland's Climate Action Plan 2023 set a target for a 25% reduction in agriculture-based greenhouse gas (GHG) emissions. Anaerobic digestion (AD) has the potential to replace a significant proportion of Ireland's fossil fuel demand and produce a digestate fertilizer source as by-product. This research investigated the GHG nitrous oxide ($N^2O$) emissions and agronomic performance from different grassland swards and from two levels of both calcium ammonium nitrate (CAN) and digestate.

### Methodology

A field experiment was designed with a fully factorial combination of four levels of sward composition, two fertilizer sources and two levels of nitrogen application. Species compositions comprised a monoculture of perennial ryegrass (PRG), and three mixtures: an equi-proportional mixture of PRG with red clover, an equi-proportional mixture of PRG with white clover, and an equi-proportional mixture of six species (PRG, timothy, red clover (RC), white clover (WC), chicory and ribwort plantain). Two fertilizer sources i.e., CAN and digestate were applied at two nitrogen (N) application rates i.e., zero (control), low and high levels. N contents for low & high level of digestate were 8.69 & 17.38 kg $ha^{-1}$; whereas N contents for low & high level of CAN were 33.33 & 66.67 kg $ha^{-1}$. Triplicate plots with the treatments followed a three-cut silage system with fertilizer application after each harvest (18th May, 21st July and 15th September in 2022).

$N^2O$ was measured using static chamber methodology (Venterea et al., 2020) and the samples were analysed by gas chromatography. Plots were harvested at 5 cm height to determine the dry-matter (DM) yield (kg $ha^{-1}$). Data presented here is from the initial two harvests and the same $N^2O$ sampling period (April 2022-July 2022) and was analysed using three-way ANOVA with four sward compositions, two fertiliser sources and three nitrogen application rates.

### Results and discussion

Preliminary results showed an effect of both fertiliser source and sward type on dry matter yield ($P < 0.01$). Comparing fertiliser sources, CAN produced higher yields than those from digestate ($P < 0.05$). Among sward types, the three mixtures had significantly higher yields compared to PRG. Moreover, PRG with RC and six-species mix with no N input had 27.6% and 4.8% higher DM yield compared to PRG with high N application rate from CAN, respectively.

There was an effect of fertiliser source on $N^2O$ emissions ($P < 0.01$), where CAN had higher $N^2O$ emissions compared to digestate ($P < 0.01$). DM-scaled $N^2O$ emissions were affected by N source and sward composition ($P < 0.01$). Among fertiliser sources, CAN had higher DM-scaled $N^2O$ emissions than digestate. PRG had 56% higher $N^2O$ emissions compared to six-species mix with high N application rate from CAN. The three mixtures had lower DM-scaled N2O emissions compared to PRG. Compared to PRG, higher yield and lower DM-scaled $N^2O$ emissions for clover-based mixtures can be due to higher N use efficiency and dry-matter yield for the clover-based mixtures (Moloney et al., 2020).

### Conclusion

From preliminary results, the use of digestate as an N source resulted in lower yields and also lower DM-scaled $N^2O$ emissions compared to CAN. Under lower N application conditions, clover-based mixtures produced lower DM-scaled $N^2O$ emissions than the perennial ryegrass monoculture.

### Acknowledgements

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## Gaseous emissions from acidified and ammonium-stripped cattle slurry and liquid digestate

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### Introduction

Farmyard manure (FYM) management systems are a large source of gaseous emissions to the atmosphere. Ammonia (NH3) volatilization and nitrous oxide ($N^2O$) emissions are critical from an environmental and an agricultural perspective. Acidification and ammonium (NH4+) stripping are management techniques which aim to increase the nitrogen use efficiency of FYM by reducing $NH^3$ volatilization. Acidification is carried out by adding acid (e.g. sulfuric acid) to slurry or liquid digestates. Typically, a pH value between 5.5 and 6.5 is targeted (Fangueiro et al., 2015). Ammonium-stripping is a recently developed technique consisting in inducing controlled $NH^3$-volatilization from FYMs in a closed system and capturing the emitted $NH^3$ as ammonium sulphate ((NH4)2SO4) e.g. in a gas washing tower (Leverenz et al., 2021).

In-field acidification can reduce NH3 volatilization from cattle slurry by about 50% (ETA-Denmark A/S, 2012). Reports on $N^2O$ emissions from acidified FYMs are contradictory (Fangueiro et al., 2017; Guo et al., 2021). So far there is a knowledge gap in terms of $N^2O$ emissions from NH4+-stripped fertilizers.

Thus, the aim of our study is to quantify $NH^3$ and $N^2O$ emissions from acidified and NH4+-stripped cattle slurry and liquid agricultural digestate to provide data for the Swiss (organic) agricultural context.

### Methodology

In field-acidification (target pH: 6.0-6.5) following the advice given by BioCover a/s (DK), was carried out adding concentrated sulfuric acid minutes before manual fertilizer application. Ammonium-stripping was carried out in an established on-farm stripping facility. The application of the derived ammonium sulfate was timed based on spectral data for crop N-uptake. Both treatments were applied to cattle slurry and liquid agricultural digestate. Untreated and unfertilized controls were used as references.

Ammonia volatilization during storage and shortly upon application was assessed under laboratory conditions with a flow through incubation setup and acid traps (colorimetry). Nitrous oxide emissions upon application are measured over two growing seasons (Wheat and Barley) using static chambers and gas chromatography under organic field conditions in Switzerland. The field trial features a split plot design with four blocks.

### Results and discussion

Data is currently being collected. Analysed results from the first field season are going to be available in August 2023. Both acidification and NH4+-stripping are expected to considerably reduce $NH^3$ losses from cattle slurry and liquid agricultural digestate. Compared to untreated references, acidified fertilizers are expected to present lower $N^2O$ emissions in the first weeks following application, but show higher cumulative $N^2O$ emissions over the entire growing season. Nitrous oxide emissions from NH4+-stripped fertilizers are expected to be lower than the untreated references.

### Conclusion

Not yet applicable.

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## Greenhouse gas emissions from digestate composting

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### Introduction

Anaerobic digestion is probably the best way to treat organic residues, providing both biogas for fossil fuel substitution, and an organic rest, digestate, with improved fertiliser qualities (Möller and Müller 2012; Foereid et al. 2021). That raises the question how digestate processing and use affect greenhouse gas (GHG) emissions. We investigated GHG emissions after application of digestate to soil, and we found that it can induce relatively high GHG emissions (Dietrich et al. 2020). Nitrous oxide emissions from after application of some liquid and one solid fraction were high, but there were no emissions when composted digestate was applied to soil. This raised the question if there were emissions from the composting process itself.

### Methodology

We composted food waste digestate and raw food waste as control, both with the same structure material in dewar flasks. We assessed GHG emission by taking out samples with a syringe after closing the flasks. Samples were analysed using GC-MS for $CO^2$, $N^2O$ and CH4. Temperature was also recorded, and the experiment was run until after the thermophilic phase of composting.

In the second experiment we compared composting digestate with autoclaved digestate, to see if microbes imported with the digestate played a role. We also assessed potential mitigation options, hygenisation at 70°C and effective microbes. We also compared to another digestate from a plant with a thermophilic biogas process.

### Results and discussion

Cumulative CH4 emissions over 3 weeks were found to be almost 12 times higher from composting digested food waste than from raw food waste (Dietrich et al. 2021). Cumulative $N^2O$ emissions were also higher when composting solid digestate was compared to composting raw food waste, but the global warming potential was mostly driven by the impact of CH4 emissions. We believed that a microbial community adapted for CH4 production in the digestate could be the reason for the high emission. This theory was confirmed in the second experiment as methane emissions were drastically reduced when the digestate was autoclaved before composting. Hygenisation at 70°C also drastically reduced emissions, but effective microorganisms had little effect. Digestate from the thermophilic process had lower emissions during composting, probably because the temperature was mostly lower than the microbes were adapted for.

### Conclusion

CH4 emissions during digestate composting can be high because the microbial community in the digestate is adapted to high CH4 production. Hygenisation at 70°C prior to composting is an effective mitigation measure.

### Acknowledgements

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## Synergistic abatement of $NH_3$ and $N_2O$ emission from composting process

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### Introduction

Livestock manure is estimated to contribute over 40% of global anthropogenic $NH^3$ and $N^2O$ emissions. Reducing reactive nitrogen (N) leakage from livestock manure management is of global concern. Aerobic composting of organic waste is an important anthropogenic source of ammonia ($NH^3$) and nitrous oxide ($N^2O$). The increasing implementation of ammonia ($NH^3$) mitigation measures in livestock production inevitably results in ammonium (NH4+) enrichment in the manure, but there is a lack of mechanistic understanding of such enrichment on N cycling and gaseous N emissions from subsequent manure management. Moreover, it is difficult to implement targeted options to mitigate emissions from this source because the dominant N2O production pathway remains unclear. Therefore, there is a pressing need to understand the NH4+-mediated mechanisms that underlie microbial N transformations in the livestock manure N2O emission achieving the synergistic abatement of NH3 and N2O emission from livestock manure.

### Methodology

A series of manure incubations were conducted in a novel system enabling simultaneous determination of dinitrogen ($N^2$), nitrous oxide ($N^2O$), nitric oxide (NO) and ammonia ($NH^3$) emissions, combined with isotope labelling and metagenomic sequencing, to investigate the impacts of ammonium (NH4+) enrichment in manure on nitrogen (N) transformation and gaseous N emissions.

### Results and discussion

Results indicated that bacterial denitrification dominated the $N^2O$ production overall, but the major $N^2O$ production pathway varied at different composting stages, with heterotrophic denitrification (HD) being most important at the early stage and nitrifier denitrification (ND) at the latter stage. Most $N^2O$ was produced at the latter stage, where the production of nitrite through ammonia oxidation provides substrate for nitrifier denitrification. Quantification of the functional genes involved in nitrification and denitrification revealed that the $N^2O$ emission rates correlated with the abundance of the amoA gene in ammonia-oxidizing bacteria (bac-amoA). The application of an electric field during composting reduced $N^2O$ emission by 28.5-75.5%. The underlying mitigation mechanism of the electric field was attributed to ammonia oxidation inhibition, as evidenced by the observed reduction in nitrite accumulation and the abundance of bac-amoA. Sequencing of the bac-amoA gene suggested that the amoA-containing family Nitrosomonadaceae was responsible for ammonia oxidation and $N^2O$ production, and the application of an electric field could reduce the proportion of Nitrosomonadaceae from 99% to 83% at the lower voltage and to a negligible level at the higher voltage assessed, which was attributed to their depressed competitiveness for oxygen ($O^2$) with heterotrophs. The application of an electric field promoted the degradation of organic matter while reducing the $O^2$ availability, as evidenced by the decreased free air space and $O^2$ concentration. The findings of this study provide evidence that an electric field could be used as an innovative nitrification inhibitor to reduce compost-derived $N^2O$ emissions.

### Conclusion

These findings indicate that upstream $NH^3$ mitigation in livestock and manure management can further minimize $N^2O$ emission peaks due to the role of the consequent manure NH4+ enrichment. These results support the promotion of more effective $NH^3$ abatement options for livestock manure management. This improved mechanistic understanding can also help the development of synergistic mitigation options for multiple reactive N gases in livestock production.

### Acknowledgements

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## Mitigation of greenhouse gas and ammoniac emissions during sewage sludge composting: a statistical analysis

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### Introduction

In Europe, composting represents one of the ways for sewage sludge management with about 1,4 million tonnes of sewage sludge dry matter processed as so in 2015 (ASTEE GT Boue, 2020). To follow the ambitions of Europe for the sustainable environmental transition the best practices must be favoured for the management of organic wastes. Special attention has to be paid to the reduction of their environmental impact. In this context, a statistical analysis of literature data has been performed to assess the level of greenhouse gas ($N^2O$ and CH4) and ammonia ($NH^3$) emissions during composting of sewage sludge, to identify key chemical parameters of the initial mixture that might affect gaseous emissions and to define the operating conditions that would contribute to the emission mitigations.

### Methodology

The databases used to create the corpus are science direct and google scholar. The corpus includes less than 30 years old papers related to sewage sludge composting and containing information on gas emissions ($N^2O$ and/or CH4 and/or $NH^3$). This corpus of 19 papers (63 data), including 8 with CH4 emission (26 data), 9 with $N^2O$ emission (31 data) and 17 with NH3 emission (52 data), was analysed for the following parameters: chemical characteristics of the initial mixture, operating conditions, cumulative gas emissions. Simple linear regressions have been carried out to assess the relationships between cumulative gas emissions and chemical characteristics of the initial mixture (total carbon (TC), total nitrogen (TN), dry matter (DM) content, pH, C/N ratio). The emission units are in g.kg-1 of DM of the initial mixture.

### Results & Discussion

The mean emissions of $NH^3$, $N^2O$ and CH4 are respectively of 2,21 ± 2,32 g.kg-1, 0,20 ± 0,16 g.kg-1 and 2,60 ± 4,72 g.kg-1. The standard deviations show a great variability in the gas emissions, especially for methane, probably due to the variability of the experimental conditions such as reactor size, bulking agents, aeration conditions and chemical parameters of the sewage sludge used. The simple linear regressions between $NH^3$ emissions and the five chemical characteristics of the initial mixture are not significant. However, a relation between these emissions, the pH and the initial TC is suggested by the data distribution and should be deepened. The simple linear regressions between $N^2O$ emissions and the TC, TN and C/N ratio are not significant. On the contrary, the linear regression between $N^2O$ emissions and the DM content is significant ($p\text{-value} < 0.05$) with a negative correlation which can be explained by the decrease of anaerobic areas with the increase of the DM content, and consequently the decrease of the denitrification path (Guardia, 2018). Moreover, a negative correlation is suggested between N2O emissions and pH ($p\text{-value} < 0.1$). The simple linear regressions between CH4 emissions and the DM content and pH are not significant. On the contrary, the linear regressions between CH4 emissions and TC, TN and C/N ratio are significant ($p\text{-value} < 0.01$). The correlations between CH4 and TC and C/N ratio are positive. The correlation between CH4 and TN is negative. Looking at these results, although cause and effect relationships have not yet been studied, it could be suggested that it is possible to act on the gas emissions by changing the characteristics of the initial mixture, especially for the $N^2O$ and CH4 emissions, although the relations between NH3 emissions and initial mixture characteristics should be deepened.

### Conclusion

The statistical analysis is not fully completed. The previous analysis is going to be deepen by multiparametric statistical analyses which will study the impact of the interactions between the chemical characteristics of the initial mixture and allow to have more hypothesizes on the emission mechanisms. It will be supplemented with a study that would seek to identify operational conditions that would induce a mitigation of gas emissions. More results will be presented at the conference.

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## Comparing directly and indirectly measured N losses as a novel approach to estimate N2 losses from (solid) livestock manures

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### Introduction

Nitrogen (N) emissions from livestock manure systems are detrimental to the environment. Nitrogen is emitted in different forms of which nitrogen gas ($N^2$) is currently impossible to measure due to the technical barriers and huge atmospheric background interference and hence often estimated. Nitrogen compounds can be tracked by directly measuring the respective compounds or by calculating a mass balance (Neysari et al., submitted). The main objective of this study was to investigate the performance of a method to estimate the $N^2$ loss by combining directly and indirectly measured and calculated total N loss (N-gap).

### Methodology

An experiment with solid poultry manure was set-up to measure N balance and ammonia emissions. The ammonia emission was measured using an acid scrubber method (Mosquera et al., 2019) from 8 vessels containing belt manure of laying hens, about 800 g each, during a 7-day lab experiment. The other N compounds including nitrous oxide ($N^2O$), nitric oxide (NO) and nitrite ($NO^2$) were estimated with ratios against ammonia derived from literature (CBS, 2020; Oenema et al., 2000). The sum of measured and estimated N compounds represented the direct total N loss. The indirect total N loss was also simultaneously conducted per vessel using N mass balance method over the same time. A paired t-test was performed by comparing the N losses calculated by direct and indirect methods per vessel to test significancy of the differences between the two methods. This difference was presumed as $N^2$ emission.

### Results and discussion

The $N^2$ emission was on average, 0.85 g or 24.4% of total indirect N loss. The performance of estimated $N^2$ per vessel in the form of coefficient of variation was calculated to be 32.6% of mean. The uncertainty involved in estimated $N^2$ loss was attributed to the variance between the vessels because of physical variation (80%) and the variance in measurement errors (20%). Sensitivity analysis of the uncertainty showed that moving from 1 to 4 vessels reduced the uncertainty by 76%-point with single sample replicate and 81%-point with triplicate sampling per vessel.

### Conclusion

This study offers a method to estimate the $N^2$ emission not only in solid manure but also conveniently in slurry manure due to its homogenous matrix/structure. The method requires enough vessels (at least 4) to perform a paired t-test for distinguishing the $N^2$ emission from the sampling and analytical errors.

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## Nitrogen ratio methods as an alternative to estimate total N losses in (solid) livestock manures

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### Introduction

Conventional N balances require the measurement of mass flows through the system, e.g., barn and storage, which is not feasible nor practical. As a proxy to the conventional N balances, N ratio methods were introduced to establish the N balance based on a relative ratio of N to a stable compound, e.g., phosphorus, potassium or ash (Oenema et al., 2007). In this way, N losses can be estimated when no mass flow information is available. In this study, we provide insight into N ratio methods and compare them to conventional N mass balance method as the reference method.

### Methodology

We conducted a laboratory experiment with belt manure from a poultry aviary house in which we measured the total N loss through a conventional N mass balance and compared it to the total N loss by using the N/P, N/K and N/ash ratios. This study was based on data from a recent experiment, reported by Neysari et al. (in progress). The experiment consisted of a lab set-up with 8 vessels as experimental units. The vessels (0.19 m diameter, 0.3 m height) were made from transparent plexi-glass (Perspex Acrylate) with perforated heads with twenty-four holes (each Ø 0.001 m) as air inlets and another hole (Ø 0.005 m) in the middle as an air outlet. The experiment was executed during a 7-day period in which N, P, K and ash compositions and the mass were measured at the start and the end of the experiment. As the vessels were fully closed on the bottom, there was no leaching of water and compounds. The assumption that minerals P, K and ash were not volatilised was evaluated by comparing the initial and final mass of each component. The systematic differences (error) between the ratio methods and the N mass balance were assessed. The precision of N loss calculated by each ratio method was assessed based on JCGM (2008) to show the variation of each ratio method.

### Results and discussion

Potassium was the most stable compound (0.98 mean and 0.04 s.d.) when comparing final and initial ratios assuming to end up to the unit (1 g $g^{-1}$). Total N loss on average was: 3.11 g, 3.76 g, 2.66 g and 2.34 g for N balance, N/P, N/K and N/ash methods, respectively. Of the mineral ratio methods, no significant difference was found between relative N loss through N mass balance and N/K ratio method. All other methods significantly deviated from the N balance. Relative N loss calculated by N/P ratio showed lower systematic error (21% of relative N loss through balance method, respectively) than N/K (-15%) and N/ash ratio method (-25%) meaning total N loss calculated by the N/K had the lowest deviation from the reference method. Precision of N/P ratio was the lowest (15%) compared to 51% precision for N/K and 49% precision for N/ash ratios meaning the N/P ratio had the best precision as alternative to the reference method. Total error of composition analyses including sampling and analytical errors for both initial and final samples showed the lowest error for K analysis (2.95% of initial total error).

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## Sustainable and efficient slurry management models for approaching climate-neutral farms

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### Introduction

The agriculture sector is an important contributor to emissions of ammonia (NH3) and greenhouse gases (GHG), to the atmosphere with deleterious effects on the environment and climate. The agriculture sector represents a share of 94% of NH3 emissions, and 56% of methane (CH4) emissions. To reduce emissions from this sector the EU Green Deal focuses its efforts to be climate-neutral in 2050. In particular, the present management of slurry and crop over-fertilization results in increased GHG and NH3 emissions, large consumption of mineral fertilisers, ineffective energy schemes, excessive road transport, etc., hindering the environmental and economic sustainability of agricultural activity in rural areas (EEA, 2021). This is a sound problem in regions where intensive livestock and agricultural production systems coexist, such as the Mediterranean countries of Italy and Spain.

The LIFE CLINMED-FARM project aims at developing sustainable and resource-efficient slurry management models approaching the idea of "climate-neutral farms". These models will be supported by the preparation and validation of robust and reliable monitoring methods. Spanish and Italian partners (Agricultural and Forest systems, Agrifood Research and Technology Centre of Aragon, Agropecuaria del Isábena, Mazana Piensos Compuestos, Mecàniques Segalés, Ecologic Biogás, Università degli Studi di Torino, and Micropower) participate in the project. The total budget is 3.562.937 € with an EU contribution of 55% (1.959.613 €) coming from the LIFE Climate Action programme.

### Methodology

The main purposes of LIFE CLINMED-FARM are aligned with the principles of the circular economy: mitigation of CH4, nitrous oxide (N2O), and NH3 emissions, recovery of the CH4 produced in storage, valorisation of biogas and surplus heat obtained in biogas upgrading as renewable energy sources for farm activities and/or adjacent industries, and reduction of mineral fertiliser consumption. To achieve these goals, simple and innovative techniques are being implemented in the three key stages of slurry management (in-house production, storage, and agricultural fertilisation) of two study cases, one in Aragón (Spain) and the second in Piedmont (Italy). These techniques will be analysed from an environmental and socioeconomic point of view by developing measurement and monitoring methodologies that provide objective and reliable data. It is worth mentioning that the activities carried out during the project are based on the strategy set by Europe for the Climate Action and the Green Pact, the Paris Agreement, the methane emission reduction strategy, and regulations such as the Emission Ceiling Directive and the Industrial Emissions Directive.

### Results and discussion

It is expected that the actions performed during the project contribute to climate change mitigation by optimising on-farm CH4 recovery and by reducing GHG and NH3 emissions produced from slurry management, minimise the consumption of external inputs by using more efficiently the nutrients available in slurry/digestate to replace synthetic fertilisers partly or completely, harness sustainable and renewable energy sources (biogas) in agricultural activities, determine the mitigation potential of the applied techniques, and develop strategies to avoid transferring the environmental impact between the different steps of the slurry management chain. In addition, the achieved results will support the development of new environmental policies and the elaboration of emission inventories.

### Conclusion

The LIFE CLINMED-FARM project will demonstrate that sustainable and efficient slurry management systems can be accomplished by implementing simple techniques based on a circular economy. Reliable monitoring procedures will be developed to generate objective data to contribute to environmental policies and emission inventories.

### Acknowledgements

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## Ammonia emission from a dairy farm

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### Introduction

Agricultural emissions, specifically losses from animal housings and manure applications, are the main contributor to the total emissions of ammonia ($NH^3$) in Switzerland (Kupper et al., 2015). The objective of this study was to estimate $NH^3$ emission from a dairy farm based on trace gas measurements and dispersion modelling.

### Methodology

The dairy farm was located at a rural site in the Swiss plateau. Line-averaged $NH^3$ concentrations were measured for approx. two months during wintertime, upwind and downwind of the dairy farm using open-path instruments. Turbulence was characterized from high-frequency ultrasonic anemometer measurements in the proximity of the concentration measurements. A backward Lagrangian stochastic (bLS) dispersion model was used to calculate $NH^3$ emissions from the concentration measurement increase due to the farm emission.

### Results and discussion

Calculated average $NH^3$ emissions were found to be in an expected range. $NH^3$ concentration reduction due to dry deposition removal was found to be not negligible. Dispersion modelling provides a suitable instrument to estimate $NH^3$ emissions, specifically if measurements can be corrected for dry deposition loss of $NH^3$.

### Conclusion

Dispersion modelling combined with line-integrated concentration measurements provides a suitable instrument to estimate $NH^3$ emissions.

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## Ammonia, methane, and nitrous oxide emissions from laying hen manure

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### Introduction

Today, reliable emission factors for the storage of poultry manure are lacking. The values that are used today in Sweden as advisor tool is based on a few studies with inadequate sampling methodology. For ammonia, there is a long list of measures implemented, but further measures will be required to meet international commitments such as the TAK Directive (OJ, 2016/2284) and the BAT (Best Available Technology) conclusions (OJ, 2017/302) for intensive breeding of poultry or pigs. The reduction of ammonia emissions from Sweden has until today partly been due to reduced animal production, which according to the Swedish food strategy is not sustainable in the longer run. The lack of data means great uncertainty with advisors, among others, because it makes the work of implementing effective measures more difficult.

To be able to evaluate measures and provide reliable national data to the EU convention, more knowledge of the ammonia emissions from stored poultry manure are needed. The aim of the presentation is to present values. of the ammonia-, methane-, and nitrous oxide emissions from storage of laying hen manure.

### Methodology

The emissions of ammonia, methane and nitrous oxide was measured over a year in a pilot-scale study. Twelve measurement occasions were conducted over one year, with more measurements during the warmer months (May to September). The pilot study includes four containers (10 m3 of poultry manure in each). Two containers have manure with a starting DM-content of 80% and two with a starting DM-content of 40 %. Over one of each DM-content a roof was built and the other two was left without a roof.

### Results & Discussion

Ammonia emissions from dryer manure under roof had 90 % lower emissions than manure without manure and ammonia emissions from wetter manure had 40 % lower emissions than manure without roof. Methane and nitrous oxide started to emit in the end of the measuring period from the manure without any roof, probably due to more water, added by rain.

### Conclusion

Roof over laying hen manure decrease ammonia, methane, and nitrous oxide emissions.

### Acknowledgements

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## Effect of Diet and Manure Handling on Dairy Manure Methane Potential

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### Introduction

In the USA, methane (CH4) emissions from dairy manure are estimated to generate 32.1 MMT CO2eq each year and comprise 42% of the total CH4 generated at the production facility (enteric + manure management; USEPA, 2023). The methods used to calculate these emissions in national inventories are based on the IPCC Tier 2 approach using total volatile solids, maximum CH4 production of the manure (Bo), and a CH4 conversion factor. Comparison of on-farm measured manure CH4 emissions to estimates using the IPCC Tier 2 approach, suggest that on-farm emissions from liquid storage are greater than those predicted, in many instances (Owen and Silver, 2014; Vechi et al., 2023). The Bo values for dairy manure used in current inventory estimates were derived from research conducted over 4 decades ago (Bryant et al., 1976; Morris, 1976) which may not be representative of current genetics, diets, and manure handling systems. The aim of this study was to evaluate the Bo of fresh faces as well as slurry going into liquid storage, before and after a solid separation system, in one of the largest dairy producing regions in the USA.

### Methodology

We evaluated the B° of fresh faces from three animal classes (lactating and dry cows, heifers) at 12 commercial dairies over 2 seasons (summer and winter). Fresh faces were collected from ~40 animals at each farm for each animal class, composited, and sent to the Anaerobic Digestion Research Education Center at Michigan State University for biochemical CH4 potential analyses. Feed samples were also collected at the time of manure collection and analysed for acid detergent fibre (ADF), neutral detergent fibre (NDF), lignin, soluble sugar, starch, fat, and non-structural carbohydrates. A follow up study is being conducted at 10 farms (open lot or freestall housing) over 4 seasons, evaluating the Bo of fresh slurry and separated solids and liquid from 5 different separation techniques (slope screen, sand settling lane, rotating drum, chain drag, and weeping wall).

### Results and discussion

Currently a B° value of 0.24 $m^3$ CH4 $kg^{-1}$ $VS^{-1}$ is used for all dairy manure in the IPCC estimates. In the current study, the Bo of fresh faces was 0.23 ± 0.05 $m^3$ CH4 $kg^{-1}$ $VS^{-1}$ for lactating cows, which was significantly greater than that of dry cows or heifers (0.16 ± 0.03 $m^3$ CH4 $kg^{-1}$ $VS^{-1}$), which were not significantly different. Dietary ADF, NDF, and lignin were good predictors of manure B°, with measured vs predicted values having an $r^2 = 0.98$ and slope of 0.99. Fresh slurry entering the manure separation systems had an average B° of 0.38 ± 0.09 m3 CH4 $kg^{-1}$ $VS^{-1}$, a 65% increase over the Bo of fresh faces. The liquid following solid separation, which would go to long term storage, had a B° of 0.40 ± 0.13 $m^3$ CH4 $kg^{-1}$ $VS^{-1}$ following single stage separation and 0.38 ± 0.04 $m^3$ CH4 $kg^{-1}$ $VS^{-1}$ following 2 stage separation. The solids from the separators had a B° of 0.20 ± 0.05 $m^3$ CH4 $kg^{-1}$ $VS^{-1}$ from primary separation and 0.24 ± 0.14 $m^3$ CH4 $kg^{-1}$ $VS^{-1}$ from 2 stage separation.

### Conclusion

This study suggests that current B° value for fresh feces from lactating cows is similar to the value used in many inventories, however lower values may need to be used for dry cows and heifers. The B° values of fresh faces may be appropriate for estimating emissions from manure that is scraped and handled as a solid, although some urinary N will likely be mixed in which may influence CH4 generation. For manure slurry going into liquid storage, Bo values were 65% greater than those currently used in the inventories, which may help explain discrepancies between on-farm and predicted CH4 emissions from liquid storage. Manure separation generated liquid with B° values similar to the incoming slurry (~0.39 $m^3$ CH4 $kg^{-1}$ $VS^{-1}$), while separated solids had Bo values more similar to fresh faces (~0.22 $m^3$ CH4 $kg^{-1}$ $VS^{-1}$). Updating B° values in current inventories may provide better estimates of CH4 emissions from manure storage.

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## Effect of changes in farm structure and management on ammonia emissions of Swiss agriculture from 1866 to 2020

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### Introduction

In conjunction with studying the historical development of agricultural ammonia emissions we made a review of the development of farm management and used the information to model ammonia emissions over the past approximately 150 years. Thus, we could study the interactions between farm structure and management and environmental impacts.

### Methodology

Besides official statistics on animal numbers, farming surface etc the Swiss ammonia (NH3) emission inventory (Kupper et al., 2022) since 1990 is based on representative data on farm management practiced for 1990, 1995, 2002, 2007, 2010, 2015, 2019 and multiple expert assumptions for 1990 and 1995. To study such interactions also before 1990, we reviewed how farming structure and management had developed since the first official national farm structure survey in 1866. Emission calculations were performed for the years 1866, 1886, 1906, 1916, 1921, 1926, 1936, 1941, 1946, 1956, 1966, 1973, 1978, 1983 and 1988 with the Nitrogen (N) flow tool Agrammon used for the NH3 emission reporting. Agrammon was based on a previous model version developed by Reidy et al. (2008). Apart from official farm statistics the calculation also included rather detailed inputs on housing and manure management systems, manure storage and application, feeding, grazing. The historical study (1866 to 1988) of Klossner et al. (2014) was updated with the current version of Agrammon and compared with the most recent inventory report (Kupper et al., 2022).

### Results and discussion

In Switzerland grassland covers more than 70% of the utilised agricultural area (excl. alpine pastures) leading to high N excretions of herbivores and excretions of livestock (before losses) contribute more than double the N in fertilizer.

N excretions of agricultural livestock were 95% higher in 2020 than in 1866. The highest amount was recorded in 1978 and 1983 with about +128% relative to 1866. In 1983 the level relative to 1866 was +123% for cattle, +987% for pigs, +210% for poultry, -52% for equids and -57% for small ruminants. The contribution of cattle always was above 75% (lowest value 1990 75.5%), that of pigs increased from 4% in 1866 to 19% in 1990 and then decreased again to 10% in 1990, that of poultry increased from 1.6% in 1866 to 2.6% in 1990 and 5.7% in 2020 and that of equids decreased from 7.0% in 1866 to 0.9% in 1990 and then rose again to 2.0% in 2020. These developments were mainly due to changes in animal numbers because economic conditions (e.g. milk quota, market demand, changing regulations, nutrient balance restrictions 1991).

The changes in N excretion of livestock strongly influenced NH3 emissions from livestock and manure management increased by +145% from 1866 to 1990 and then decreased again to +102% in 2020 (relative to 1866). The share of cattle always was around 80%. For pigs the share increased from 5% in 1866 to 23% in 1990 and then decreased to 16% in 2020, for poultry the share was always around 3% until 2002 and the rose to 5.3% in 2020. The share of NH3 emissions from the housing area (incl. yard) was slightly below 20% until about 1960 and then increased (mainly since 1995) to 36% in 2020 due to more animal friendly housing systems. The share of NH3 emissions from manure application decreased from around 55% until 1946 to around 47% from 1983 to 1995 and then decreased to 44% in 2020 due to incentives promoting low emission slurry spreading techniques where the topography allows it.

### Conclusion

Manure is and always was the most important fertilizer in Swiss agriculture. Its turnover and thus also its $NH^3$ emissions strongly increased until 1978 (N excretion +129% relative to 1866) and since than decreased again, mainly due to new legal restrictions (1990 to 2020 -15% and -22% of N excretions and NH3 emissions resp.). Besides the lower N excretions, the N fertilizer import of Swiss agriculture decreased by 38%. This means: good achievements but still further potential.

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## Controls of dairy manure composition on associated ammonia, nitrous oxide, and methane emissions

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### Introduction

Manure management and utilisation are essential for profitable and sustainable farming practices, especially in mixed systems such as dairy systems, where manure is recycled on the own farm. Inefficient manure management can reduce nutrient use efficiency and lead to substantial environmental losses. Ammonia (NH3) volatilisation from manure upon application can greatly reduce nitrogen (N) availability to crops while leading to acidification and/or eutrophication in areas where it is deposited. Moreover, manure-induced emissions of greenhouse gases such as nitrous oxide (N2O) and methane (CH4) may contribute to global warming. The occurrence and magnitude of these gaseous emissions are likely to be determined, amongst other factors, by manure chemical composition. Although international conventions such as the Gothenburg Protocol and Paris Climate convention require annual national inventories of the emission of these gases, underlying models or methodologies rarely include differentiation based on manure composition (EEA, 2019; IPCC, 2006).

The aims of this study were (i) to characterise the variation in NH3, N2O, and CH4 emissions resulting from dairy manures, and (ii) to explore to what extent the variation in emissions from these manures can be explained by manure chemical composition parameters.

### Methodology

Slurry manure samples were collected from fifty dairy farms throughout the northern and eastern part of the Netherlands and split in two subsamples. One subsample of each manure sample was analysed for their chemical and mineral composition (dry matter, organic matter, pH, total N, ammoniacal N, P, K, S, etc.) by ALNN laboratory in Ferwert. In the other subsample, gaseous emissions were determined using a series of incubation experiments. The direct NH3 and CH4 emissions from the manures were determined by a short lab trial of a few minutes, without the use of soil. Additionally, $NH^3$ and $N^2O$ emissions after manure application at 100 kg N $ha^{-1}$ to a sandy soil (through surface-application or injection) were determined in a 21-day incubation experiment. In both cases gas concentrations were measured using an INNOVA 1512 photoacoustic gas analyser. A combination of principle component analysis and multiple regression with mixed linear models was applied to investigate the relationship between manure composition and gaseous emissions.

### Results and discussion

The fifty manure samples varied considerably in both chemical composition as well as gaseous emissions from the incubation experiments. Coefficients of variation for the tested chemical parameters ranged from 20% to 40%, and for direct emissions of $NH^3$ and CH4 the highest emitting sample recorded values that were respectively 12 and 44 times as high as those found for the lowest emitter. In the incubation experiment, there was a clear reduction in $NH^3$ emissions when manure was injected into the soil, whereas this effect was absent for $N^2O$ emissions. Mixed model result showed that not total or ammoniacal N, but rather manure pH was the main factor explaining $NH^3$ emissions (emissions increased with manure pH), although inclusion of total or ammoniacal N did improve model performance. The $N^2O$ emissions after application of the manures to soils were governed by the amount of moisture added with the manure at the set rate of 100 kg N $ha^{-1}$. Other significant factors in the best models for $N^2O$ and CH4 emissions were organic C and N, and C/N ratio. This set of experiments shows that, although emission calculation methods for national inventories and nutrient flow models are often based on handbook values or standard emission factors, variability of emission potential is high, even within an animal category. Including easily obtainable information on manure composition, such as pH and nutritional content, could provide a way to improve manure emission calculations.

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## Greenhouse gas removals and techno-economics of biochar production from food waste digestate in the UK

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### Introduction

As a Greenhouse Gas Removal (GGR) technology, biochar can potentially contribute to achieve UK's net zero emission target by 2050 (https://assets.publishing.service.gov.uk). However, the limited availability of conventional feedstocks such as wood hinders its deployment. Biomass wastes such as anaerobic digestate which are less attractive in energy applications can extend the scale of biochar deployment. Application of stable biochar in the soil has a potential in achieving a long-term carbon storage with prospective co-benefits for improving the soil quality (Ding et al., 2016; Oni et al., 2019). Hydrothermal carbonisation, with subsequent high temperature torrefaction, is capable of directly producing stable biochar from wet wastes such as digestates. However, the economic and environmental evaluation of the potential scale of biochar production from anaerobic digestates is required for the implementation of digestate to biochar scheme. Anaerobic digestion (AD) treats numerous feedstocks which has expanded to around 685 operational AD plants by 2021 in the UK including the processing of over 3.2 million tonnes of food waste (https://www.biogastradeshow.com; https://wrap.org.uk). Future growth in the sector will be driven by food waste management, where AD is viewed as an environmentally favourable treatment method for unavoidable food waste.

### Methodology

In this work we assessed the life cycle of food waste digestate to biochar production and its application as a soil amendment through techno-economic and life cycle analyses to recognize the environmental and economic viability of the food waste digestate to biochar approach in the UK for year 2030.

### Results and discussion

Our analyses indicate the biochar production from food waste digestate achieving a substantial net greenhouse gas (GHG) removals of approximately 1.6 t-CO2eq t-biochar-$^{1}$. Soil effects from the application of biochar are still unclear but, the soil effects and the transportation of feedstock and biochar are estimated to have a small impact on GHG emissions, highlighting that the majority of emissions reductions are from the physical storage of carbon in biochar (1.9 t-$CO^{2}$eq t-biochar-$^{1}$). The use of 50% of the UK's projected available food waste digestate by 2030 can sequester around 85 kt-CO2eq p.a, requiring 28 individual 20 kt p.a biochar production facilities. Commercial biochar production from food waste digestate is able to provide cost-effective GHG removals of less than £100 t-$CO^{2}$-$^{1}$ avoided. Other wet wastes such as green waste will command a lower gate fee resulting in higher costs of avoiding $CO^{2}$. Sensitivity analysis demonstrates the heavy influence of the gate fee and its importance for biochar process establishment. This work considers a highly promising opportunity in solving a waste disposal burden and simultaneously removing atmospheric GHGs. Multiple sources of biochar will be required to make significant contributions to the UK's GGR target.

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## Agricultural ammonia emission control is essential for reducing nitrogen deposition

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### Introduction

Over the past few decades, human activities associated with energy and food production (e.g., industrial, traffic, agricultural, and waste disposal sources) have substantially increased emissions of reactive nitrogen (Nr) to the atmosphere which leads to excessive atmospheric nitrogen (N) deposition on land (Liu et al., 2013). China is a global hotspot of N deposition and has implemented strict atmospheric policies in the last decade (Liu et al., 2022). Yet, the responses of N deposition to these policies are not well known. This study used a global chemistry transport model to simulate the variation and main contributors of anthropogenic N deposition in China, helping to design effective, practicable policies for reducing N deposition in the future.

### Methodology

First, we used a nested version of GEOS-Chem with the native horizontal resolution of 0.5°×0.625° over China (Zhao et al., 2017) to simulate N deposition for the 2010s and to examine temporal trends and the spatial distribution of N deposition via different pathways and in various chemical forms. Then, we clarified the response of N deposition to the implemented policies and the contribution of the total N deposition from emission sectors by a series of sensitive tests.

### Results and discussion

1. At a national scale, N deposition from human activities only decreased by 4% during the 2010s (from 13.1 Tg N/yr to 12.6 Tg N/yr), with NHx deposition increasing by 1.3 Tg N/yr and NOy deposition decreasing by 1.7 Tg N/yr.

2. The average ratio of NHx/NOy deposition underwent significant changes during the past decade, rising from 0.7 to 1.2, especially in the eastern and southern regions of China.

3. The positive effects of the policies reflect the decrease of dry nitric acid ($HNO^3$) deposition, but the increased NHx deposition compensated for the decrease of NOy deposition caused by the increases in dry ammonia ($NH^3$) and wet ammonium (NH4+) deposition.

4. Agriculture has been identified as the most significant source of total N deposition, contributing an average of over 30% to the total N deposition during the 2010s.

5. The primary changes in N deposition between 2011 and 2019 were observed in the agriculture and power plant emission sectors. The increases in total N deposition from agriculture mainly occurred in the southern regions, such as the Yangtze basin, while the decreases in total N deposition from power plant sources mainly occurred in the North China Plain.

### Conclusions

In the 2010s, the amounts of N deposition only declined by 4% in China, mostly due to the increases in NHx deposition. Agriculture was estimated as the most important source of N deposition, contributing 30% and 37% to the total N deposition in 2011 and 2019. Thus, agricultural $NH^3$ emission control is essential to reduce N deposition pollution in the future, but the emission control strategies should be designed in a region-specific manner, taking into account local economic, ecological, and environmental conditions.

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## Effect of biogas operation parameters and input feedstocks on nitrogen fertilising properties of digestates from full-scale plants

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### Introduction

The quality of digestates from anaerobic digestion (AD) and their fertilising value vary depending on the biogas plants' input feedstocks and operation parameters (Guilayn et al. 2019). The digestate composition variations make precise fertilisation challenging and act as a barrier to using digestates to substitute mineral fertilisers (Dahlin et al. 2015). With the increasing use of variable recalcitrant biomasses, AD optimisation focuses more on biogas yield and methane production, while digestate quality is overlooked. This results in digestates with undesired properties such as high dry matter content, negatively influencing nitrogen use efficiency by field application.

In this study, we evaluated the effects of varying operation temperatures, hydraulic retention time (HRT) and input feedstock types at full-scale biogas plants on N turnover in soil during 80 days following digestate application. Additionally, we developed a regression model to predict plant-available N from digestates based on the operation parameters of the biogas plants and feedstock types aimed at optimising the quality of digestate as fertiliser.

### Methodology

Digestates for this study were collected from 21 full-scale biogas plants in Denmark between November 2021 and April 2022. The sampled biogas plants provide a good cross-section of the variations in Danish biogas plants in terms of biomass composition and selected operational parameters. The samples were collected from storage tanks, homogenised and divided into two portions from each tank. The first portion was used to evaluate the residual methane potential of the digestates, while the second portion was used for this study.

The digestates were applied to a loamy sand soil at 200 mg N $Kg^{-1}$ and incubated at 10°C in a dark room. A non-amended soil was included as a control and a reference treatment with mineral N. Soil samples were destructively sampled on days 0, 2, 7, 14, 32 and 80 after application in three replicates and extracted with 1M KCl for analysis of ammonium-N and nitrate-N in soil.

### Results and discussion

The HRT and input feedstocks significantly ($p < 0.001$) influenced the net inorganic N release in the soil after 80 days of soil incubation. High net inorganic N release (% of N input) was observed in digestates whose residence times ranged from 38 to 75 days, with low net N inorganic release in digestates with < 38 days HRT. Extending HRT for >75 days did not result in higher N release in the soil, and this could probably be explained by plants using substrates with low degradability also using longer HRT. Digestates from mesophilic digestion temperatures resulted in higher net inorganic N release than those derived from thermophilic reactors, with an increase of 5°C resulting in a 2 % unit decrease in net inorganic N release in soil. The negative effect of increasing temperatures could be ascribed to the fact that AD temperature only influences the rate of substrate degradation and not ultimate biodegradability.

Digestates with Input feedstock containing a mixture of energy crops and grass resulted in the highest net inorganic N release (% of N input) compared to digestates from biogas plants with straw inputs. Less net inorganic N release from straw-derived digestates could be attributed to N immobilisation following digestate application due to lignocellulosic compounds in straw that could only be decomposed in soil and not during digestion.

### Acknowledgements

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## Effect of operating conditions on the abundance of antibiotic resistance genes in semi-continuous mesophilic anaerobic reactors

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### Introduction

Manure or digestate spreading can lead to the dissemination of antibiotic resistance genes (ARGs) in agro-environments, thereby potentially impacting human health (Wolters et al., 2016). There are various options for managing manure, including dewatering, composting or anaerobic digestion (AD). Few studies have examined the fate of ARGs during anaerobic digestion of manure (Burch et al., 2022). Moreover, the influence of operating conditions of AD on the persistence of ARGs has rarely been documented in the literature. The objective of this study was to evaluate, at a laboratory scale, the effect of three digester operational parameters on the abundance of 14 ARGs, and the intI1 gene. The selected parameters were the hydraulic residence time (HRT), organic load rate (OLR), and the application of a thermal pre-treatment (70°C for 1 hour) required by the EU Commission regulation EU 142/2011 on animal by-products.

### Methodology

Pig manure and digestate, collected from a mesophilic biogas plant, were filtered through a 5-mm mesh sieve. The digestate used as inoculum was transferred into the reactors immediately after sieving. The influent consisted of a mixture of manure, heated or not, and pelleted horse feed as co-substrate. Four mesophilic semi-continuous stirred reactors were used. Once the steady state was reached, digestates were sampled twice at a 4-week interval. The ratio of manure and co-substrate, and the feed volume were determined for each reactor according to the selected OLR and HRT. Screening experiments were performed using a two-level factorial design. Two quantitative factors (HRT and OLR) and one qualitative factor (heat treatment of manure at 70°C, 1 h) were investigated. The experimental design was conducted in one block, and central points were performed in duplicate. The two levels and the central point of HRT and OLR were 24, 46 and 35 days, and 2, 4 and 3 g COD L−1 d−1, respectively. DNA from samples was extracted using the NucleoSpin® Soil kit. Quantification of 16S rDNA, intI1, and of 14 ARGs (tetA(P), tetB(P), tet(M), tet(A), blaCTX-M1, blaCTX-M9, mcr-1, sul1, sul2, qnrA, qnrD, vanA, vanB, ermQ) was carried out by real-time PCR in triplicate.

### Results and discussion

Mesophilic anaerobic digestion of pig manure leads to a decrease in all the ARGs, with a variable reduction rate depending on the gene, the sul genes being the least affected by the process. The vanA and vanB genes present in the manure at a concentration of 2.2 105 and 2.2 106 gene copies g-1, respectively, were not detected in the digestates. Eight targeted genes (intI1 gene, tetracycline, sulfonamide and macrolide resistant genes) were detected and quantified in both manure and digestates. Their absolute abundance ranged from 4.9 107 gene copies $g^{-1}$ (tet(A)) to 3.8 109 gene copies $g^{-1}$ (tetA(P)) in digestates. The reduction of the ARGs abundance depended on the operating conditions. While HRT had no significant impact, increasing OLR led to a significant reduction in the abundance of the intI1, tetB(P) and ermQ genes. Only the tet(A) gene was significantly impacted by the 70°C pre-treatment. However, the differences in concentrations of this gene between the digestates from the reactors fed with heated and not heated manure did not exceed 0.7 Log10. The effect of temperature on tet(A) gene has been reported by Zou et al. (2020) who observed a reduction of 0.7 and 1.2 Log10, under mesophilic and thermophilic conditions, respectively.

### Conclusion

None of the three operational parameters had an impact on all of the targeted genes. It is noteworthy that the heat pre-treatment of the manure, required by the European regulation EU 142/2011 and intended to reduce pathogenic bacteria, had little or no effect on the abundance of targeted ARGs.

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## Ammonia removal and recovery from anaerobically digested liquid dairy manure using vacuum thermal stripping-acid absorption process

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### Introduction

Liquid dairy manure is generally applied to the arable lands in the US after anaerobic digestion (AD) to reduce greenhouse gas emissions. During AD of liquid dairy manure organic nitrogen is converted to ammonia nitrogen ($NH^3$-N) (Holly et al., 2017) which subsequently escalates the $NH^3$-N concentrations in manure (Huchzermeier and Tao, 2012). Among different available $NH^3$-N removal processes treating anaerobically digested liquid dairy manure (ADLDM), vacuum thermal stripping is reported to be an effective technique (Tao and Ukwuani, 2015). However, none of the studies have performed multi-parameter optimization, which is of utmost significance in maximizing process efficiency. This study aimed at optimizing critical operational parameters for vacuum thermal stripping on $NH^3$-N from ADLDM and modelling the vacuum thermal stripping process to predict ammonia removal potential.

### Methodology

The process critical operational parameters were optimized and modelled via integrating grey relational analysis (GRA)-based Taguchi design, response surface methodology (RSM) and RSM-artificial neural network (ANN). The initial experimental trials were conducted using the GRA coupled with Taguchi L16 orthogonal array and revealed the order of influence of the process parameters on $NH^3$-N removal as vacuum pressure (kPa) > temperature (°C) > treatment time (min) > mixing speed (rpm) > pH. The values of the first three most influential operating parameters were then further optimized and modelled using RSM and RSM-ANN models. Stripped NH3 was fed into a 500 ml flask containing 100 ml H2SO4 (1 N) solution pre-saturated with ammonium sulphate ((NH4)2SO4) for $NH^3$-N recovery in solid form. The structure and elemental composition of the recovered (NH4)2SO4 were analysed using scanning electron microscope and energy-dispersive X-ray spectroscopy.

### Results and discussion

Under the optimized conditions (temperature: 69.6 °C, vacuum pressure: 43.5 kPa, and treatment time: 87.65 min) the $NH^3$-N removal efficiency of 93.58 ± 0.59 % was experimentally observed and was in line with the RSM and RSM-ANN models' predicted values. Both the RSM and RSM_ANN models showed adequate prediction potential. The RSM-ANN model showed a better prediction potential than did the RSM model when compared statistically. Moreover, the nutrient contents (nitrogen, N and sulphur, S) of the recovered $NH^3$-N as $(NH4)^2SO4$ were in reasonable agreement with the market-available $(NH4)^2SO4$ fertilizer.

### Conclusion

Three most influential $NH^3$-N removal parameters tested were the vacuum, temperature, and treatment time. The proposed second-order polynomial quadratic equation using RSM showed adequate prediction potential. The RSM_ANN model is better than RSM model in terms of prediction of NH3-N removal. The experimentally obtained NH3-N removal was within the 95% low and high confidence intervals from both the RSM and RSM_ANN models. The $NH^3$-N stripped during the treatment can be recovered in the form of $(NH4)^2SO4$. The findings of the study can be used as a prediction guide for $NH^3$-N removal and recovery from ADLDM using the vacuum thermal stripping process.

### Acknowledgements

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## Comparison of the ecological risk assessment and risk assessment code of manure products and derived digestates and hydrochars

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### Introduction

Hydrothermal carbonization (HTC) can be directly applied to biomass with high moisture content, resulting a liquid and a carbon-rich solid phase - called hydrochar – which can be further valorized as soil amendment (Kambo and Dutta, 2015). Some researches state the decrease of available fractions of heavy metals (HMs) in hydrochars compared to their input materials (Lang et al., 2019; Lu et al., 2021). Although these studies have contributed to understanding the speciation of HMs in hydrochars and manure, there is still limited data concerning the potential environmental risks associated with the process. Therefore, this research compares the ecological risk assessment and the risk assessment code (RAC) in manure and maize from contaminated land and their derived digestates and hydrochars. While the RAC allows assessing the availability of HMs in these products, the ecological risk assessment evaluates the degree of contamination of these materials, contributing to the management decision of using these end-products as soil amendments.

### Methodology

Fractions of HMs in hydrochars and input materials have been determined using the modified Community Bureau of Reference (BCR) sequential extraction procedure described elsewhere (Liu et al., 2018). After the BCR extraction, the HMs were quantified by ICP-OES (iCAP 7400 Radial, USA), followed by their classification into four fractions: exchangeable and acid soluble fraction (F1), reducible fraction associated to Fe and Mn oxides (F2), oxidizable fraction bound to organic matters (F3) and residual fraction (F4). The indices for the ecological risk assessment have been calculated according to Eq. (1), Eq. (2), and Eq. (3) taken from a previous study (Devi and Saroha, 2014).

$$C_f = C_i/C_n \quad (1); \qquad E_r = T_r \, x \, C_f \quad (2); \qquad RI = \sum E_r \quad (3)$$

Where: $C_f$ = Contamination factor of the individual HM; $C_i$ and $C_n$ are the mobile and stable fractions of HMs, respectively; Tr = Toxicity response factor of the individual HM; Er = Potential ecological index of the individual HM, and RI = Sum of potential ecological risk factors of the contaminants. To assess the RAC values, the availability of HMs was measured using the percentage of HMs in the F1 fraction of samples, and the following categories have been considered: no risk (NR), RAC < 1%; low risk (LR), 1% ≤ RAC ≤ 10%; medium risk (MR), 11% ≤ RAC ≤ 30%; high risk (HR), 31% ≤ RAC < 50%; very high risk (VHR), RAC > 50% (Alipour et al., 2021).

### Results and Discussion

According to the BCR extraction, most elements could be found in available fractions of hydrochars derived from mono and co-digestates, and feedstocks. The Zn element was associated with F1 and F2; whereas Cr, Cu and Fe were mainly found in F3, and Mn in F1. The association of Mn and Cu with the aforementioned fractions were also found elsewhere (Lang et al., 2019). However, further investigations are needed to understand the predominance of Zn in F1 and its effects as micronutrient on crops absorption.

### Acknowledgements

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## Impact of regulatory thermal treatment (70 °C / 1 hour) on microbial and physico-chemical parameters in lab-scale mesophilic anaerobic digestion reactors

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### Introduction

The number of on-farm biogas plants (BP) has boomed in France over the last decade, increasing from 90 in 2012 to 889 plants in 2022. The anaerobic digestion (AD) process transforms organic matter, in particular livestock manure into biogas and digestate. The EC regulation N° 1069/2009 and EU regulation N° 142/2011 require the application of a heat treatment at 70°C for 1 hour (HT) to animal by-products (including animal manure) before entering the BP. However, few studies have been conducted up to know to evaluate the impact of this HT on the fate of bacteria naturally present in manure. Moreover, a recent study showed the persistence of enterococci and clostridia in the digestate, despite the application of HT, suggesting that this treatment does not guarantee the sanitary safety of the digestate (Derongs et al. 2021). The objective of this study was to evaluate the effect of HT, applied either upstream or downstream of continuous mesophilic lab-scale anaerobic reactors, on microbial and physico-chemical parameters as well as on biogas production. The fate of naturally occurring enterococci and of artificially inoculated spores of Clostridioides difficile and of Clostridium novyi (used as a non-toxic model of group III C. botulinum) was studied.

### Methodology

Nine lab-scale mesophilic (37 °C) anaerobic reactors were fed, according to an organic load of 2 g COD·L-1·d-1, with a mixture (later referred to as influent) of horse feed and pig manure spiked with C. difficile and C. novyi spores. The hydraulic retention time (HRT) was 30 days and digestates were collected after 3 HRT for further analyses. Three conditions were tested in triplicate: 1) HT was applied to the influent before entering the reactors, 2) HT was applied at the end of the experiment on the digestates, 3) no HT was applied (control). The enumeration of enterococci, C. difficile, C. novyi and measure of physico-chemical parameters were carried out in all influent and digestate samples, and the biogas production was monitored for three months.

### Results and discussion

The average reductions of the concentrations of enterococci, C. difficile and C. novyi between influent and digestate in the control reactors were 1.8, 0.1, and 0.6 log10 respectively. The HT led to a reduction of the concentrations of enterococci and of C. difficile in the digestates by more than 2.4 and 2 log10, respectively. It is noteworthy that enterococci were detected in only one of the three reactors fed with HT influent and not detected when HT was applied after AD. The impact of HT on C. novyi was very limited as its concentration in digestate fed with HT influent was around 1 log10 higher than in digestate fed with untreated influent or when the HT was applied after AD. The pH and the FOS/TAC values and the methane productions were stable regardless of the reactors during the monitoring period, indicating a high stability of the AD. The low VFA contents in the digestates (< 0.11 g.L-1) confirmed the correct performance of AD. The specific methane production of the HT influent-fed reactors increased by 10% with 0.504 L $CH_4 \cdot L_{reactor}^{-1} \cdot d^{-1}$. compared to about 0.460 L CH4·Lreactor-1·d-1 in the other reactors. COD abatement ranged from 40% to 36% while the NH4+/NTK ratio was lower in digestates fed with the HT influent (59.3%) than in control digestates (65.7%), indicating that ammonification of organic nitrogen during AD was less efficient with HT.

### Conclusion

The impact of HT depends on the bacterial species but it did not allow the total removal of spore-forming bacteria, applied either before or after AD. Moreover, when applied on influent before AD, it resulted in a increase in methane production and COD abatement and a decrease in ammonification questioning the relevance of its application from a process, economic and sanitary perspective.

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## Coupling pruning wastes from Mediterranean orchards with agri-food sludge through co-composting

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### Introduction

Huge amounts of organic wastes from agri-food systems are being managed without an integrated view to maximize nutrient recovery and circular economy. In Mediterranean areas, pruning from orchards can be coupled with agri-food industry in order to produce biofertilizers. In this work, development of added-value composts using the annual pruning of the main orchard crops (citric, CIP; vine, VP; pomegranate, PP; khaki, KP; and rice straw, RS), and agri-food sludge derived from citric juice industry (CAS) has been done. In each scenario of co-composting manure (goat, G or cow-sheep, CS) was used as starter of the processes.

### Methodology

Seven co-composting procedures have been conducted using two composting methods: 1) composting in 600L composter with manual turning, and 2) composting in 600L composter with forced aeration and turning. Five processes using Meth1 were done (C1, 74%CAS+18%KP+8%G; C2, 76%CAS+16%PP+8%G; C3, 88%CAS+2%RS+10%G; C4, 80%CAS+10%CIP+10%G; C5, 80%CAS+11%VP+9%GO. Two processes were developed using Meth2 (C6: 59%CAS+32%KP+9%CS; C7: 60%CAS+30%PP+10%CS). During these processes, exothermic profile and several physico-chemical and chemical properties were monitored. In mature composts not only agronomic and stability assessment were done but also in vitro suppressive effect against soilborne diseases (Fusarium oxysporum sp. melonis) and hydro-physical and physical properties related to potential use in soilless purposes (Bustamante et al., 2012).

### Results and Discussion

Composting processes using forced aeration (Meth2) induced higher exothermic profile compared to the manually turned (Meth1), including higher losses of organic matter (48% and 58% for C6 & C7). The use of variable C to N ratio (mainly linked to CAS presence) induced different behaviour in N dynamics, producing significant losses in C1 to C5 mixtures but increments in N in aerated systems during the composting period. Regarding fertilizing capacities, all the composts had high N values (3-4%) and P2O5 (4-6%). The evolution of organic matter, cation exchange capacity and humification indexes showed that the proposed mixtures produced mature compost. Composts obtained showed adequate hydro-physical properties respect reference materials (Abad et al., 2001). Significant differences on hydrophobicity were detected, being higher in compost with presence of CIP and PP. The in vitro inhibition of phytopathogen Fusarium oxysporum sp. melonis was mainly related to biotic mechanisms (100% inhibition in non-sterile samples for all compost) but the combined suppressiveness effect ranged between 50-64%, being higher for C2, C6 and C7, without relationships with salinity.

### Conclusion

The co-composting of the tested orchard pruning biomass and CAS has been revealed as feasible option in the range of mixtures of 60-80% of CAS f.w.b, being necessary an enhanced aeration in higher range of CAS participation. The composts produced showed balanced fertilizing capacities and added value properties linked to its potential use as ingredient for formulation of substrates and due to its suppressive effect against Fusarium oxysporum sp. melonis.

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## Compost quality characteristics: how are they related to each other and to composting practice?

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### Introduction

Compost application to land has beneficial impacts on soil characteristics, e.g. for nutrient status, pH, increasing soil carbon content, and soil life (Diacono & Montemurro, 2010; D'Hose et al., 2016). However, compost characteristics, and the effects when incorporated into soil, can differ widely due to the large variety of feedstocks and composting practice (Raviv, 2005). Information on compost characteristics is crucial in the promotion of compost use by farmers who, sometimes, are reluctant due to bad experiences with ill-defined, contaminated, or impure compost. Farmers also fear the possible presence of nematodes. During the North Sea Region Interreg project Soilcom (2019-2023) 62 composts from varying origin were collected and analysed for physical, chemical and biological parameters (Amery et al., 2020) in order to show averages, ranges and relationships in compost characteristics and links with feedstocks and composting practices.

### Methodology

Thirty-eight composts from commercial producers and 29 farm composts were collected during 2019-2022 from Flanders (Belgium), The Netherlands, Germany, Denmark and Scotland. Chemical (moisture, pH, electrical conductivity (EC), NO3- and NH4+ in water extract, organic matter (OM), volume weight, cell wall components, total (TC), inorganic (IC) and organic carbon (TOC), Total Nitrogen (TN), total macro elements and heavy metals, cation exchange capacity (CEC), germinating weeds and impurities) and biological parameters (phospholipid fatty acid (PLFA) determination to distinguish bacterial and fungal groups and nematodes analysis) were measured at ILVO Unit Plant Laboratory Crop and Husbandry (Belgium), physical parameters (particle size distribution, bulk density, hydraulic conductivity and water holding capacity) were assessed by the James Hutton Institute.

### Results and discussion

A preliminary data analysis on a refined selection of the data set revealed 5- to 10-fold variation in most of the compost characteristics highlighting significant variability based on origin, feedstock, and composting practice. Farm composts had in general higher OM, TN, CEC, and total biomass compared to composts from commercial producers. Compost CEC and total biomass were partly explained by the OM content of the compost. It should be noted that all composts had heavy metal contents and impurities below legal thresholds. A final and more detailed analysis on all composts, including results of physical analysis, bacterial and fungal groups and nematodes will be completed and presented at the RAMIRAN conference.

### Acknowledgements

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## Potential adverse effect of different types of Polyethylene-based plastics (LDPE, LLDPE, hLDPE) presence during the vermicomposting process of agricultural waste

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### Introduction

Plastic wastes are produced and accumulated in agri-food waste due to its wide use in plasticulture for multiple purpose. Polyethynele-based plastics are the most commonly used as mulching film due to its characteristics (high elasticity, low density, high impact resistance). Several studies have been demonstrated that the extent and rate of biodegradation largely depend on the physicochemical structure of the polymer as well as the presence of additives. However, the toxicology associated with presence of different type of plastic and additives has not been investigated. In this study, the potential adverse effect on vermicompost quality as well as the toxicology response of E. fetida was examined in relation to different polyethylene-based plastics (LDPE, LLDPE and hLLDPE) presence during vermicomposting process.

### Methodology

The vermicomposting bioassay at bench scale consisted in an incubation in Petri dishes (ø15 cm) (Dominguez et al.,2018) with 80 g of feedstock partially composted (agri-food sludge 45%, + cow manure 15%+ vineyard pruning 40%) and adjusted to 70% of moisture content. Three replicates (n=3) were prepared for each kind of plastic (LDPE, LLDPE and hLLDPE), which has been tested in Film debris format (1cm² and irregular shape) and Microplastic format (1-1000 µm). The plastic material was added in 1,25 % f.w. proportion, a treatment was made without the addition of plastic as Control. Finally, 25 citellated adults of E. fetida were added to each replicate. At the end of the bioassay (45 days), the quality and stabilization degree, as well as the change induced by plastic presence in enzymatic activity (CbE, CAT, and DHE) in vermicompost, were assessed. The response and health status of E. fetida also assessed through the measurement of the main biomarkers (CbE, AChE, and PerLip) involved in metabolic and oxidative stress.

### Results and discussion

The result obtained showed a significant decrease ($p < 0.05$) in E. fetida body weight in all treatment with plastic material if compared with control treatment. The worsen effect was as follow: hLLDPE>LLDPE>LDPE with a decrease of -52.9, -31.5, -20.7 %, respectively. Additionally, in all treatments with plastic material, the rate of survival showed a decrease trend, especially in initial stage of bioassay, while in the control treatment was obtained a survival of 94%. The treatment with the highest mortality was hLLDPE, in general the microplastic format showed a higher mortality if compared with the same plastic material in film format. Significant changes were detected in vermicompost obtained with an increase in CbE in film format treatment and a decrease in DHE in microplastic format, which maintained a significant higher ($p<0.01$) water soluble carbon content. Regarding to biomarkers determined, different behavior were observed if compared film and MP, significant increase of AChE and PerLip were detected in film, especially in LDPE. In opposite trend, MP induced slight change in AChE and not change in Perlip were found.

### Conclusion

In this study, the significant differences in body weight and mortality of E. fetida showed by occurrence of Polyethylene-based plastic can be an evidence that the negative morphology effect largely depend of the particle size but also of the additive presence. In addition, the changes determined in plastic presence in the CbE activity and especially in DHE and WSC content seem to indicate a slowdown in degradative capacities of worms. Finally, as shown AChE and PerLip activity, different levels of oxidative stress and tissue damage were detected based on the type and format of plastic.

### Acknowledgements

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## Manure collecting robots: a survey on cattle farms

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### Introduction

Manure collecting robots are being used more and more frequently in cattle husbandry, both in new buildings and in conversions, to clean exercise areas, especially solid floors. Depending on the manufacturer, these collect faeces, urine, straw and feed residues from floors via a vacuum, rotating lifting system or snail rotor and transport the mixture to a discharge point. No systematic studies of this relatively new technique are known to date. The aim of this survey on commercial farms was to gather experiences of farm managers regarding functionality, management, limits of use, animal welfare, etc.

### Methodology

From August 2021 to January 2022, 31 farm visits with a structured interview and a housing inspection with photo documentation were carried out in Switzerland and southern Germany. The results were presented descriptively and graphically.

### Results and discussion

Among the farms, 23 had a robot from Lely (Lely Discovery Collector, Lely International N.V., Maassluis, The Netherlands) and four each had a robot from DeLaval (DeLaval Collecting Robot rc 550/700, DeLaval AB, Tumba, Sweden) and JOZ (Barn-E, JOZ BV, Westwoud, The Netherlands). Twenty-four farms used the robot for dairy cattle, five for suckler cows and two for young stock. Converted buildings were used in 22 farms, new buildings were used in nine.

Function (18), automatic and frequent manure removal (14), dealer or brand loyalty (13), flexible routes including cleaning of cross aisles and outdoor exercise areas (8) were the most frequently cited reasons for the purchase decision. More frequent manure removal compared to stationary scrapers was also mentioned (14). However, this is currently not realistic compared to automated stationary scrapers due to the long charging times of the robot.

None of the farms carried out any specific adaptation of the animals to the robot. According to the farm managers, observations of the animals in the initial phase were not targeted but rather random. Eight farm managers mentioned that they occasionally observed anxious and nervous animals.

The challenges in terms of functionality identified by farm managers were bedding and feed residues (17) and weather conditions (5). Other challenges named were structural conditions, capacity, animal welfare and health, and safety issues. Farm managers mentioned calves being pushed by the robot (16), other injuries/loss of calves (3), tail injuries (13), injuries to animals trapped in the feeding barrier (5) and injuries to a person (1). Potential hazards to the animals were identified as management errors (e.g. forgetting to unlock the feeding barrier, calving outside the calving pen, etc.), dead ends, poorly secured discharge points and a lack of a contact breaker on one robot type.

### Conclusion

Most farm managers were generally satisfied with their manure collecting robot. The advantages of manure collecting robots are their ability to clean different areas and their flexibility. The critical points mentioned above must be avoided by careful planning, responsible operation and technical optimisation. Further investigations on cleaning quality are underway.

### Acknowledgements

We would like to thank the 31 farmers for their willingness to cooperate in the farm visits and interviews.

## An evaluation of the potential for 'Bokashi' manure treatment in the UK

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### Introduction

Bokashi is the Japanese word for "well-fermented organic matter". The organisms responsible for the Bokashi fermentation process thrive in anaerobic (oxygen-free) conditions and for that reason, the process occurs inside sealed bags or vessels. It is similar to the process used to create silage. Bokashi Manure Treatment involves spraying animal bedding with a liquid mixture of microorganisms (known as Effective Microorganisms or EM®) which gradually colonise the bedding and dung mixture in animal housing. These organisms begin to break down the bedding and dung during the housing period. Once the animals have been removed from the housing, the bedding and dung are taken out, mixed and covered with an impermeable membrane (usually plastic) and left for at least 6 to 8 weeks. The resulting dung can be used in the same way as dung produced by other means (e.g. outdoor stacking, covered stacking and turning or composting).

### Methodology

This poster will present the results of a review (currently being undertaken) of the scientific and grey literature relevant to the topic. The review will determine the extent of current knowledge of the impact of Bokashi manure treatment on livestock health, the cost and carbon footprint of manure treatment, manure quality and soil health. The review will inform the design of the planned practical work, the nature of which will also be briefly outlined in the poster.

### Results and discussion

An initial literature search has shown that the following benefits have been reported following Bokashi treatment of

solid manures:

- Improved health of housed animals;
- Lower odours;
- Drier bedding;
- Reduced incidence of flies;
- Reduced nutrient losses from the finished manure and improved carbon and nutrient retention;
- Reduced manure management costs;
- Reduced carbon footprint associated with manure management.

A more detailed review of the literature will determine the extent to which these benefits have been realised in previous studies and may provide pointers as to how to conduct the planned UK trials.

### Conclusion

The potential for Bokashi manure treatment is clear, but practical trials in a UK context will be required to determine whether the benefits can be realised in the UK.

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## Life Green Ammonia or how to reduce ammonia emissions from livestock farms

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### Introduction

Ammonia emissions reduction is of major impotance for the competitiveness of the EU livestock sector. For that, great effort is been made in order to develop new technology to reduce $NH^3$ emissions in farms. The gas permeable membrane technology (GPMT), that is addressed to recover $NH^3$ producing a RENURE material, has been developed and tested in two farm-scale pilot plants. The technology has also been developed through the LIFE+ Ammonia Trapping project. Due to the successful results of this project, the GPMT is been improving through the LIFE+ Green Ammonia project in order to achieve a TRL 8-9 (technology readiness level) technology. It is thus intended to get commercial prototypes at the end of the project. Therefore, the aim of this work is to present the final results of the LIFE+ Ammonia Trapping Project and to present the new Green Ammonia project.

### Methodology

Two pilot plants were designed, built and tested on farm: one was addressed to recover $NH^3$ from the air (Sotol-Herranz et al., 2021) and the other was addressed to recover $NH^3$ in liquids (Molinuevo-Salces et al., 2020; Riaño et al., 2021). Both pilot plants were similarly equipped. The main difference among them was based on the layout of the membrances: immersed in the manure or hanged to capture $NH^3$ from the air. The pilot planrs were continuously working for more than 16 months to optimize different parameters.

### Results and discussion

Nitrogen was successfully recovered to obtain a RENURE material. The temperature positively influenced TAN (total ammonium nitrogen) recovery rates in both systems. The highest N-recovery rate obtained inside the animal houses were 3.9g TAN $m^{-2}$ $day^{-1}$ during the poultry litter composting. In the case of manure and digestate the maximim N-recovery rate was 38.2 and 21g TAN $m^{-2}$ $day^{-1}$ respectively.

### Conclusion

Ammonia Trapping Project was a success from a technical point of view. It is necessary to improve the prototype design to make it easier to operate on farms, which will be done in Green Ammonia project.

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## From apple pomace to soil fertility; the SMS Green project approach for understanding the contribution of digestate, compost, and hydrochar to orchards fertility.

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### Introduction

The Farm to Fork strategy of the New European Green Deal aims to reach a reduction of 20% in mineral fertilisers and a reduction of 50% in nutrient loss. The Bioeconomy and Circular Economy European policies, at the same time, aim to reduce the use of natural resources and to exploit waste and residues. In this context, mountain agriculture plays a crucial role in creating positive synergies to improve the use of local biomass. The SMS Green project focuses on using the apple pomace produced after apple processing to obtain efficient organic fertilisers. The use of these products can lead to better managing the soil organic matter in mountain orchards, creating a valuable and sustainable chain at the local level. The project has been approved and started in 2022 and is now in progress. The project is co-founded by FEASR PSR 2014-2020.

### Methodology

Three different apple pomace samples are being considered: raw apple pomace (AP), apple pomace after sugar (and pectin) extraction (APS), and apple pomace after cavitation (APC). All the samples were characterized considering the nutrient and organic carbon content, biomethane potential, and biological stability. Three processes are being considered to optimize the exploitation of these residues: composting, anaerobic digestion, and hydrothermal carbonisation. Recently it has been assessed that the co-composting improves the agro-environmental properties of hydrochar (Bona et al., 2022) and for this reason, the hydrochar co-composting will be considered (as described in Scrinzi et al., 2022). The processes will be monitored to understand yield and performance. All products obtained (hydrochar, compost, digestate, and co-compost) will be assessed for their agronomic and environmental properties considering chemical composition, phytotoxicity, and effect on plant growth and on soils, after incubations for 12 months in mesocosms (as described in Bona et al., 2022). The effect on the soil microbial community will be assessed by metagenomics and meta-taxonomic analysis after DNA extraction and Illumina® MiSeq PE300 sequencing of ITS1 and 16S V4 regions. The final activity is to define the most efficient use of each organic fertiliser, by monitoring 100 different orchards, to collect data about soil organic matter and phosphorus content in the orchards.

### Results and discussion

The productions of the amendments and the monitoring of 100 sites (in orchards) are under study. The three AP considered are characterized to identify the differences among dry matter content, organic carbon content, and the biomethane potential (as Nm3 CH4/kg VS). The compost is produced by mixing the three different apple pomaces with manure and lignocellulosic waste to give the correct CN ratio and porosity to the compost piles. The digestate is obtained after anaerobic digestion in a 2 m3 pilot plant (located in FEM) by adequately mixing the AP and manure, with different percentages. The reactor is fed semi-continuously, and the process is monitored considering the biogas produced and its composition, the VFA/TA ratio, pH, and VS content. The hydrochar and co-compost will be produced in the HTC lab reactor and the aerobic reactors of the University of Trento, which collaborate with the project.

### Conclusions

The integration of the data collected from the project (amendment production from AP, agro-environmental properties and effect of the amendment, and the SOM and P content of orchards) will enhance the knowledge of fertilisers and will improve their use for soil fertility management, by proper exploitation of local biomass from a circular economy point of view.

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## Case Study of a Large Mixing-Vessel Composting System at Pig Farm

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### Introduction

Most of the pig farms in the U.S. utilize long-term storage and liquid manure handling as manure management system. Only few large-scale pig farms utilize composting as manure treatment. Composting is an aerobic process in which microorganisms convert organic materials into soil-like material, which can effectively convert animal manure into value-added products. This abstract summarizes the important finding of a case study conducted to highlight some aspects of system design, operation, & management of a mixing-vessel composting system at a swine finishing farm (Li et al., 2023).

### Methodology

A commercial mixing-vessel composting system (Compost-A-Matic 610M, Aggero, LLC., Statesboro, Georgia, U.S.) was used to treat manure produced by 24,000 head of finishing pigs, located at the Midwest area of U.S. A scraper system under the slatted floor was constructed to remove the pig manure daily. Scraped manure was then pumped to a nearby composting facility where two compost turners and six concrete composting pit rows, and compost screening machine and other relevant machinery were housed.

The mixing-vessel system automatically advanced through the compost rows to provide turning and aerating. The turning also moved older material to the rear end, while fresh manure, green and recycled woodchips were added to the front end. The system was installed with air supply pipelines at the bottom of the pit rows but was abandoned since early stage of the operation. The air supply outlet holes were easily blocked, and the mixing vessel was found to be able to provide enough aeration. The mixing vessel was designed to mix each of the three pit rows once a day, but the farm crew often repeated mixing the same pit to save time, thus, some pit rows were mixed twice daily. Urban waste wood was used to prepare fresh woodchips. The compost was screened and divided into coarse recycled woodchips and fine compost for either recycling into the composting process or piled in the same barn to be cured, until the moisture content (MC) reached 30-35%.

### Results and discussion

Samples collected shows that MC decreased gradually along the compost row, indicating the composting process with mixing was able to evaporate a significant amount of moisture. Eventually, the MC of screened finer compost dropped to below 40%, while the MC of cured compost decreased to 27.2%. The carbon/nitrogen (C/N) ratio of new woodchips was more than 80, proving that woodchips were an appropriate substrate as a carbon source. The C/N ratio of the recycling compost was lower than the new woodchips but higher than all other substrates, including the screened and cured compost. the nitrogen (N), phosphorus (P), and potassium (K) concentrations of the cured compost were the highest, while the N, P, and K concentrations were found to be closely correlated to the MC values of the different composting stage samples. Estimated annual expenses for the composting operation were summarized, the higher costs were labor, fresh woodchips, and fuel needed by the equipment. Potential income was estimated for the compost product, based on market price of $46-$52 per m3, which was priced based on the N, P, and K values. The compost was primarily land applied to nearby crop fields of the farm, used as soil amendments, and were especially helpful to the edges of the fields where manure could not be applied due to nutrient management regulations.

### Conclusion

The large commercial farm has been operating a mixing-vessel composting system to convert untreated manure into compost, for over 12 years. The system utilized relatively inexpensive woodchips and recycled hardy and larger chips to minimize cost. The system produced 5,700 m3 of compost every year without producing wastewater. Although the system did not make profit for the farm, the system did not require long-term liquid manure storage and agitating and applying large amounts liquid manure or lagoon effluent to nearby fields. This can be critical to animal farms that are landlocked and facing manure nutrient management challenges.

### Acknowledgements

The help of the farm management team and local extension faculty, and funding support by USDA-NIFA, grant award (# 2018-68011-28691).

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## Soil application of sanitized animal slurry through pH modification: effects on soil physicochemical properties and $NH_3$ emissions

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### Introduction

The application of animal slurry (AS) as a fertilizer in horticulture broadens the spectrum for its agricultural use and offers alternatives to more expensive mineral fertilizers. However, this practice requires caution, as it can lead to contamination of crops, soil and water resources by pathogens present in the slurry. Technological solutions are required, and the sanitization of AS by pH adjustment can be a cheap solution, but, on the other hand, it can affect its agronomic value after application to soil, by influencing soil pH value, electrical conductivity (EC), N dynamics and nutrient availability. Changing N dynamics can affect not only its mineralization (NH4+ and NO3- formation), but also N losses due to NH3 emissions. Two incubation experiments were set-up: #1 - to evaluate the effects of PS sanitization on N mineralization, soil pH, soil electrical conductivity, and P/K extractability; and #2 - to evaluate the effects of PS sanitization on NH3 emissions after application to a sandy soil.

### Methodology

The incubation experiment used a sandy soil treated with raw pig slurry (PS), and PS sanitised by pH modification: acidified slurry (AC: with H2SO4 to pH 5.0), alkalinized slurry (AL: with KOH to pH 9.5), and neutralized slurry (NE: alkalinization with KOH to pH 9.5, followed by acidification with H2SO4 to pH 7.0), as described by Rodrigues et al. (2021). Therefore, five treatments were tested (PS, AC, AL, NE, Control), with an application dose of 12 g slurry/kg of soil, using three replicates. The soil was maintained at 65% water holding capacity (WHC; 165 g of water kg-1 soil), for 91 days, and soil samples were collected on days 0, 3, 7, 14, 21, 28, 35, 42, 49, 56, 63 (every week), 77, and 91 (every two weeks) and analysed for: soil pH (1:2.5 in deionized water), soil electrical conductivity (EC, 1:2 in deionized water), mineral N concentration (ammonia (NH4+-N) and nitrates (NO3--N)), and extractable P and K (Egner-Rhiem). A second experiment was assembled, with the same applications rates (12 g/kg of PS, AC, AL, NE, Control), maintained at 65% WHC, four replicates per treatment. The NH3 fluxes were measured by the dynamic chamber technique, during the first eight days following slurry application to soil, measuring the ammonia retained in an acid trap (200 ml of 0.05 M H3PO4), at a constant airflow (3 L min−1). The amount of NH4+ trapped in the acid was then quantified by molecular absorption spectrophotometry and cumulative NH3 losses were calculated.

### Results and discussion

An acidification effect was observed in all treatments, including in the control soil, which showed the smallest pH drop (0.72 pH units), while the soil with raw slurry suffered the highest pH drop (2.48 pH units). The slurries' N dynamics was modified by the treatments, with nitrification being delayed by acidification. All treatments allowed similar concentrations of extractable P concentrations in the soil after slurry applications, which did not vary significantly during the incubation experiment. The same did not occur with extractable K, which increased significantly with the alkalinized and neutralized slurries, doubling its concentration in relation to the application of raw and acidified slurry, and the values were maintained throughout the incubation experiment. Slurry acidification was the only sanitizing treatment capable of reducing soil NH3 emissions in the first eight days after application (40% reduction, compared to the other treatments). Raw slurry and alkalinized slurry led to similar NH3 emissions throughout the experiment, ending up with equal emissions, while neutralized slurry, despite having started with lower NH3 emissions, increased these values over time, ending up with emissions like those observed for the other non-acidified slurries.

### Conclusions

PS acidification was the only sanitizing treatment that allowed a delayed nitrification, enabling its behaviour as a slow N release fertilizer, and significantly decreased the risk of NH3 losses from a sandy soil.

### Acknowledgements

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## Agro-industrial by-products can serve as alternative additives to modify the pH of pig slurry

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### Introduction

The application of animal slurry to the soil is a bio-based alternative to mineral fertilisers and is considered a valuable source of nutrients and organic matter. However, raw slurry can be a source of pathogenic microorganisms that can eventually enter the agro-food chain. pH modification with chemical additives has proved to be efficient to sanitize animal slurry and further enhance its fertilizer value(1). Nevertheless, the use of chemical compounds to perform acidification and/or alkalinization is still an additional cost for farmers. Agro-industrial by-products of low economic value are a possible alternative to those additives. Recent studies have focused on the impact of different by-products on slurry pH and greenhouse gases and ammonia emissions. Conversely, little attention has been paid to slurry sanitization, nutrient availability, and seed germination. The present study aims to evaluate the effectiveness of different agro-industrial by-products as sustainable additives for the sanitization of pig slurry by modifying the pH.

### Methodology

Three strategies were used to modify the pH of pig slurry, namely acidification, bio-acidification (pH 5, respectively) and alkalinization (pH 9.5). Agro-industrial by-products from the paper, yeast and brewing industry were considered with a total of 14 different additives and additive combination assessed. Only the additives that allowed to reach the target pH values with a dose < 20% (m/m) were considered. For the retained additives, treated slurry samples were analyzed for the presence of Salmonella in 25 g of slurry (ISO 6579-1) and enumeration of Escherichia coli (ISO 16649-2). A phytotoxicity bioassay and potential N mineralization (PNM) experiment also took place to assess the impact of treated slurry on the germination of watercress (Lepidium sativum L.) and plant N availability, respectively.

### Results and discussion

The use of by-products to acidify or alkalinize swine slurry appeared to be efficient to reach the target pH at a dose of less than 20% (m/m). Substitution of sulphuric acid (H2SO4) with Spent.A (by-product from paper-making facilities) resulted in mitigating the use of the former by 30%. By-products used for slurry bio-acidification were unable to reduce the pH to 5 suggesting that the fermentation process requires materials with more easily available carbohydrates. Although slurry sanitization was not guaranteed by all treatments, all additives resulted in a reduction of the E.coli population. The phytotoxicity bioassay revealed that the total germination of watercress seeds was not considerably reduced, however, sensitive germination indexes such as mean germination time and root length were negatively affected by some additives, such as Dregs & Grits (solid residue produced at pulp and paper facilities). Slurry alkalinization to pH 9.5 appeared to show the greatest N mineralization whereas acidification with H2SO4 and Spent.A showed evidence of N immobilization.

### Conclusion

It can be concluded that agro-industrial by-products can serve as alternative additives to modify the pH of animal slurry. Provided that the target pH is achieved, pathogens present in the slurry can be reduced with both chemical and alternative slurry additives. Phytotoxicity phenomena by alternative additives may delay but not inhibit seed germination. Future studies should address the sustainability of pH modified slurry and further explore the nutrient availability of the resulting material.

### Acknowledgements

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## Combining organic materials and industrial waste for recovery of rare earth elements through phytomining

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### Introduction

Recovered organic materials might play an important role in bioeconomy, sustainable development and implementation of circulars solution in many sectors. This might include substitution of chemical fertilisers, soil management in agricultural and urban areas, substitution of peat, organic matter alternative to manure in areas with no animal production. One of the options is also use of organic materials for development of substrates for recovery of fossils. The increasing demand for strategic resources, e.g. rare earth elements (REEs), related mainly to the development of modern technologies has spurred an increase in mining activities and consequently a release of REEs into the environment. This might pose a potential threat to functioning of the environment and even human health. REEs are increasingly used in the high-tech industry, agriculture and medical technologies, which in consequence causes release of REEs and some other potentially toxic elements into soils, water and waste. REEs have been included in the current list of CRMs. On one hand this means that increasing amounts of REEs are released to the environmental cycling, on the other hand effective ways of their recovery need to be developed. Some other elements included in the CRM list, such as antimony (Sb) and vanadium (V) shall focus similar attention as REEs. Knowledge on the effects of their increasing release into the environment is still limited. Similarly, despite phytomining has been successfully applied at a field-scale to recover nickel (Ni), data for REEs recovery potential and its optimisation is lacking.

### Methodology

We present the outcomes of the ongoing National Science Centre project. The strategic objective of the project is to fill the gap in knowledge on bioavailability and ecotoxicity of REEs, Sb and V in connection to their contents in soils and wastes and to enable understanding their recovery capacity through phytomining. The specific objectives of the project are:

i) determine current status and long term trends in contents of REEs, Sb and V in representative soils and such wastes as sewage sludge, ash and industrial wastelands;

ii) exaustively determine and understand the level and driving forces of REEs, Sb and V bioavailability and mobility in soils and wastes;

iii) evaluate the most effective mixtures of organic materials and RE rich waste for phytomining REE, Sb and V;

iv) select plants species and evaluate REEs, Sb and V recovery capacity through phytomining;.

### Results and discussion

The results reveal great diversity of REE contents in industrial ash and other types of waste. Mobility of REE in various materials will be presented. The presentation will provide information on capacity of various plants to recover REEs from constructed substrates, consisting with ash, compost, manure, sewage sludge, mine waste and soil. Eight plants with potential of element phytomining were selected on a range of constructed substrates. The level of REE and other elements accumulation in roots and shoots were measured to evaluate of the phytoextraction potential.

### Conclusions

High variability of plant responses and phytoextraction capacity were observed across plant species and substrate variants. Compost enriched substrates exhibited substantial capacity to support recovery of various elements, partly through supporting plant growth conditions and release of humic substances.

### Acknowledgements

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## Comparison of the ecological risk assessment and risk assessment code of manure products and derived digestates and hydrochars

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### Introduction

Hydrothermal carbonization (HTC) can be directly applied to biomass with high moisture content, resulting a liquid and a carbon-rich solid phase - called hydrochar – which can be further valorized as soil amendment (Kambo and Dutta, 2015). Some researches state the decrease of available fractions of heavy metals (HMs) in hydrochars compared to their input materials (Lang et al., 2019; Lu et al., 2021). Although these studies have contributed to understanding the speciation of HMs in hydrochars and manure, there is still limited data concerning the potential environmental risks associated with the process. Therefore, this research compares the ecological risk assessment and the risk assessment code (RAC) in manure and maize from contaminated land and their derived digestates and hydrochars. While the RAC allows assessing the availability of HMs in these products, the ecological risk assessment evaluates the degree of contamination of these materials, contributing to the management decision of using these end-products as soil amendments.

### Methodology

Fractions of HMs in hydrochars and input materials have been determined using the modified Community Bureau of Reference (BCR) sequential extraction procedure described elsewhere (Liu et al., 2018). After the BCR extraction, the HMs were quantified by ICP-OES (iCAP 7400 Radial, USA), followed by their classification into four fractions: exchangeable and acid soluble fraction (F1), reducible fraction associated to Fe and Mn oxides (F2), oxidizable fraction bound to organic matters (F3) and residual fraction (F4). The indices for the ecological risk assessment have been calculated according to Eq. (1), Eq. (2), and Eq. (3) taken from a previous study (Devi and Saroha, 2014).

$$C_f = C_i / C_n \quad (1); \qquad E_r = T_r \, x \, C_f \quad (2); \qquad RI = \sum E_r \quad (3)$$

Where: $C_f$ = Contamination factor of the individual HM; $C_i$ and $C_n$ are the mobile and stable fractions of HMs, respectively; Tr = Toxicity response factor of the individual HM; Er = Potential ecological index of the individual HM, and RI = Sum of potential ecological risk factors of the contaminants. To assess the RAC values, the availability of HMs was measured using the percentage of HMs in the F1 fraction of samples, and the following categories have been considered: no risk (NR), RAC < 1%; low risk (LR), 1% ≤ RAC ≤ 10%; medium risk (MR), 11% ≤ RAC ≤ 30%; high risk (HR), 31% ≤ RAC < 50%; very high risk (VHR), RAC > 50% (Alipour et al., 2021).

### Results and Discussion

According to the BCR extraction, most elements could be found in available fractions of hydrochars derived from mono and co-digestates, and feedstocks. The Zn element was associated with F1 and F2; whereas Cr, Cu and Fe were mainly found in F3, and Mn in F1. The association of Mn and Cu with the aforementioned fractions were also found elsewhere (Lang et al., 2019). However, further investigations are needed to understand the predominance of Zn in F1 and its effects as micronutrient on crops absorption.

### Acknowledgements

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## Restoration of abandoned evaporation ponds from olive oil industries through bioremediation strategies

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### Introduction

The accumulation and storage of liquid wastes from the three-phase olive oil extraction procedures ("alpechin") in evaporation ponds (OWP) has been one of the most used management methods. After the significant migration to two-phase olive oil extraction systems from 1980-90 until now, a quite high number of abandoned OWP (around 3000 just in Spain) still remains containing alpechin sludge (organic recalcitrant compounds) suffering also aging processes that promotes changes in their composition and characteristics. Kavvadias et al. (2017) reported that transformations of alpechin into more polluting sediments, partially dry, where toxic compounds are concentrated while their organic matter content becomes more recalcitrant. Therefore, these environments suppose a certain risk of pollution for surrounding areas, highlighting the need to study environmentally friendly restoration approaches to solve this hazard. In this sense, the LIFE+ REGROW project (www.liferegrow.eu) demonstrates the capacity of four main bioremediation strategies (landfarming, phytoremediation, composting and vermicomposting) coupled with the inoculation of a microbial consortium specially isolated and developed to degrade phenolic compounds as the main group of polluting compounds.

### Methodology

For this demonstrative project, 8 abandoned OWP ponds located in Mora (Toledo, Spain) with an important olive-related sector, has been chosen (25,000 m2). In a fist stage, a 3D sampling and characterization was done in order to know the key pollutant-hazards (phenols, recalcitrant OM, extreme pH and salinity, heavy metals). Secondly, landfarming, phytoremediation, composting and vermicomposting bioremediation strategies (BRS) were implemented using exogenous organic matter amendment, based on animal manure (rabbit and poultry) and spent mushroom substrate, that was mixed with alpechin sludge (2 to 1 ration f.w.b). Each BRS were duplicated (with and without inoculum) in order to evaluate the efficiency of microbial consortium of Aspergillus ochraceus (H2) and Scedosporium apiospermum (H16) on specific and general remediation. Finally, the best two combinations of the BRS (as treatment cascades) were developed at pond scale (2,400 m2 each) in order to validate the upscaling capacities.

### Results & Discussion

In the studied area, more than 20K m3 of alpechin sludge and sludge-spiked matrix were quantified. Analysis of 220 sampling points at two depths gave an average of 20,000 mg kg-1 of hydro-soluble phenols and very high values of phyto- and eco-toxicity. The results obtained have been evaluated based on several indicators related to economic costs, bioremediation or decontamination criteria, soil quality and environmental footprint, for each of the four strategies, with and without inoculum. The combined composting-vermicomposting strategy followed by landfarming were the most effective for decontamination, showing the greatest reduction of the content in phenolic compounds. The presence of the inoculum improves some of these qualities, especially in the case of vermicomposting. However, comparative analysis showed that the most economically effective strategies were landfarming and phytoremediation. The best two combinations (landfarming+phytoremediation for low polluted materials and composting-vermicomposting for highly polluted ones) were applied at real scale obtaining reductions of phenols ranging from 75 to 92%. Inoculum addition improved the phenol degradation between 3 and 8% compared to non-inoculated material.

### Conclusions

All tested BRS strategies reduced the polluting load of OWP materials. Depending on the nature of polluted material, two options must be selected depending on OM and phenol content: for low polluted material (<5000 ppm phenols and <30% OM) landfarming-phytoremediation cascade; for the highly polluted material, composting and vermicomposting as post-treatment was the best solution, including the production of a biofertilizer that is suitable for in situ revegetation.

### Acknowledgements

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## Small-scale bio-waste management: example of community composting in the Valencian Community (Spain)

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### Introduction

The shift towards a circular model of organic waste management has led to the development of new composting models, such as community composting (Storino et al., 2018). These models are beneficial for reducing environmental pollution and recovering essential nutrients for crops. However, the lack of standardisation and control may pose a risk to human health and the environment. The aim of the work was to evaluate a composting cycle in two municipalities of the Valencian Community (Spain) to ensure the quality and safety of the compost obtained for agricultural use.

### Methodology

Two composting piles were prepared using the organic fraction from the selective collection of the organic fraction of municipal solid waste (OFMW) from the municipalities of Otos and Cerdá (Valencia, Spain), mixed with pruning waste (PW). The composting piles were developed in the community composting islands of the COR-V5 Consorcio de Residuos of both municipalities. Trapezoidal piles were formed and managed with a turned windrow composting system and mechanical turning every month until the end of the bio-oxidative phase. The process conditions (temperature and humidity) were controlled, 4 samplings were carried out (initial, thermophilic phase, end of bio-oxidative phase and maturation) and physico-chemical, chemical and biological parameters were analysed.

### Results and discussion

All piles reached thermophilic temperatures (>60°C) during the first days. The duration of the bio-oxidative phase was of 147 days in both piles and met the criteria of EU Regulation 2019/1009 to ensure the sanitization of the compost. The physico-chemical and chemical characteristics of both composts were within the normal range (Bustamante et al., 2008), except for the high EC and Na content leading to restrictions of use in sensitive crops. The maturity, humification and stability parameters were adequate, as well as the heavy metal contents (Naher et al. 2018). On the other hand, pathogenic microorganisms (E. coli) were only high in the Otos pile.

### Conclusion

Community composting is a management strategy that generally allows to obtain quality, mature, stable and sanitised compost. However, the control of the process, of the initial materials and of the final compost is fundamental to guarantee its stability and sanitisation, as well as to obtain final products with added value that allow its use in agriculture.

### Acknowledgements

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## P removal from organic waste fluxes using lactic fermentation and mineral P recovery

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### Introduction

As mined P²O5-rock reserves are being depleted, it is urgent for the fertilizer industry globally to find alternative P sources. In this work, we explore the recovery of mineral phosphorus (P) from waste streams by means of lactic fermentation by Lactobacillus acidophilus using diverse sugar sources such as sucrose and molasses. The aim of this approach is to replace the use of purchased acids normally used for P extraction lowering the overall cost. At the same time, it helps to transform residues into resources reducing their environmental impact and assisting on their processing. We test 11 organic residues grouped in three waste types: sewage sludge, agrifood sludge and manure since all of these are known to have a high P content.

### Methodology

As a start point, we gathered a residue collection consisting of: pig slurry solid fraction; cow, goat, chicken and rabbit manure; sewage sludges of different origins, and agrifood sludges (derived from cheese, canned vegetables and juice industries among others). Based on the approach developed by Vanotti and Szogi (2019), we optimized the waste to sugar source ratio using increased amounts of sugar (sucrose or molasses). All the combinations were incubated at 37°C with a shaking frequency of 35 rpm for 48h. We monitored the pH decrease during the fermentative process. Afterwards, centrifugation was used to recover P in the supernatant. Recovered P levels were analyzed by ICP. After an alkaline treatment, mineral P crystals were precipitated and analyzed.

### Results & Discussion

According to literature, a pH decrease to 4-5 was sufficient to achieve an optimal phosphorus extraction. Our results show that the selected wastes can be used to effectively extract P using our procedure. We observed a pH decrease of 4 to 5 values with 1, 1.5, 2 and 3 g of sugar. P recovery yield was significantly higher when the residue was incubated with L. acidophilus in the presence of sugar rather than when no sugar was added to the mixture. Depending on the type of sugar source and residue, optimal conditions varied. General recovery of P ranged from 20-70% of total P in wastes. Sewage sludges and pig slurry were the residues with the highest intrinsic concentration of P and accordingly, we expected a greater P recovery from these materials. Controversially, P extraction was higher for manures compared to urban and agrifood sludges even in same pH conditions. Enhanced procedure was applied to sludges in order to increase P recovery. The phosphorus was precipitated with calcium or magnesium compounds, obtaining concentrated phosphate products with > 90% plant available phosphorus.

### Conclusions

Lactic fermentation was efficient to extract P from a different types of organic residues employed. Further research is necessary to optimize the P recovery procedure for each kind of organic waste, and alternative sugar sources can be used to increase circularity even from waste fluxes.

### Acknowledgements

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## Project-based learning on developing a novel technology for slurry management

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### Introduction

Farming is responsible of 30 % of all greenhouse emissions (Lal, 2021). The UK Government has set an agricultural transition plan for the period 2021 to 2024 that includes a slurry investment scheme, which grants funding for new slurry stores and equipment to protect the environment in ways that exceed current regulatory requirements (DEFRA, 2020, p. 55). Many farms are opting for the CATNAP (Cheapest Available Technology Narrowly Avoiding Prosecution) approach that is not fully regulated (e.g., use of chemical amendments of slurry) and could be not very cost-effective (Buckley et al., 2020; Lanigan et al., 2018). Particularly, some of these slurry additives claim to reduce the gaseous emissions despite being cocktails of microbes that promote the fermentation of slurry (Kavanagh et al., 2021). A novel technology for managing slurry has been proposed, combining the benefits of using chemical amendments and operating under the conditions of the covered slurry stores (Moure Abelenda et al., 2023). The present investigation tests a flexible model to ease the knowledge transfer and the commercialization of this technology, which is presented to society as a didactic tool to improve the project-based learning (PBL) of Advanced Level students.

### Methodology

The PBL methodology, which was conceived in previous investigations (Moure Abelenda et al., 2023), was applied with 6 A-level students (i.e. 2 groups of 3 students), selected following the criteria of In2ScienceUK (2023) to address their pedagogic needs and provide them with a real experience of an entrepreneurial project beyond academic research. The £400-prototypes of the novel technology of processing animal slurry are prepared in advance to provide the working groups of project promotors with a quick start for the 10 3-hour sessions of the PBL (Make it happen!). Their investigation on optimizing the best conditions to promote the hydration of calcium chloride and the drying of limed manure is meant to consider the best fitting of the artifact in the current infrastructure and logistics of managing manure at small farm scale (400 ton y-1). For this purpose, the 5th session of the PBL (Make it happen!) is devoted to primary market research visiting a local farm in Lancashire County and for the 10th session stakeholders of the agroindustry are invited, when students have the chance of presenting how their artifact addresses the needs of potential clients.

### Results and discussion

The engagement activity takes place on the week commencing 24th July 2023, as per the programme of In2Science (2023) and availability of the funding. The preliminary SWOT analysis of the didactic proposal estimates that the outreaching event will constitute a transversal experience for A-level students. The coordination and cooperative learning of the group members is meant to be promoted with the use of an adapted business model canvas template, which includes the Rumsfeld matrix to enable their metacognition and to improve the action lines that the groups of students are drafting to address the problems of the potential clients (Moure Abelenda et al., 2023). The flexible model for the commercialization of the environmental technology in the farming and educational sectors is considered suitable for this first edition of the PBL (Make it happen!). The advances in the development of the prototype and the expansion of the network enhances the adoption of the technology in the industry but hinder the application of subsequent editions of this project on slurry management in educational institutions.

### Acknowledgements

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## Improved biogas potential from cattle slurry using a novel methanogenic inhibitor

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### Introduction

Anaerobic digestion (AD) of livestock slurries is an established measure capable of mitigating the environmental impact of agricultural production by capturing greenhouse gases (GHGs), whilst generating a diversified energy source and a valuable rural income stream (Pérez Domínguez et al., 2016). However, the viability of cattle slurry as an AD feedstock is hampered by its relatively low biogas methane potential, which diminishes further through losses to the atmosphere during storage. Treatment options to limit gaseous emissions from slurry and thereby retain its biomethane potential typically involve substantial capital investment (refrigeration) and/or rely on acidification (Kavanagh et al., 2019), which reduces the suitability of slurry for downstream AD. An approach to limit methanogenic activity should, ideally, limit methane losses during storage without interrupting microbial hydrolysis and fermentation. In this study, we assessed the potential for improved biogas production from AD of slurry amended with a novel, reactive oxygen halide-based methanogenic inhibitor.

### Methodology

The inhibitory additive technology was applied to replicated, 15 kg cattle slurry mesocosms, compared to matched, untreated slurry mesocosms. Biogas production was monitored for the 68-day storage duration. Treated and untreated slurry were each co-digested with fats, oils and grease (2:1) in triplicate 10 L mesophilic continuously stirred tank reactors in a semi-continuous feeding regime. Biogas volume and methane concentration were monitored, as were pH, total and soluble chemical oxygen demand (tCOD & sCOD), total solids (TS) and volatile solids (VS) of the feedstock and resulting digestate, using standard methods.

### Results & Discussion

A >90% reduction in biogas production from stored slurry was achieved with 4 phases of additive treatment, with inhibition effect lasting longer in each phase, from 7 to more than 20 days. Treated slurry TS and VS were slightly (3-5%) higher, reflecting retention of carbon otherwise lost during storage. The primary physicochemical difference arising from treatment was the 20% higher sCOD in treated slurry compared with untreated slurry. As with the solids results, this can partly be explained by gaseous losses from the untreated slurry, but is also indicative of targeted inhibition. Specifically, although methanogenesis was inhibited, bacterial hydrolysis, typically the rate limiting step for AD of slurry, as well as fermentation/ acidogenesis, proceeded unimpeded. Cyclical anaerobic co-digestion of treated and then untreated slurry over 150 days resulted in consistently increased methane production (18-22%) from treated slurry. The accumulation of soluble organic matter proved to be the differentiating factor, as additional sCOD was completely utilised, so that mL CH4 g-1 sCOD fed was consistent between cycles. There was no lag phase between cycling to treated slurry and increased methane output, meaning that the additional sCOD was rapidly utilised.

### Conclusions

Use of the novel methanogenic inhibitor shows significant potential for mitigating greenhouse gas emissions from stored manures and slurries, and for improving the viability of agriculture-based AD. By specifically targeting methanogenesis, this treatment can increase output and productivity of agriculture-based AD systems without altering workflow.

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## Development of a decision support tool for North China Plain (NCP) to improve nutrient utilization from manures (Biowaste Nutrient Management Tool, BNM-Tool)

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### Introduction

The North China Plain (NCP) is one of the most intensive agricultural and livestock production regions in China, which has resulted in a growing quantity of chemical fertilizer use and livestock manure being generated. However, nitrogen use efficiency (NUE) in crop production is less than 40% and the manure recycling rate is only ca. 19% in NCP, which are both lower values compared with other regions in the world. This has led to significant nitrogen (N) losses to the environment and severe environmental impacts. There is an urgent need to promote management strategies to optimise manure nutrient use to meet crop demand, and to substantially reduce the nutrient losses in NCP. However, two significant barriers need to be overcome to achieve this ambitious target. There is a lack of: (1) accurate information on the nutrient composition of different manure types and an understanding of the effects of contrasting timings and methods of manure application on crop nutrient supply, and (2) a complete nutrient management guidance for local soil-crop system, which synthesizes such information.

MANNER-NPK (MANure Nutrient Evaluation Routine) is a decision support tool for quantifying the crop-available nutrient supply, the N losses and transformations to the wider environment after manure (and other organic material) application that forms the basis of guidance in the United Kingdom (UK), and has been listed as a model of e-agriculture practice by the International Food and Agriculture Organization (FAO). Therefore, the overall objective of this research is to establish a framework about livestock manure nutrient management support tool for NCP which builds upon the MANNER-NPK modelling framework.

### Methodology

This PhD research project comprises several activities: (1) Assessing nutrient losses; including systematic literature searches, data selection and extraction to generate databases about nutrient losses following manure application, such as ammonia ($NH^3$) volatilisation, nitrous oxide ($N^2O$) emission, nitrogen ($N^2$) emission, nitrate leaching, and soil organic carbon (SOC) losses; and the use of boosted regression tree (BRT) analysis to identify important impact factors controlling these losses; (2) Determining nitrogen mineralisation kinetics for different manure types; (3) Developing relationships between nutrient losses and environmental and management factors; (4) Establishing model and sub-model structures with decision support rules, and (5) Validating the BNM-Tool with appropriate experimental data.

### Results & Discussion

Currently, only the $NH^3$ volatilisation and $N^2O$ sub-models have been built. We found that: There were a total of 889 and 506 case studies (from 108 and 62 published papers) containing information about $NH^3$ and $N^2O$, respectively, following manure (only) applications in China. Our BRT analysis results indicated that manure ammonium (NH4+) content, soil pH, SOC, temperature, windspeed and application method were significant controls of $NH^3$ volatilization following manure application, but $NH^3$ emissions following slurry application were additionally impacted by precipitation. $N^2O$ emissions following manure application were significantly affected by regional climate, temperature and precipitation. Climatic properties, soil factors (e.g. bulk density, soil pH) and management factors (e.g. application method) modulated the contributions of nitrification and denitrification to $N^2O$ production. The measured $NH^3$ and $N^2O$ losses were best fitted with Michaelis-Menten responses to time, and soil NH4+-N content respectively. Currently, the $NH^3$ and $N^2O$ modules of BNM-Tool can predict 62% and 41% of $NH^3$ and $N^2O$ emissions from soil under manure application successfully, further improvements are still needed.

### Conclusion

In the future, manure application needs to link with regional conditions. BNM-Tool might provide a robust estimate of the fertilizer N replacement value of different types of farm manures spread under a range of conditions and give precise nutrient management suggestions for each farmer in NCP region.

### Acknowledgements

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## The online support-tool "RAX" for fertilization recommendation with slurry in grassland

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### Introduction

On dairy farms in northern Spain, the best use of slurry is found in its use as fertilizer in the crops that are grown to feed the animals, improving the economic margin and the sustainability of the farms.

An online support-tool RAX (www.ciam.gal) has been developed for grasslands, which has the great advantage of integrating and valuing organic nutrients, helping technicians and farmers to get fertilization recommendations and reduce ammonia volatilization. Other tools RAX are for winter forages, forage maize and alfalfa (García et al., 2018).

### Methodology

The online support-tool RAX makes grassland fertilization recommendations while considering that the best nutrient source on dairy farms is slurry recycled as organic fertilizer.

The following data is required: Chemical composition of dairy or pig slurry (dry matter, nitrogen, ammoniacal nitrogen, phosphorus and potassium) and there are four options to enter it: a) Laboratory analysis, b) Regional mean value c) Estimation from the density, d) Estimation from the electrical conductivity and the density; Soil analysis: according to the P or K level content (ppm) fertilizers will be saved for high nutrient soils or an extra will be added for low-nutrient soils; Grass management (grazing, silage with one cut, silage with two cuts) and dry matter yield (t ha-1) for every grazing or cut; Grassland legume content to estimate nitrogen fixation (Bossuet et al., 2006); Techniques and conditions of slurry application to calculate the loss of nitrogen by ammonia volatilization and there are two options to estimate it: standard efficiency tables where low emissions slurry spreading techniques were included or the ALFAM2-Model (Hafner et al., 2019), the excel model v2.3 was incorporated to the tool and type of slurry, slurry dry matter and pH, application method and rate, incorporation (shallow or deep), air temperature, wind speed and rainfall rate were considered.

The outputs shown by the tool are time and number of applications, slurry dose (m3 ha-1) to satisfy the nutrient needs of the grassland in N, P and K and once the dose is chosen the kg of N, P2O5 and K2O required to supplement nutrient needs are shown. Finally, a specific mineral fertilizer is selected and the tool gives us the nutrient needs that may remain unfilled.

### Results and discussion

RAX is a tool under continuous review. The last incorporations to calculate the fertilizer recommendations were: ammoniacal N of the slurry, chemical composition of pig slurry, type of grass management and dry matter yield, nitrogen fixation by legumes, low emission spreading techniques applied and nitrogen loss by volatilization calculated with ALFAM2-Model. The mineralization of organic matter will be soon added to the tool. These incorporations, along with soil analysis and quick on-site methods for estimating nutrients content of slurry allow to obtain recommendations adjusted to the reality of each plot and farm, as well as reducing ammonia volatilization. The slurry doses are provided immediately, with the subsequent environmental and economic benefits for the Spanish dairy farms. Currently, the tool RAX has more than 1500 users including technicians and farmers.

### Conclusion

The support-tool RAX for grassland is helping technicians and farmers get fertilization recommendations in Spanish dairy farms, considering that the best nutrient source on dairy farm is in slurries recycled as fertilizers, as well as the technique and conditions more suitable to minimize the ammonia volatilization and increase the nitrogen use efficiency.

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## MIXED production at the landscape level: an emergy assessment on different agricultural systems under the same management.

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### Introduction

Mixed production – integrated crop-livestock system - at farm scale level is decreasing due to obstacles as costs associated to livestock, decrease on knowledge and changes in regulations (Martin et al., 2016). On the other hand, mixed production at a landscape level is an interesting way to develop new synergies and to promote socioeconomic benefits to the farmers. Through a spatial organization and land-use allocations it allows several economic opportunities. By promoting these synergies between farms, it enables the enlargement of product scope and the exchange and reutilisation of materials (i.e., feed, tools, machinery).

Montado is a typical Mediterranean extensive silvo-pastoral system with cork and holm oak production and animal grazing. In Alentejo, south Portugal, it is common for farmers to have different farms to offset modifications in regulations – in particular subsidies - and conventional market price fluctuations of different products. In this study, we are evaluating three different farms under the same owner: two farms with Montado and an olive and hay production farm. Between these three farms, there is a direct raw materials exchange and a temporal and spatial integration between them. Allowing several management conducts to be held depending on actual conditions - both external and internal to the farms. To address these complex systems at a landscape level, we did an emergy assessment to measure and understand its economic, social, and ecologic contributions and implications.

### Methodology

Emergy methodology, developed by H.T.Odum in 1983, accounts for all types of energy required to produce a service or a product. It is a tool grounded on thermodynamics and general ecological system's theory used to assess the performance and sustainability of a system, in this case agroecosystems. This method uses solar emjoules (sej) as the common energy base. All flows of money, mass, energy (€, kg, J) are transformed into solar emergy by multiplying them by a conversion factor called the unit emergy value (UEV). Unit emergy values represent the amount of solar emergy required to produce one unit of the output under study (sej/unit).

To understand the system's sustainability and resilience, indicators such as the environmental loading ratio (ELR), emergy yield ratio (EYR), the emergy sustainability index (ESI) and the renewability (%R) were used.

### Results and discussion

Preliminary results show the Montado systems are highly sustainable and can be resilient to the high demands from the supply chain when combining resources between different farms.

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## The Portuguese nitrogen footprint, a challenge in a Mediterranean country

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### Introduction

A nitrogen (N) footprint quantifies and connects N losses with consumption patterns. This concept emerged out of the necessity to communicate the importance and the negative effects of N to the general public (Galloway et al., 2014). Agriculture is the main source of reactive N (Nr) emissions to the global environment where beef and dairy products are responsible for 56% of Nr emissions in Europe. Regardless Portugal is a Mediterranean country, the typical Mediterranean diet seems not to be followed at risk.

### Methodology

The N footprint of Portugal was estimated for consumption and production, based on Leach et al. (2012) approach, and compared to a typical Mediterranean diet. Total N footprint takes into consideration the footprints from energy consumption (housing and transport) and food consumption and production. For food consumption was assumed that all N consumed is excreted and released into the environment as human waste since the average adult does not incorporate N as muscle mass. For food production, the concept of Virtual Nitrogen Factor (VNF) was used where all Nr losses to the environment are accounted from the initial N input as fertilizer until what is actually consumed. The VNF represent the amount of Nr loss to the environment per N consumption and was estimated for each by-product, crop and animal produced in Portugal (Leach et al., 2012). The Mediterranean diet N footprint was estimated based on the national food wheel recommendations and compared to the Portuguese food N footprint.

### Results and discussion

The N footprint in Portugal is overall 27.9 kg N cap-$^{1}$ yr-$^{1}$, estimated for the last year of available data. Food production is the main contributor sector of the Portuguese N footprint (~ 80%), mainly from animal-based products, followed by food consumption, transport and housing sectors. The food product with the highest contribution for this result is bovine meat. Following the Mediterranean dietary recommendations, food consumption and production N footprint in Portugal can achieve a reduction of 44% and 69%, respectively.

### Conclusion

Mediterranean diet can reduce the impact on the final N footprint, especially by favoring the consumption of fish over meat and increasing the consumption of plant-based proteins. Mediterranean diet helps to mitigate N losses into the environment, not only in Portugal but across other Mediterranean countries. This diet has the potential to be stated as a sustainable N footprint.

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## Nigeria Case Studies on Connecting Agricultural Waste to Livestock Production

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### Introduction

Many agricultural activities, such as aquaculture, animal rearing, and farming, produce a variety of agricultural wastes, as well as domestic human food wastes, that are difficult to dispose. Typical food wastes in the region include, rice barns, cassava peels, different vegetable and yam peels, and various leftover dishes such as rice and beans.

### Methodology

The participants will learn that agricultural wastes can be utilized to support animal rearing. The policy will be discussed, and the outcomes will be tracked, with an in-field demonstration carried out to inform producers.

### Results & Discussion

This study highlights the different connections that the poultry industry might make, with wastes also used to feed rabbits, and rice husks included in the preparation of various fisheries' feed. It was discovered via the field studies, observation and group discussions that it is not being addressed. Although while there are currently no laws that can force this, some people are fighting to change this and support more research into the variables that affect relationships. In which these wastes, when properly managed through the application of the knowledge of agricultural waste management systems such as the "3Rs," can be transformed into beneficial materials for human and agricultural use and various innovative, sustainable food production, and consumption patterns that encourage synergies and consumption patterns.

### Conclusion

It is important to effectively manage the organic waste materials produced in Nigeria by composting and bio-gasification in order to provide an outcome that is beneficial in agriculture as well as generating an income.

**Barriers, facilitators, and impacts regarding the adoption of new technologies for excess nutrient minimization in animal production.**

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## Introduction

Technological innovation adoption is the process by which a commonly used practice is replaced by a novel one (Liu et al., 2018). This paper presents the results of a Workshop with professionals on the possible implementation of critical technologies for slurry and nutrient management in animal production, exploring obstacles, facilitators, and impacts of their adoption.

## Methodology

A Workshop, "Environmental Indicators in Livestock Production," with 60 participants from Argentina, Chile, and Uruguay, was held during an international congress in Argentina on animal production. The conceptual framework was provided through four conferences, with speakers from Argentina, Portugal, Spain, and USA, discussing technological adoption indicators and referring to specific problems and solutions for manure management. The participants included livestock consultants, university professors, and scientists who worked in three groups on a list of 15 critical technologies (CT) that varied from general to specific. General CTs were based on nutrient evaluation and management, nitrogen/phosphorus utilization plans, and the availability of professional agronomic support. Specific CTs were based on nutrient input/output records, available technologies, facilities, and skilled labour trained to operate the new technologies. The participants had to validate and select CTs according to the livestock production system (dairy, swine, or beef production) and size scale (small, medium, or large based on the number of heads on the farm). They also had to compare technological pathways recommended for the production systems analysed, choose two CTs, and define two obstacles and two facilitators for their adoption in a selected farm and two affected impact indicators.

## Results and discussion

The participants agreed that recommended technological pathways to deal with excess nutrients in animal production differed among the three production systems and their scale, depending on the type of manure and confinement levels, similar to other studies (Lui et al., 2018). They also agreed with the CTs from the initial list of 15. Further, they incorporated ten additional CTs related to confinement type and duration, sanitary controls, water use/reuse, facility design, and nutrient management plans and technologies. For the large-scale group, the participants selected as CT, the use of geomembranes and implementation of records to improve nutrient management; as facilitators, the integration of producers into associations to accelerate the collection of information, a crucial positive aspect considered by Mozzato et al.(2018) too, and the implementation of controls and monitoring; the selected obstacles were high costs and lack of skilled labour and baseline information; among the impact indicators, they suggested more information and number of records, soil and water quality. For the medium scale group, they considered as CTs the gaps in water treatment and management; as facilitators, the existence of incipient laws; as obstacles, the lack of regulations and loans and the lack of knowledge about slurry quality as fertilizer; and the impacts were linked to water quality and salinization indicators. Finally, for the small-scale group, records and facilities were selected as CTs; as facilitators, greater control of nutrient management, environmental awareness, and knowledge improvement with local technologies; among the obstacles, the pressure to make complex decisions and lack of policies on manure management from their government and did not consider impacts.

## Conclusion

There was general agreement among the participants that manure is different according to species. Consequently, the recommended technological path also changes, impacting its management, animal nutrition, and facilities. Common obstacles to adoption were high costs, lack of regulations, lack of skilled labour, and need for more information to facilitate decision-making. All participants highlighted the importance of nutrient utilization. However, it was recognized that producers in the region generally do not know that manure and slurries should be seen as a product containing valuable crop nutrients, and significant education efforts will be needed to change that perception.

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## Assessing optimal manure recycling strategy to balance crop requirements, mitigate soil acidification and minimize nutrient losses

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### Introduction

Enhanced mineral nitrogen (N) fertilizer application has strongly elevated agricultural productivity, but also caused significant soil acidification affecting food security and agricultural sustainability (Guo et al., 2010; Zhu et al., 2020). Recycling animal manure rich in base cations (BC) and replacing mineral N can mitigate soil acidification and improve soil fertility, but the required amount of manure to counteract acidification may lead to the accumulation of soil phosphorus (P) causing eutrophication (Cai et al., 2021; Wang et al., 2022). This study describes an approach to identify the optimal combination of mineral fertilizer, manure and lime to match agronomic and environmental targets for N, P and BC at regional scale, integrating soil acidification amendment and nutrient management strategies.

### Methodology

The study was conducted in Qiyang County, China. The process-based soil acidification model VSD+ (Bonten et al., 2018) was calibrated by comparing the simulated and observed soil pH both in a long-term experiment (field level) with variable amounts of inorganic N, P and potassium, lime and organic manure, and at county level, where the nutrient inputs and crop yields were assessed by regional survey. The calibrated model was then applied to assess the impacts of various combinations of mineral fertilizer, organic manure and lime application on soil acidification and on N and P surpluses for croplands. Finally, an optimal combination was identified based on agronomic and environmental targets for N, P and BC.

### Results and discussion

At field level, the VSD+ model well simulated historic soil pH changes of different nutrient management practices in the long-term fertilization experiment. A scenario based on balanced N fertilization, while substituting N fertilizers with manure counteracted acidification but strongly increased the annual P surplus. An optimized combination of fertilizer, manure and lime was identified balancing crop N, P and BC demands and unavoidable N and BC leaching, minimizing N and P surpluses and counteracting soil acidification. At county level, the average soil pH of non-calcareous paddy and upland soils decreased by 0.66 and 0.09 units during the period 2014-2019, with the average deviation between simulated and observed pH values within 10%. Paddy soils acidified faster due to less manure input and higher bicarbonate (HCO3-) leaching, induced by higher CO2 pressure under irrigated circumstances. Net HCO3- leaching and N transformation mainly contributed to the acidification in paddy and upland soils, respectively. Optimal management practices for each survey site and optimal manure recycling strategy for the whole county are assessed considering the potential available amount of organic manure and agronomic and environmental targets for N, P and BC.

### Conclusion

The VSD+ model can be used as a sustainable nutrient and acidity management tool to derive optimal application rates of fertilizer, manure and lime in agricultural systems. The model may further guide optimal manure recycling strategy for agricultural sustainability both at field and regional level.

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## A simple and effective indicator to monitor the sanitation levels of pig facilities after washing processes

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### Introduction

In the pig farming industry, it is critical to rapidly assess the cleanliness of the facility after washing processes, to take corrective measures and maintain proper sanitation conditions. However, traditional inspection methods, such as bacterial colony counting on culture plates, can be time-consuming when determining the microbial levels of the environment (Azeredo et al., 2017; González-Rivas et al., 2018). Therefore, the objective of this study was to develop a simple and effective indicator to quickly assess the cleanliness and sanitation levels of a building, and to establish a benchmark for an "acceptable" level of cleanliness.

### Methodology

Four methods were tested to assess the washing efficiency in a pig facility: 1) adenosine triphosphate (ATP) bioluminescence measurement, 2) enzymatic reaction using Biofinder, 3) biofilm staining with Crystal Violet, and 4) metabolic reaction using Alamar Blue (resazurin). Six different materials were used, including cast-in-place concrete, vibrated pressed concrete, stainless steel, cast iron, HDPE, and PVC. Initially, these methods were evaluated in a controlled laboratory environment, and subsequently validated in pig farms after cleaning procedures. Diluted slurry was used to simulate varying levels of contamination. Bacterial colony counts were performed on culture plates for each dilution of slurry, providing the concentrations of Escherichia coli and total coliforms.

### Results and discussion

Although both the Crystal Violet and Alamar Blue methods provide visual analysis, they take considerably longer to yield results and have other disadvantages. The former is toxic, while the latter requires a humid environment for the reaction to occur. In contrast, the Biofinder and ATP bioluminescence measurements offer a quick assessment of surface hygiene and are simple and easy to use. In addition, Biofinder measurement provides a visual analysis though bubble formation in contaminated surfaces and ATP bioluminescence measurement provides a semiquantitative value of the level contamination. These two methods were chosen to test in pigs' farms after cleaning procedures. A rating scale ranging from zero to three has been created, where a score of zero was assigned if there was no reaction, i.e., no bubbles were produced, and a score of three was assigned if there was abundant bubble formation, creating a white foam. This scale is based on dilutions of slurry at ratios of 1/640, 1/80, and 1/10, which correspond to scales 1, 2, and 3 respectively. Bacterial counts for these dilutions were 0, 1, and 2.5 log CFU/ml for Escherichia coli and 1.6, 2.7, and 3.9 log CFU/ml for total coliforms. Washing is considered satisfactory when the visual analysis is rated 1, while scales 2 and 3 are deemed inadequate. By establishing a correlation between slurry dilutions and ATP values measured in the laboratory for scale 1, it has been determined that an ATP value of less than 1500 is considered acceptable for pig farms. It's worth noting that although these analysis methods are convenient, they do not provide an accurate quantification of bacterial contamination levels. However, they can still be useful for quickly evaluating the effectiveness of cleaning and monitoring the changes in contamination levels over time.

### Conclusion

Therefore, ATP and Biofinder measurements have significant potential as quick indicators of surface hygiene following washing operations for producers.

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## Effect of clover adoption by Irish dairy farmers on farm-gate N balances

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### Introduction

Farm-gate N balances can be used to determine the amount of surplus of N generated by a food production system and are a strong indicator of the potential for N loss from a particular system. Therefore, it is imperative to reduce N balances within our food production systems to improve their environmental sustainability. Artificial N fertiliser is the largest input of N on Irish dairy farms. Reduction in its use is one potential option to reduce farm-gate N surpluses. White and red clover have the ability to fix atmospheric N and thus reduce the reliance on artificial N fertiliser. The objective of this study was to actively engage with dairy farmers to establish red/white clover to reduce artificial N input and monitor the farms-gate N balances of these farms over time.

### Methodology

Thirteen dairy farmers from Ireland were enlisted in this study in 2020. Farm size ranged from 43 ha to 172 ha (mean: 91) and whole farm stocking rate ranged from 2 to 2.68 livestock units ha-1 (mean: 2.43). The group of farmers met five times per year for a period of 3 hours at a time. Meetings were held on the group members' farms, at Teagasc research farms or online via 'Zoom' and were facilitated by advisors and clover researchers. During meetings the farmers knowledge was exchanged regarding various aspects of clover establishment and management. Farm-gate N inputs and exports were collected on an annual basis (2020, 2021 and 2022) to determine the farm-gate nitrogen balance and use efficiency of the farms (Burchill et al., 2016). Collected data included N inputs (artificial N fertiliser usage, concentrate and forage purchases, livestock purchases) and N exports (sale of agricultural products; milk and livestock). The total N inputs minus the total N exports was the farm-gate N balance. The N use efficiency (NUE) of the farms was calculated as total N exports divided by total N inputs multiplied by 100.

### Results and discussion

The farm-gate N balance across the farms declined from 204 ± 15.6 (mean±stderr) kg N ha-¹ in 2020 to 130 ± 14 kg N ha-¹ in 2022. Corresponding farm-gate NUE of the farms increased from 29 ± 1.1% in 2020 to 40.5 ± 2.4% in 2022. This is substantially higher that previous farm-gate NUE reported for seventeen dairy farmers in Ireland of 24% across a three-year study (2010 to 2012) (Mihailescu et al., 2015). The major factor causing the reduction in the farm-gate N balances in the current study was a reduction in artificial N fertiliser use across the farms from 240 ± 16.3 kg N ha-¹ in 2020 to 153 ± 11.2 kg N ha-¹ in 2022 with a highly significant positive relationship between artificial fertiliser N use and farm-gate N balances ($y = 0.9461x - 21.191$: $R^2 = 0.94$). Despite the reduction in artificial N use farm productivity, as indicated by farm total N exports, remained static over time being 81.3 ± 4 kg N ha-¹ in 2020 and 82.6 ± 4 kg N ha-¹ in 2022. The active adoption of clover by the farms and subsequent fixation of atmospheric N most likely off set the reduction of chemical N fertiliser and maintained the productivity of the farms. While biologically fixed N is a source of N, similar to artificial N, its environmental impact is much lower in terms of $N^2O$ emissions and carbon footprint (Yan et al., 2013).

### Conclusion

This study found that the adoption of clover on dairy farms in Ireland can allow for a significant reduction in artificial N fertiliser while maintaining farm productively and reducing farm-gate N surpluses.

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