



Product information sheets (WPT1_D3.4)

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Introduction

Europe demands critical attention towards the inappropriate management of agricultural nutrients. One of the key steps to ensure the environmental security of the European Union (EU) is to close the nutrient loop and thus warrant the efficient use of agricultural nutrients. The transformation of Europe to a more circular economy can be brought by the recovery and reuse of nutrients from biomass streams like animal manure, sewage sludge and food waste which can contribute greatly towards improving the efficiency of nutrient management. Different nutrient recovery technologies (NRTs) are indispensable to enable the recovery of nutrients from biomass streams and, currently, there are several established NRTs in the market. Each technology, however, deals with its own issues related to implementation and/or operation. Moreover, marketing of the final products (i.e. recycling-derived fertilisers (RDFs)) and their acceptance by end-users are crucial for closing the nutrient loop in EU agriculture.

ReNu2Farm is an Interreg North West Europe (NWE) project that focusses on nutrient recycling and upscaling from pilot level to farms and fields. Its priority specific objective is to optimise the reuse of material and natural resources in NWE. One of the tasks of the project is to summarise the final project results from three technical work packages for nine RDFs that were tested in ReNu2Farm full scale field trials. The results are summarised in the form of the product factsheet sheets. Each sheet provides information on: i) technology description, ii) product characteristics (physicochemical and biological analyses), iii) agronomic aspects (crop yield and nitrogen or phosphorus fertiliser replacement value), iv) environmental aspects (nitrate leaching, soil phosphorus test, biological analysis (P cycling) and assessment of microbial and nematode communities), and v) legal aspects on the use of the RDF. The RDFs presented in the fact sheets are:

- (i) Ammonium sulphate solution
- (ii) Ammonium nitrate solution
- (iii) Pig urine
- (iv) Struvite from potato wastewater processing
- (v) Struvite from municipal wastewater processing
- (vi) AshDec sewage sludge ash
- (vii) Poultry litter ash
- (viii) Household biowaste compost
- (ix) Composted animal manure

Ammonium sulphate solution

Technology description

Ammonia (NH₃) and greenhouse gas emissions are some major negative consequences of intensive pig farming and the subsequent manure production. A technique like acid-air scrubbing is recommended for the mitigation of NH₃ emission. This technology can be applied to animal stables, drying units and composting installations, especially those with a mechanical ventilation. The technology setup is that air from the above mentioned premises is drawn through ventilation units and passed through a filter where a circulating acid scrubber (e.g. sulphuric acid) is sprayed.

A scrubber is a reactor filled with inorganic packing material, with large porosity and a large specific area. To prevent any loss of unwashed exhaust air, water is sprayed with nozzles over the packing material, without leaving any area

dry. The NH₃-rich exhaust air from the unit is blown into the system either horizontally (cross-current) or upwards (counter-current). The contact between air and water facilitates the mass transfer between the two phases.

In chemical scrubbers, the pH is maintained between 1.5 - 4 by addition of acid, shifting the equilibrium towards ammonium, thus increasing its absorption into the aqueous phase and ensuing the release of clean air. The ammonium sulphate (AS) tested in ReNu2Farm was obtained from an air-scrubber installed in a pig stable where water is mixed with 96 or 98% sulphuric acid to obtain the final N-rich product (Figure 1).



Figure 1 Ammonia scrubbing unit at pig farm in Merkem (Belgium).

Product characteristics

AS solution from a scrubbing unit in a pig stable (Figure 2) was analysed for physicochemical and biological parameters (Table 1).

Physicochemical analyses

Total N in AS solution is entirely in mineral form as NH₄⁺-N. The scrubbing agent used is sulphuric acid and this results in the AS solution having a considerable amount of total S.

The electrical conductivity (EC) and pH of the product can vary and are usually dependent on the amount of sulphuric acid added in the scrubber. Low acidic pH values are a point of attention as they can cause machinery corrosion and affect crop development (depending on the used application strategy), whereas high pH levels can result in higher risk of NH₃ volatilisation. Moreover, a high EC level could become an issue when the product is applied in the cultivation of salt sensitive crops.

Since the product is obtained by NH₃ scrubbing, other macronutrients (i.e. C, P, K, etc.) and metals are found in negligible concentrations.

Biological analyses

Total bacterial and fungal counts, determined by the total viable count method, revealed the presence of little to no aerobic mesophiles per ml of AS (< 10 CFU/ml).

Tests performed for detection of the pathogens *Salmonella* spp. and *Listeria* spp. confirmed their absence per 25ml of AS. Enumeration methods employed for the pathogens *Escherichia coli* and *Campylobacter* spp. exhibited <10 CFU per ml AS. These results are in accordance with the EU Fertilising Products Regulation 2019/1009.



Figure 2 Ammonium sulphate solution produced by scrubbing of pig-stable air.

Table 1 Physicochemical (expressed on fresh weight basis) and biological characteristics of the ammonium sulphate solution produced by scrubbing the exhaust air from the pig stable.

Physicochemical analyses		Biological analyses	
pH	2 - 7	Bacterial load (CFU/ml)	<10
EC (mS/cm)	157 - 262	Fungal load (CFU/ml)	<10
Dry matter (%)	15 - 33	<i>Salmonella</i> spp. present or absent/25ml	Absent
Total N (g/kg)	30 - 86	<i>Listeria</i> spp. present or absent/25ml	Absent
NO ₃ ⁻ -N (g/kg)	<0.002	<i>E.coli</i> (CFU/ml)	<10
NH ₄ ⁺ -N (g/kg)	30 - 86	<i>Campylobacter</i> spp. (CFU/ml)	<10
Total P (g/kg)	0.0004 - 0.07		
Total K (g/kg)	0.12 - 0.23		
Total S (g/kg)	28 - 100		

*EC: electrical conductivity; CFU: colony forming units

Agronomic aspects

The field trials aimed to assess the effect of the AS solution on crop yield and to determine its N fertiliser replacement value (NFRV) in comparison to the reference, i.e. synthetic ammonium nitrate fertiliser (33% N). NFRV (%) indicates saved amount of synthetic mineral fertiliser when using a bio-based fertiliser, such as AS solution, and is determined as follows:

$$\frac{((N \text{ uptake}_{AS} - N \text{ uptake}_{CON}) / (\text{total N applied}_{AS}))}{((N \text{ uptake}_{REF} - N \text{ uptake}_{CON}) / \text{total N applied}_{REF})}$$

where AS = ammonium sulphate treatment, CON = unfertilised control and REF = synthetic fertiliser reference. Maize and spinach were the test crops for the trials of 2019 and 2020, respectively. The field trials were performed with incremental N doses during both years (40%, 70% and 100% crop N demand).

For the year 2019, no significant differences in fresh and dry yield were observed between maize grown with the synthetic reference and AS for all three tested N doses (Figure 3). The N uptake in maize fertilised with AS solution was similar to that of maize fertilised with the synthetic reference.

The 2020 trial results were greatly influenced by the unfavourable weather conditions that prevailed during the trial.

Environmental aspects

In order to assess the effect of AS on the environment, during the field trial duration, an environmental monitoring campaign was conducted in regard to: i) risk for nitrate leaching by determining nitrate residue, ii) soil analyses at harvest and iii) effect on nematode community.

Nitrate residue

The nitrate residue is measured in post-harvest period by determining nitrate content in 0-90 cm soil profile during the period of 1/10 - 15/11. For both years, no significant differences were observed between the reference and AS treatment (Figure 4), although, for the year 2019, both treatments

Very dry weather conditions, concurrently with the occurrence of a sandstorm, impaired the growth of plants, resulting in significant damages. This caused high variability among replicates of individual treatments, as evident by the high standard deviations exhibited by the AS treatment. Due to loss of plants by storm damage, one out of the four blocks of the field was eliminated from the trial result interpretation. Subsequently, it was difficult to obtain statistical differences between the CAN and the AS treatment with regard to the fresh and dry yield, and N uptake in spinach, which in turn caused the NFRV to exhibit high standard deviation. Overall, a reduced N uptake due to dryer soil conditions was observed for all the treatments tested. Among the doses applied, the highest yield ($20 \pm 14 \text{ tonne ha}^{-1}$) was observed for AS at 100% N demand, but highest NFRV ($256 \pm 199 \%$) was observed for AS at 40% N (Figure 3).

Further testing in plant growth trials will be done to understand the behaviour of the product and examine reasons for high variability in spinach yield induced by the use of AS.

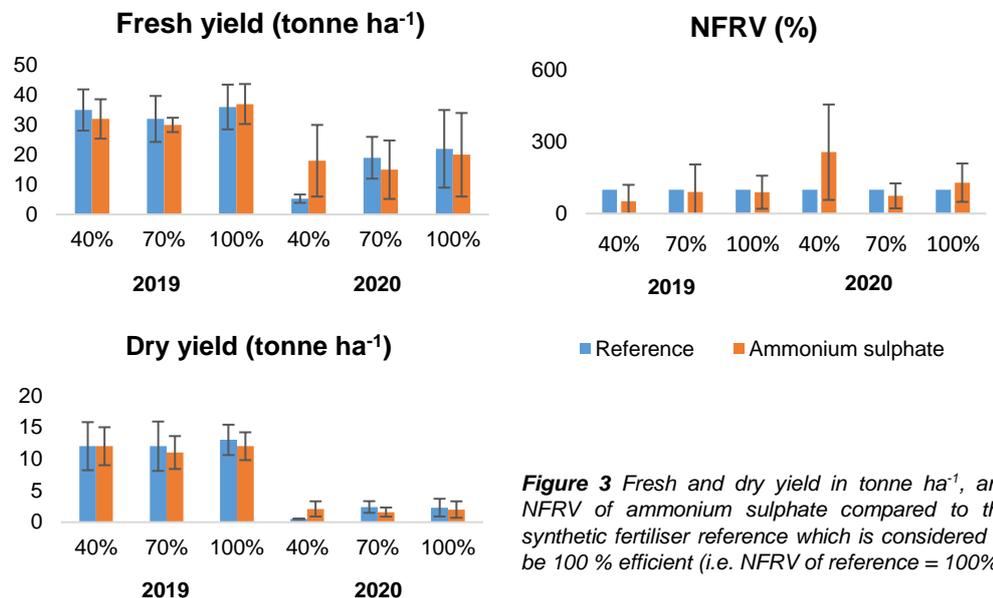


Figure 3 Fresh and dry yield in tonne ha⁻¹, and NFRV of ammonium sulphate compared to the synthetic fertiliser reference which is considered to be 100 % efficient (i.e. NFRV of reference = 100%).

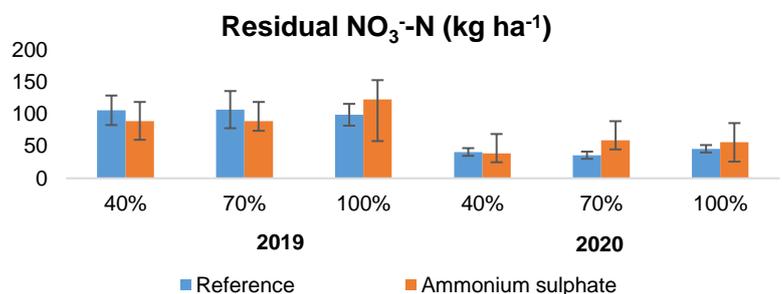


Figure 4 Residual nitrate content measured in the soil profile 0-90 cm in autumn to assess nitrate leaching.

exceeded the legal limit of 80 kg NO₃-N ha⁻¹ imposed by Flemish legislation. Exceeding the set limits could imply a risk of nitrate leaching during winter.

Soil characteristics

No significant differences in soil heavy metal content between treatments were observed for either year. The pH and EC content of the soil was not affected by the addition of AS.

Microbial and nematode communities

The soil planted with maize in 2019 field trial was analysed for the response of bacterial, fungal and nematode communities to the application of AS treatment at 100% N dosage, using DNA sequencing technologies. Alpha and beta diversity indices were used to investigate significant differences in diversity of microbial and nematode communities between AS, unfertilised control and reference treatment.

Microbial and nematode community structures were not significantly different in soil treated with AS when compared with the unfertilised control and synthetic reference treatment. Bacterial diversity was significantly increased in AS treated soil, whereas nematode diversity was found to be similar to that in the control treatments (Figure 5). The nematode community after AS application was more matured and structured and less disturbed when compared with the community in synthetic reference treated soil. Healthy microbial and nematode communities are indicative of healthy soils.

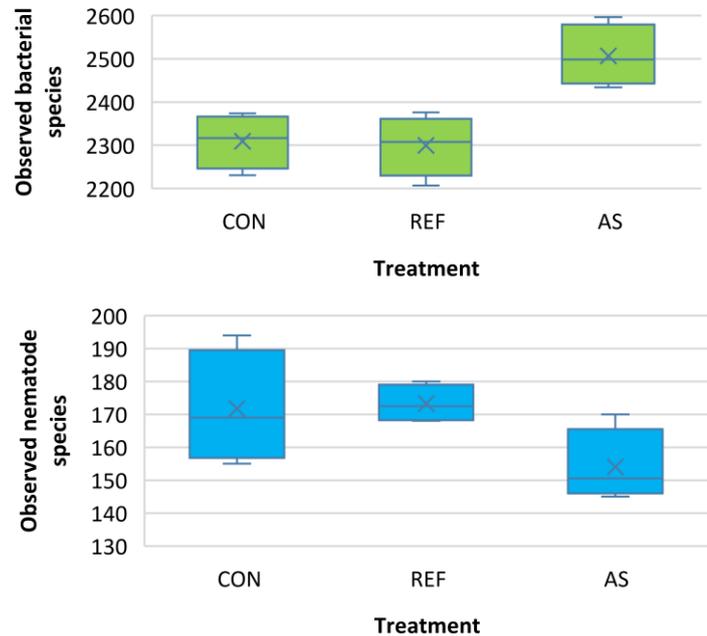


Figure 5 Boxplot of observed bacterial and nematode species numbers ($n=4$) in each treatment, CON = unfertilised control, REF = synthetic ammonium nitrate fertiliser reference, AS = ammonium sulphate.

Legal aspects

The liquid ammonium sulphate solution from the acid air scrubber is legally considered as a waste product. To be used as a fertiliser it has to be authorised as such.

Ammonium sulphate from air scrubbing as an EU fertilising product with CE marking

The EU Fertilising Products regulation (2019/1009) does not yet include recovered ammonium sulphate solutions. However, the use of ammonium sulphate from scrubbing of stable air is foreseen in a proposed additional component material category CMC 15: recovered high purity materials. The proposed criteria are: the ammonium salt has a purity of 95% the dry matter, an organic carbon content of < 0.5%. In addition, there are threshold levels for some pathogens and PAH₁₆, Cr and Tl. The ammonium salt solution or the input materials must be hygienised. The salts must also be REACH registered (with conditions).

Ammonium sulphate salts that meet the final criteria of CMC 15 (expected to be adopted before July 16 2022) may then be used for the production of a straight liquid inorganic macronutrient fertiliser (PFC 1(C)(I)(b)(i)). However, not all ammonium sulphate solutions from air scrubbing will meet the criteria for nutrient content: N (>1.5% by mass) and SO₃ (>0,75% by mass) and the sum of N+SO₃ at least 7% by mass. The high purity salts that do meet the requirements for CMC 15 may be mixed with materials from other CMC's, even if they do not meet the requirement of the PFC1(C)(I)(b)(i) themselves. The EU 2019/1009 does set threshold levels for heavy metals and arsenic, biuret and perchlorate in EU fertilising products.

Ammonium sulphate from air scrubbing as national fertilising product without CE marking

In the Netherlands and Flanders, ammonium sulphate from scrubbing of stable air is authorised to be used as a mineral fertiliser. As such it is exempted from prerequisites of the waste regulation and does not have to be treated as a waste product in transport, storage and handling. In Germany as well, ammonium sulphate from acid air scrubbers is authorised as input for fertiliser production. In France, ammonium sulphate is theoretically authorised but the minimum N content of 20% is unrealistically high, so that no ammonium sulphate product from stable air scrubbing will meet this standard.



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Ammonium nitrate solution

Technology description

An up-concentration of nitrogen (N) from N-rich biomass streams (e.g. animal manure, digestate, and their respective liquid fractions (LF)) can be achieved via the ammonia stripping/scrubbing process.

The operating principle of this technology is that ammonium (NH_4^+) present in the biomass stream is 'stripped' in the form of ammonia (NH_3) by air, steam or vacuum in a stripping reactor, by the conversion of NH_4^+ into volatile ammonia (NH_3). This shift in the $\text{NH}_3:\text{NH}_4^+$ equilibrium is made possible by increasing temperature and/or pH. Depending on the applied pH and temperature levels, the NH_3 removal efficiency of the technology is reported to vary between 70-90%.

Product characteristics

The AN solution from Detricon (Figure 2) was analysed for physicochemical and biological parameters (Table 1).

Physicochemical analyses

Total N in the AN solution is entirely in the mineral form as $\text{NH}_4^+\text{-N}$ and $\text{NO}_3^-\text{-N}$, similarly to its synthetically produced counterparts.

The electrical conductivity (EC) and pH of the product can vary and are usually dependent on the amount of nitric acid added in the scrubber. Low acidic pH values are a point of attention as they can cause machinery corrosion and affect crop development (depending on the used application strategy), whereas high pH levels can result in higher risk of NH_3 volatilisation. In general the pH of the product can be controlled and kept at constant level, depending on the user requirement. Moreover, a high EC level could become an issue when the product is applied in the cultivation of salt sensitive crops.

Since the product is obtained by NH_3 stripping/scrubbing (and thus volatilisation), other macronutrients (i.e. C, P, K, etc) and metals are found in negligible concentration.

The gaseous NH_3 is 'scrubbed' in a chemical scrubber using strong acids (e.g. nitric, sulphuric acid, etc.). If nitric acid is used, an ammonium nitrate (AN) solution will be produced.

Out of the myriad NH_3 stripping/scrubbing configurations, the AN solution tested in the ReNu2Farm project is obtained from an end-of pipe pathway where digested animal manure is separated into solid fraction and LF, after which the LF is stripped and scrubbed to obtain AN solution. The operating temperature is between 42-50 °C with the pH maintained between 7.5 - 9. This process is located in Gistel (Belgium) at the site of Detricon (Figure 1).



Figure 1 Ammonia stripping/scrubbing installation plant at Detricon site (Gistel, Belgium).

Biological analyses

Aerobic, mesophilic bacteria and fungi were few to non-existent in the AN solution, determined by total viable count methods. Tests performed for detection of the pathogens *Salmonella* spp. and *Listeria* spp. confirmed their absence per 25ml of AN. Enumeration methods employed for the pathogens *Escherichia coli* and *Campylobacter* spp. exhibited <10 colony forming units per ml AN. All these results are in compliance with the EU Fertilising Products Regulation 2019/1009.

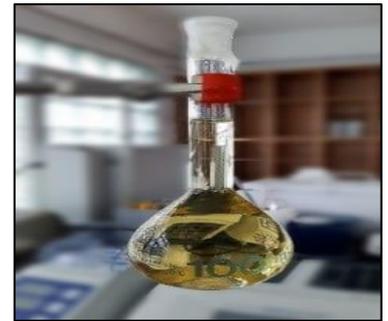


Figure 2 Ammonium nitrate solution produced by stripping/scrubbing process.

Table 1 Physicochemical and biological characteristics (expressed on fresh weight basis) of the ammonium nitrate solution produced by the stripping/scrubbing process. Values for physicochemical data are reported in ranges to reflect the product composition that was assessed on several occasions during the lifetime of the ReNu2Farm project.

Physicochemical analyses		Biological analyses	
pH	5.3 - 7.9	Bacterial load (CFU/ml)	<10
EC (mS/cm)	303 - 327	Fungal load (CFU/ml)	0
Dry matter (%)	23 - 40	<i>Salmonella</i> spp. present or absent/25ml	Absent
Total N (g/kg)	82 - 102	<i>Listeria</i> spp. present or absent/25ml	Absent
$\text{NO}_3^-\text{-N}$ (g/kg)	34 - 50	<i>E.coli</i> (CFU/ml)	<10
$\text{NH}_4^+\text{-N}$ (g/kg)	48 - 52.3	<i>Campylobacter</i> spp. (CFU/ml)	<10
Total P (g/kg)	<0.00038		
Total K (g/kg)	0.01 - 0.03		
Total S (g/kg)	0.03 - 0.61		

*EC: electrical conductivity; CFU: colony forming units

Agronomic aspects

The ReNu2Farm field trials aimed to assess the effect of AN solution on crop yield and to determine its N fertiliser replacement value (NFRV) in comparison to the reference, i.e. synthetic ammonium nitrate fertiliser (33% N). NFRV (%) indicates saved amount of synthetic mineral fertiliser when using a bio-based fertiliser, such as AN solution, and is determined as follows:

$$\frac{((N \text{ uptake}_{AN} - N \text{ uptake}_{CON}) / \text{total N applied}_{AN})}{((N \text{ uptake}_{REF} - N \text{ uptake}_{CON}) / \text{total N applied}_{REF})}$$

where AN = ammonium nitrate treatment, CON = unfertilised control and REF= synthetic fertiliser reference. Maize and spinach were the test crops for the trials of 2019 and 2020, respectively. The field trials were performed with incremental N doses during both years (40%, 70% and 100% crop N demand).

For year 2019, no significant differences in fresh and dry yield were observed between maize grown with the synthetic and bio-based AN for all three tested N doses (Figure 3). The maize N uptake in AN treatment was found to be similar to the that of N fertilised reference. However, high variability was seen in the NFRV values (visible from high standard deviation) which led to observation of no significant differences between

Environmental aspects

In order to assess the effect of AN on the environment, during the field trial duration an environmental monitoring campaign was conducted in regard to: i) risk for nitrate leaching by determining nitrate residue, ii) soil analyses at harvest and iii) effect on microbial and nematode communities.

Nitrate residue

The nitrate residue is measured in the post-harvest period by determining nitrate content in 0-90 cm soil profile during the period of 1/10 -15/11. For both years, there was no significant difference between the reference and AN treatment (Figure 4). In 2019, however, both treatments exceeded the

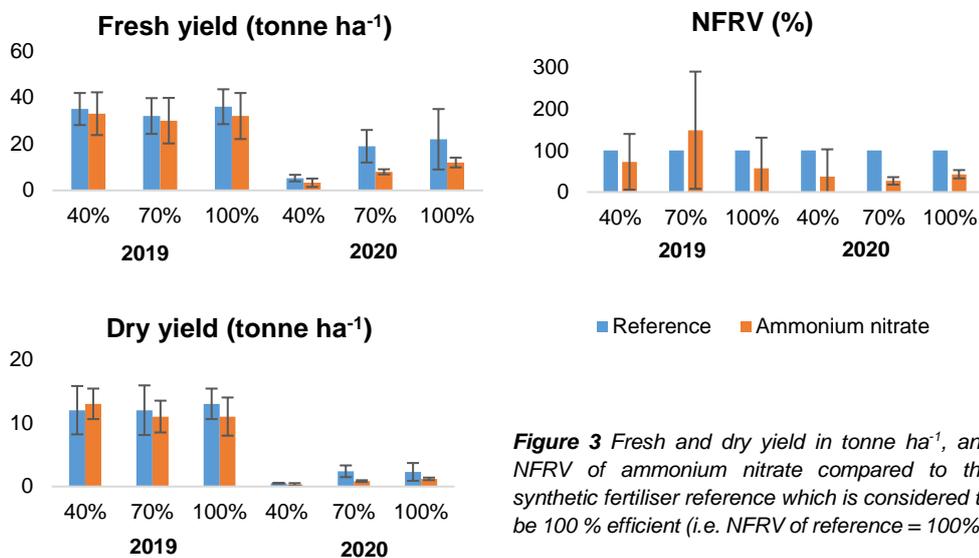


Figure 3 Fresh and dry yield in tonne ha⁻¹, and NFRV of ammonium nitrate compared to the synthetic fertiliser reference which is considered to be 100 % efficient (i.e. NFRV of reference = 100%).

treatments. In 2020, the performance of AN in spinach cultivation was poorer relative to the synthetic reference. The N uptake of spinach in AN treatment was significantly lower than in reference treatment, leading to very low NFRV values of AN as compared to synthetic reference (Figure 3). The reasons for poor performance of AN are still not clear, and further tests will be done to assess the potential links between the product and spinach as a salt sensitive crop.

Additionally, AN was also used in a controlled laboratory experiment to grow lettuce (another salt sensitive crop), and results were promising. The experiment was performed at two N doses (50% and 100% crop N demand) and calcium ammonium nitrate (CAN) was used as a reference. Fresh lettuce yield in AN treatment (67 ± 3.0 g pot⁻¹) at 100% dose was comparable to the CAN treatment (56 ± 6.1 g pot⁻¹), whereas at 50% dose was significantly higher (57 ± 2.2 g pot⁻¹) than the lettuce yield with CAN (49 ± 1.0 g pot⁻¹). Consequently, NFRV values (%) of AN at both doses were above 100%, however, they were not significantly different from the CAN treatment: 116 ± 39 at 50% dose and 147 ± 78 at 100% dose as compared to CAN being 100% efficient.

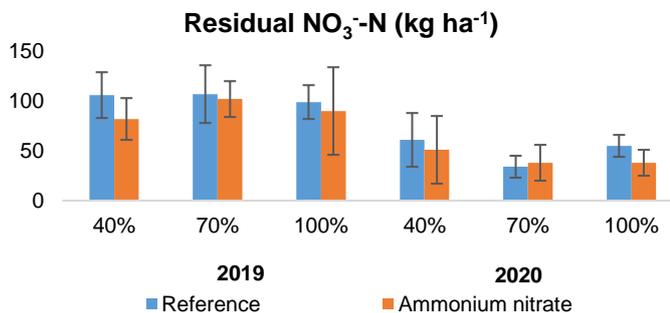


Figure 4 Residual nitrate content measured in the soil profile 0-90 cm in autumn to assess nitrate leaching.

allowable legal limit of 80 kg NO₃⁻-N ha⁻¹. This legal limit is imposed by Flemish legislation, and its exceedance means that there might be risk for nitrate leaching during winter time. In 2020, since spinach was harvested in June, the fields were cultivated afterwards with maize without any N fertilisation, and harvested in autumn. After the maize harvest, NO₃⁻-N contents were found to be within the permissible limit of 80 kg NO₃⁻-N ha⁻¹, and there was no significant difference between tested treatments.

Ammonium nitrate solution

Soil characteristics

No significant differences in soil heavy metal content between treatments were observed for either year. The pH and EC content of the soil was not affected by the addition of AN.

Microbial and nematode communities

The bacterial, fungal and nematode community structures of soil treated with AN did not significantly differ to those in soil treated with synthetic reference fertiliser (REF) in maize field trial. Levels of bacterial diversity significantly increased (Figure 5) in soil fertilised with AN. High bacterial diversity is associated with healthy, productive soils. Fungal populations were equally diverse

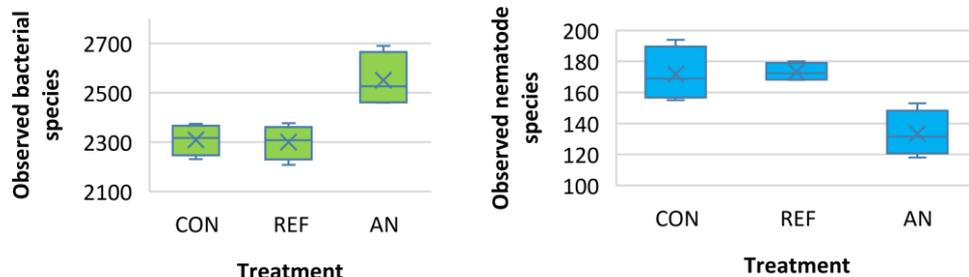


Figure 5 Boxplot of observed bacterial and nematode species numbers ($n=4$) in each treatment, CON = unfertilised control, REF = synthetic ammonium nitrate fertiliser reference, AN = ammonium nitrate.

between soil fertilised with AN and conventional treatments. Meanwhile, the number of observed nematode species in the AN treatment significantly decreased when compared to unfertilised control and synthetic reference treatment (Figure 5). Healthy microbial and nematode communities are indicative of healthy soils.

Legal aspects

In general, there is no consensus on the legal status of the ammonium salts that are produced from NH_3 stripping/scrubbing of manure. Some EU countries consider them as a mineral fertiliser, as they are not derived directly from manure but from the off gasses of the manure processing and also because of the high purity of the product. Other countries follow the definition of manure as stated in the Nitrates Directive where all products produced from manure remain manure. With the manure status, the same rules and prerequisites for the handling and use of animal manure from the EC Animal By-Products (ABP) regulation apply. This means that all actors, actions (transport, handling, distributing) and materials (plants, vehicles, storage sites) from farm to the end user are subject to notifications, registration, approval and controls.

Ammonium salts from stripping and scrubbing as an EU fertilising product with CE marking

The EU Fertilising Products (FPR) regulation (2009/1009) does not yet include recovered ammonium salts from NH_3 stripping/scrubbing. However, the use of ammonium salts from the stripping and scrubbing of manure or manure derived products is foreseen in a proposed additional component material category (CMC) 15: recovered high purity materials. The proposed criteria are that the product has a purity of 95% dry matter, and an organic carbon content of $< 0.5\%$. In addition, there are threshold levels for some pathogens and PAH₁₆, Cr and Tl. The ammonium salt solution or the input materials must be hygienised. The salts must also be REACH registered (with conditions). High purity ammonium salts that meet the final criteria of CMC 15 (expected to be adopted before July 16 2022) may then be used as a straight liquid inorganic macronutrient fertiliser with N ($>1.5\%$ by mass) and SO_3 ($>0.75\%$ by mass) and the sum of $\text{N}+\text{SO}_3$ at least 7% by mass, defined as PFC 1(C)(I)(b)(i). The high purity salts that do meet the requirements for CMC 15 may be mixed with materials from other CMC's, even if they do not meet the requirement of the PFC1(C)(I)(b)(i) themselves. The FPR does set threshold levels for heavy metals and arsenic, biuret and perchlorate in EU fertilisers.

Ammonium salts from stripping and scrubbing as national fertiliser without CE marking

Ammonium salt solutions derived from stripping and scrubbing that do not comply with the (expected) requirements of the FPR or for which the producer does not want to proceed with the conformity assessment can be brought on the market under national legislation without the CE marking. In Belgium, the Netherlands and Denmark the manure derived ammonium salts are considered as manure and therefore subjected to all the rules and requirements that the ABP regulation poses on manure. In Germany, ammonium sulphate solution (but not ammonium nitrate) with at least 5% N and 6% SO_3 may be used to produce mineral fertilisers without restrictions from the ABP regulation. France, Ireland and the UK do not have large scale manure processing and have not yet defined an opinion on the legal status.

RENURE and user limit from the Nitrates Directive

The amount of manure that may be applied to land is limited by the 'user application limit' of $170 \text{ kg N ha}^{-1} \text{ y}^{-1}$ according to the Nitrates Directive. This also applies to manure derived products. The SafeManure proposal has set criteria for materials produced from manure that should be excluded from this user application limit, the so called RENURE materials. The ammonium salts of stripping and scrubbing are compliant with the RENURE criteria (mineral N:total N ratio $\geq 90\%$ or a total organic carbon (TOC):total N ratio ≤ 3 , thresholds for Cu, Zn and Hg). However, the SafeManure proposal for RENURE materials has not been implemented yet. In the countries that consider the ammonium salts as manure, the application is limited to the user application limit of $170 \text{ kg N ha}^{-1} \text{ y}^{-1}$ (or derogation amount). In the countries that consider the solutions as a mineral fertiliser the user application limit for manure does not apply.



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Pig urine

Pig urine from separated stable construction

Technology description

Intensive pig farming and the subsequent manure production result in ammonia (NH₃) and greenhouse gas emissions. A source-based separation technique, such as a pig-manure separation system, is recommended to mitigate manure emissions. The Vermeulen Dobbelaere Welfare System (VeDoWS) is one of the source-based separation techniques developed in Flanders, Belgium. The separation occurs utilising a partly-slatted floor system.

The VeDoWS system ensures efficient separation of animal excreta (~30%) and urine (~70%), aiming to counteract the formation of urease, which is harmful to both humans and animals due to the emission of NH₃.

By using a manure and liquid manure gutter with manure scraper, the VeDoWS stable system separates the drainage of manure and urine. Underneath the slatted floor, a shallow cellar is constructed which enables the separation of urine and solid manure (Figure 1). Using a scraper, the solid manure is removed from the manure gutter daily. This primary separation of manure in the cellar helps in lowering the NH₃ emissions thus lowering loss of N by volatilisation. The pig-manure separation systems are simple to operate and are designed to minimise NH₃ emissions rather than their removal (like the stripping/scrubbing technologies).



Figure 1 The VeDoWS system for manure separation from Vermeulen Construct: a) pipeline which collects urine from all the stable units; b) conveyor belt to transfer the solid manure from the slatted floor to the manure storage area; c) gutter for urine collection.

Product characteristics

Pig urine (PU) obtained from the VeDoWS manure separation system (Figure 2) was analysed for physicochemical and biological parameters (Table 1).

Physicochemical analyses

PU being the liquid fraction of the separated manure, has a very low dry matter content and contains 82 – 90 % of total N in the form of NH₄⁺-N and almost negligible amounts of NO₃⁻-N. Its pH is in the neutral to slightly alkaline spectrum and PU has low electrical conductivity (EC).

The separated urine contains very low P and S content, but has considerable K content. The product can hence be used as an NK-fertiliser.

Biological analyses

The total bacterial count method showed that approximately 2 x 10³ bacterial aerobic mesophiles were present per ml of PU, while little to no fungal aerobic mesophiles were detected.

Tests performed for detection of the pathogens *Salmonella* spp. and *Listeria* spp. confirmed their absence per 25ml of PU. Enumeration methods employed for the pathogens *Escherichia coli* and *Campylobacter* spp. exhibited <10 colony forming units per ml PU. These results are in compliance with the EU Fertilising Products Regulation 2019/1009.



Figure 2 Pig urine from VeDoWs separated stable construction.

Table 1 Physicochemical (expressed on fresh weight basis) and biological characteristics of pig urine from separated stable construction.

Physicochemical analyses		Biological analyses	
pH	7.6 - 9.3	Bacterial load (CFU/ml)	~2000
EC (mS/cm)	24 - 48	Fungal load (CFU/ml)	<10
Dry matter (%)	0.60 - 2.7	<i>Salmonella</i> spp. present or absent/25ml	Absent
Total N (g/kg)	3.3 - 6.2	<i>Listeria</i> spp. present or absent/25ml	Absent
NO ₃ ⁻ -N (g/kg)	<0.002	<i>E.coli</i> (CFU/ml)	<10
NH ₄ ⁺ -N (g/kg)	3.0 - 5.1	<i>Campylobacter</i> spp. (CFU/ml)	<10
Total P (g/kg)	0.04 - 0.05		
Total K (g/kg)	2.7 - 3.5		
Total S (g/kg)	0.25 - 0.76		

*EC: electrical conductivity; CFU: colony forming units

Pig urine from separated stable construction

Agronomic aspects

The field trials aimed to assess the effect of PU on crop yield and to determine its N fertiliser replacement value (NFRV) in comparison to the reference, i.e. synthetic ammonium nitrate fertiliser (33% N). NFRV (%) indicates saved amount of synthetic mineral fertiliser when using a bio-based fertiliser, such as PU, and is determined as follows:

$$\frac{((N \text{ uptake}_{PU} - N \text{ uptake}_{CON}) / (\text{total N applied}_{PU}))}{((N \text{ uptake}_{REF} - N \text{ uptake}_{CON}) / \text{total N applied}_{REF})}$$

where PU = pig urine treatment, CON = unfertilised control and REF = reference. Maize and spinach were the test crops for the trials of 2019 and 2020, respectively. The field trials were performed with incremental N doses during both years (40%, 70% and 100% crop N demand).

For the year 2019, no significant differences in fresh and dry yield were observed between maize grown with PU and the synthetic reference for all three tested N doses (Figure 3). The N uptake in maize fertilised with PU was similar to that of the N uptake of maize fertilised with the synthetic reference. However, high variability was observed in the results as is evident from the high standard deviation of NFRV values.

The 2020 trial results were greatly influenced by the unfavourable weather conditions that prevailed during the trial. This caused high variability among replicates of individual treatments, as evident by the high standard deviations exhibited by the PU treatment. Subsequently, it was difficult to obtain statistical differences between the synthetic reference and PU treatments in the fresh and dry yield, and N uptake in spinach, which in turn resulted in the NFRV to exhibit high standard deviation. Overall, a reduced N uptake due to dryer soil conditions was observed for all the tested treatments.

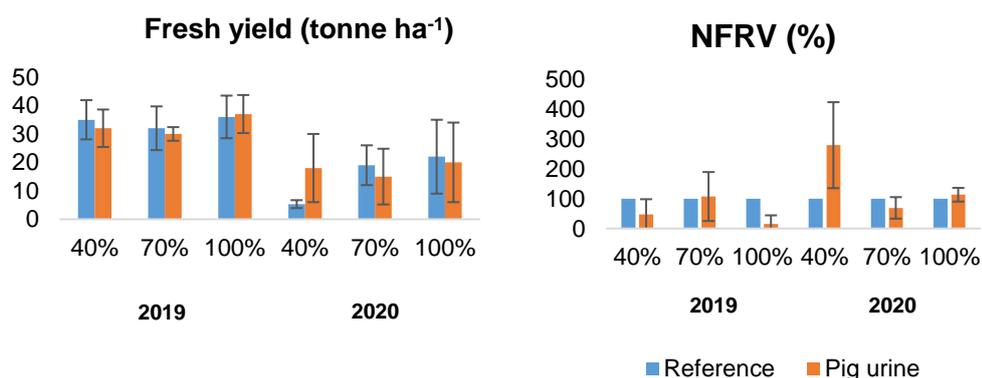
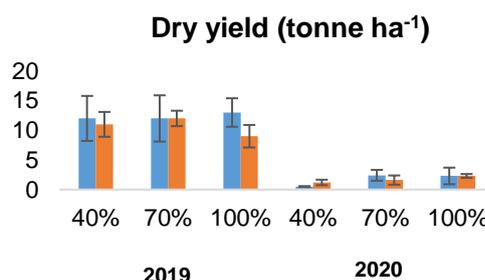


Figure 3 Fresh and dry yield in tonne ha⁻¹, and NFRV of pig urine compared to the synthetic fertiliser reference which is considered to be 100% efficient (i.e. NFRV of reference = 100%).



Environmental aspects

In order to assess the effect of PU on the environment, during the field trial duration, an environmental monitoring campaign was conducted in regard to: i) risk for nitrate leaching by determining nitrate residue, ii) soil analyses at harvest and iii) effect on nematode community.

Nitrate residue

The nitrate residue is measured in post-harvest period by determining nitrate content in 0-90 cm soil profile during the period of 1/10 -15/11.

No significant differences were observed in 2019, but both treatments exceeded the maximal allowable legal limit of 80 kg NO₃-N ha⁻¹ imposed by Flemish legislation for

Residual NO₃-N (kg ha⁻¹)

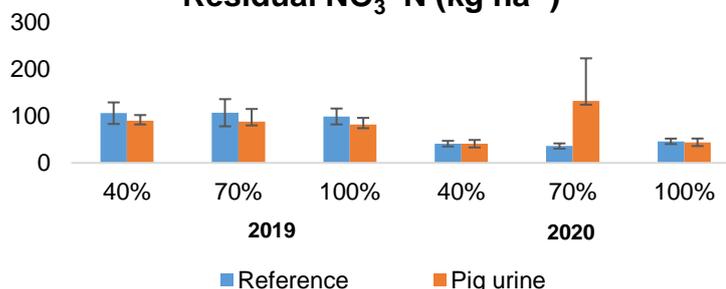


Figure 4 Residual nitrate content measured in the soil profile 0-90 cm in autumn to assess nitrate leaching.

protection of groundwater bodies (Figure 4). In 2020, since spinach was harvested in June, the fields were cultivated with maize afterwards without any N fertilisation and harvested in autumn. Residual nitrate in the soil was then measured after the harvest of maize. PU at 70% N dose exhibited significantly higher NO₃-N in comparison to the synthetic fertiliser and also exceeded the legal limit of 80 kg NO₃-N ha⁻¹. PU fertilisation at other doses and all doses of the reference treatment were within the permissible limit.

Pig urine from separated stable construction

Soil characteristics

No significant differences in soil heavy metal content between treatments were observed for either year. The pH and EC content of the soil was not affected by the addition of PU.

Microbial and nematode communities

The response of soil bacterial, fungal and nematode communities to the application of a pig urine treatment were analysed using high throughput DNA sequencing technologies. Total soil DNA was extracted from soil samples collected in maize field trial 2019. The treatment received a 100% N dose. Alpha and beta diversity indices were used to investigate significant differences in diversity of microbial and nematode communities between pig urine, unfertilised control and reference treatment.

No acute shifts were detected in microbial community structures in plots treated with pig urine when compared with those treated with synthetic reference treatment.

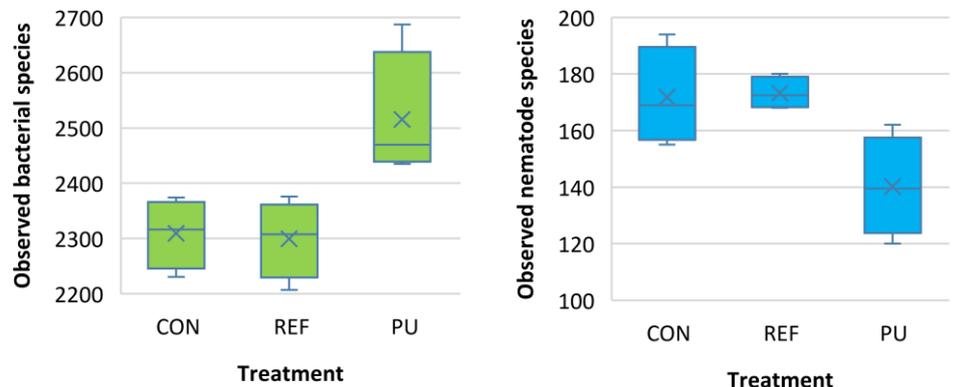


Figure 5 Boxplot of observed bacterial and nematode species numbers ($n=4$) in each treatment, CON = unfertilised control, REF = synthetic ammonium nitrate fertiliser reference, PU = pig urine.

The bacterial diversity levels were significantly increased (Figure 5) when pig urine was applied as the N source. The number of observed nematode species in the pig urine treatment was significantly lower when compared with those in synthetic reference treatment (Figure 5). Although in the pig urine treatment the number of observed species was reduced, this might have been due to the correlation between the nematode taxa and various soil chemical properties. Healthy microbial and nematode communities are indicative of healthy soils.

Legal aspects

Pig urine is defined as an animal manure in the EC Animal By-Product (ABP) regulation. The rules and prerequisites for ABP category 2 materials apply. This means that all actors, actions (transport, handling, distributing) and materials (plants, vehicles, storage sites) from farm to the end user are subject to notifications, registration, approval and controls.

Under the ABP regulation pig urine may be applied to land without any further processing.

The pig urine application to land is further regulated by the Nitrates Directive and country specific Action programmes. The use of animal manure has an application limit to $170 \text{ kg N ha}^{-1} \text{ y}^{-1}$ in the Nitrate Vulnerable Zones, the so-called application limit. In the country specific Nitrate Action programmes further requirements are set for the storage and time period and methods of land application.

The use of source separated animal manure as EU fertilising product with CE marking is not included and not foreseen in the new EU regulation 2019/1009 on fertilising products.



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EUROPEAN UNION

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ReNu2Farm

European Regional Development Fund



Struvite from potato wastewater processing

Struvite from potato wastewater processing

Technology description

Struvite (magnesium ammonium phosphate ($\text{NH}_4\text{MgPO}_4 \cdot 6\text{H}_2\text{O}$)) formation is a natural phenomenon at wastewater treatment plants (WWTPs) and occurs at equimolar concentrations of Mg:NH₄:PO₄ (1:1:1). It is a co-precipitate when Mg, NH₄⁺ and ortho-phosphate are present in concentrations above the solubility constant.

In WWTPs with enhanced biological phosphorus (P) removal, numerous examples of struvite deposition and its associated problems have been reported. Its deposition clogs pipes through encrustation and scaling, resulting in high costs for operation and maintenance. Therefore, WWTPs nowadays implement intentional struvite recovery either on the centrate or the sludge line. While struvite recovery is known to improve WWTP performance, it also provides a 'bioavailable-P' product which could be a possible substitute for synthetic P fertilisers.

Nutrients Recovery Systems (NuReSys)[®] is a Belgian company founded in 2011 which supplies in particular controlled struvite crystallisation technology. The technology is not just applicable on digested sludge and post dewatering, but also on combining both. The struvite tested in the ReNu2Farm project is obtained from the processing of wastewater from a potato processing company that employs the NuReSys[®] technology.

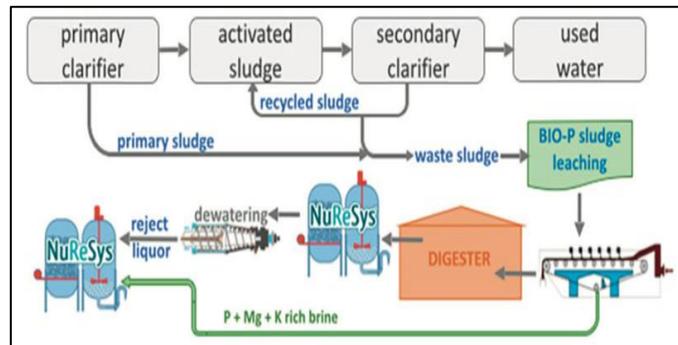


Figure 1 NuReSys[®] technology of struvite production.



Figure 2 Struvite produced from the processing of wastewater from potato processing company using the NuReSys[®] technology.

Product characteristics

The struvite obtained from processing potato wastewater (PWStruvite) was analysed for physicochemical and biological parameters (Table 1).

Physicochemical analyses

With a dry matter content of 56%, the PWStruvite has a slightly basic water-pH and very low electrical conductivity. With approximately 5% N content, PWStruvite is also a P and Mg-rich product (15% P and 10% Mg) with 1-2% K and a negligible S and Ca content. All heavy metals are present in low concentrations and below the prescribed legal limits (EU Fertilising Products Regulation 2019/1009).

Biological analyses

Up to 10,000 bacterial aerobic mesophiles were present per g of the PWStruvite as determined by plate count techniques, while very few viable fungi were found. Tests performed for detection of the pathogens *Salmonella* spp. and *Listeria* spp. confirmed

their absence per 25g of product. Enumeration methods employed for the pathogens *Escherichia coli* and *Campylobacter* spp. exhibited <10 colony forming units per g of the PWStruvite. These results are in compliance with the EU Fertilising Products Regulation 2019/1009.

Table 1 Physicochemical and biological characteristics (expressed on fresh weight basis if not indicated otherwise) of the struvite produced by the NuResys[®] technology from potato wastewater.

Physicochemical analyses			
pH-water	8.7	Total Mg (g/kg)	99
EC (mS/cm)	0.85	Total Zn (mg/kg DM)	<4
Dry matter (%)	56*	Total Fe (mg/kg DM)	25
Total C _{org} (g/kg)	0.46	Total Cu (mg/kg DM)	0.70
Total N (g/kg)	51	Total Al (mg/kg DM)	36
NO ₃ -N (g/kg)	0.01	Total Cr (mg/kg DM)	1.7
NH ₄ ⁺ -N (g/kg)	51	Total Mn (mg/kg DM)	93
Total P (g/kg)	153	Total Ni (mg/kg DM)	0.089
Total K (g/kg)	19	Total Co (mg/kg DM)	<0.079
Total S (g/kg)	0.28	Total Cd (mg/kg DM)	<0.079
Total Ca (g/kg)	0.27	Total Pb (mg/kg DM)	<0.079
Biological analyses			
Bacterial load (CFU/g)	10 ³ - 10 ⁴	<i>Listeria</i> spp. present or absent/25g	Absent
Fungal load (CFU/g)	<10	<i>E.coli</i> (CFU/g)	<10
<i>Salmonella</i> spp. present or absent/25g	Absent	<i>Campylobacter</i> spp. (CFU/g)	<10

EC: electrical conductivity; DM: dry matter; CFU: colony forming unit

*Dry matter was determined at 105°C until constant weight

Struvite from potato wastewater processing

Agronomic impact

A field-scale agronomic trial in a sandy loam temperate grassland with a low plant available soil P level was conducted by Teagasc in Ireland. The goal was to assess the mineral P fertiliser replacement value (PFRV) and crop yield performance of PWStruvite at 40 kg P/ha in comparison to reference super phosphate mineral fertiliser at 40 kg P/ha (P40) as well as a P free control (P0 treatment). The PFRV (%) was determined by using the following equation:

$$\frac{(P \text{ uptake}_{PWStruvite} - P \text{ uptake}_{CON}) / \text{total P applied}_{PWStruvite}}{(P \text{ uptake}_{REF} - P \text{ uptake}_{CON}) / \text{total P applied}_{REF}}$$

where PWStruvite = struvite treatment; CON = P unfertilised treatment and REF = synthetic fertiliser reference (i.e. super phosphate). The experimental design was a randomised complete block with five replications. Grass yield and P uptake were assessed in 2019 and 2020 with 4 harvests per year.

Biomass dry biomass yield was not statistically different between mineral P40, PWStruvite and P0 control in both 2019 and 2020 harvests. However, P uptake was significantly greater in the fertilised treatments. The mean P concentrations and cumulative P uptake in PWStruvite and P40 treatments were significantly higher than in the control treatment (Table 2).

Environmental impact

In order to assess the effect of PWStruvite on the environment, during the field trial duration an environmental monitoring campaign was conducted in regard to: i) soil test P levels, ii) the capacity to cycle P and iii) effect on microbial and nematode communities.

Soil test P levels

Plant available soil P (via Morgan's extracting reagent) decreased significantly for P0 treatment when pre- and post-harvest soils were compared, while this change was not different for P40 and PWStruvite (Figure 4). The result indicates that the crop removal of P (up to 34.8 kg ha⁻¹ in the 1st year) across

The apparent P recovery (APR (%)) = (P uptake treatment – P uptake CON)/total P applied treatment) increased with the duration of the trial with generally higher APR values for PWStruvite than mineral P40 (Figure 3). As such the PFRV of PWStruvite compared to reference mineral P40 is determined to be higher (1st harvest 125% and first-year 141%). The findings indicate that PWStruvite has a superior PFRV to mineral P fertiliser in terms of growing season P availability and PWStruvite can be recommended as a potential alternative P fertiliser that can supply readily available P for crop uptake.

Table 2 P uptake and concentrations in herbage for 2019 and 2020. P0 = P unfertilised control; P40 = super phosphate at 40 kg-P ha⁻¹; PWStruvite = struvite from potato waste processing. Mean values denoted by the common letter are not statistically different at the 5% probability level.

Treatment	Cumulative P uptake (kg/ha)		Mean P concentration (%)	
	2019	2020	2019	2020
P0	26.2 ^b ± 4.1	29.4 ^a ± 1.1	0.22 ^b ± 0.02	0.22 ^a ± 0.01
P40	32.3 ^a ± 3.7	30.2 ^a ± 3.2	0.25 ^a ± 0.01	0.23 ^a ± 0.02
PWStruvite	34.8 ^a ± 2.8	31.6 ^a ± 3.7	0.27 ^a ± 0.02	0.23 ^a ± 0.02

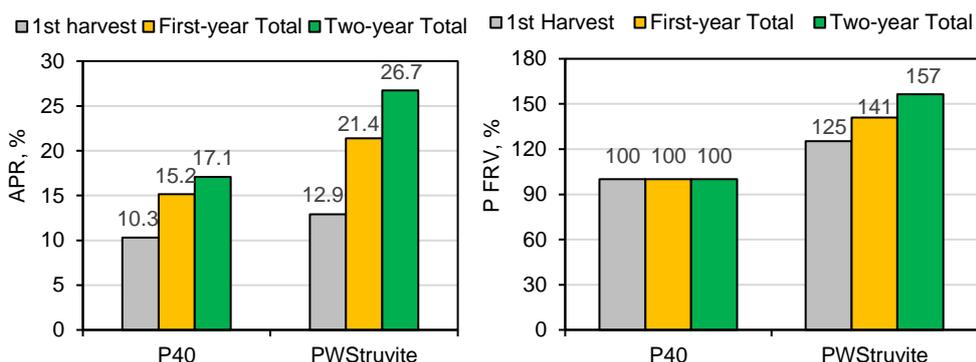


Figure 3 Apparent P recovery (APR) and P Fertiliser replacement value (PFRV). P40 = super phosphate at 40 kg-P ha⁻¹; PWStruvite = struvite from potato waste processing.

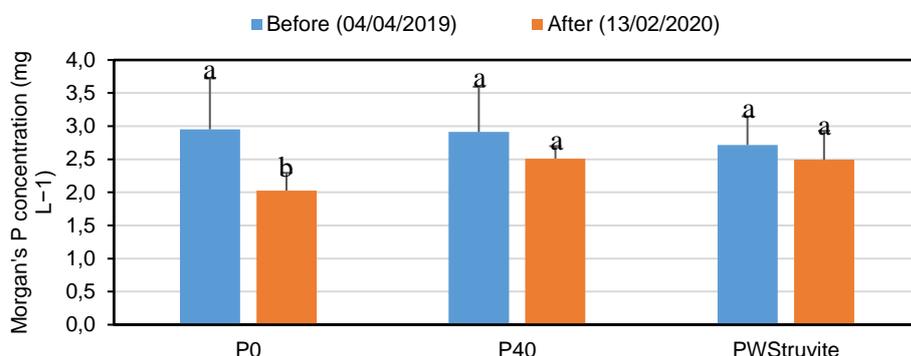


Figure 4 Pre- and post-harvest comparison of crop available Morgan's P concentrations across treatments. P0 = P unfertilised control; P40 = super phosphate at 40 kg-P ha⁻¹; PWStruvite = struvite from potato waste processing. Mean values denoted by the common letter are not statistically different at the 5% probability level.

treatments was replenished by P applications. This contrasts with the P0 treatment where the plant removal of 26.2 kg ha⁻¹ caused plant available soil P reduction of 1 mg/L (33% drop) compared to their initial levels.

Struvite from potato wastewater processing

Biological analysis – P cycling

In soils, approximately 99% of the P is not directly plant available but immobilised in either organic or inorganic forms. Soil microbes play a key role in making these P sources available. The capacity to cycle P in the fields fertilised with PWStruvite has been compared to that of synthetic fertilised reference and unfertilised P control. This was done by assessing the soil enzymatic capacity, the ability of soil bacteria to release P, the abundance of bacterial genes, quantifying the bacteria with the capacity to release P and analysing the diversity of P cycling genes.

In the grassland field trial, the soil enzymatic activity was higher in PWStruvite when compared to superphosphate applications. Likewise, PWStruvite application increased the abundance of calcium-phosphate solubilizing bacteria when compared to superphosphate. Diversity of the phosphatase genes differed between the superphosphate and PWStruvite treatments in 2020. In summary, no negative effects were identified on the natural ability of soil microbes

to cycle P under PWStruvite. Instead, potential beneficial effects by PWStruvite may improve microbial P cycling in the medium term.

Microbial and nematode communities

The response of soil bacterial, fungal and nematode communities to the application of PWStruvite in 2020 field trial were analysed using high throughput DNA sequencing technologies, and compared against control treatments (i.e. super phosphate and P unfertilised control). Results showed bacterial, fungal and nematode diversity and communities of soil fertilised with PWStruvite to be highly similar to those resulting from fertilisation with superphosphate (Figure 5). PWStruvite can be therefore applied by farmers, as the main source of P, without posing a threat to terrestrial microbial and nematode communities. Healthy microbial communities are indicative of healthy soils.

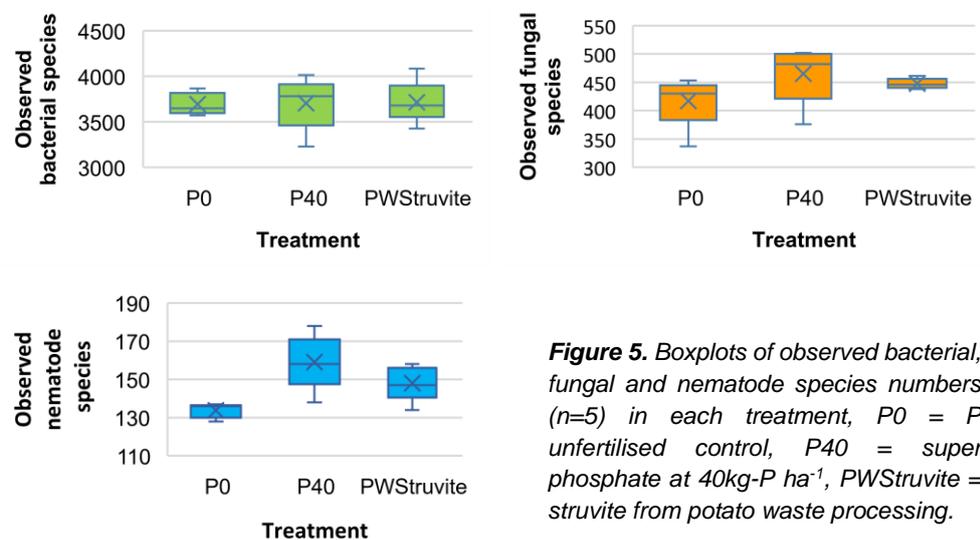


Figure 5. Boxplots of observed bacterial, fungal and nematode species numbers ($n=5$) in each treatment, P0 = P unfertilised control, P40 = super phosphate at 40kg-P ha^{-1} , PWStruvite = struvite from potato waste processing.

Legal aspects

Struvite is that is derived from treatment of wastewaters and sludge from food processing is legally considered a waste product. It has to be authorised to be used as a recovered fertiliser product.

Struvite as an EU fertilising product with CE marking

The revised EU Fertilising Products regulation 2019/1009 (applies from 16 July 2022) allows the use of struvite as a component for the production of EU fertilising products. The criteria are laid down in the CMC 12 Precipitated phosphorus salts. The struvite has to contain at least 16% of P_2O_5 (equivalent to 7% of P) of the dry weight and no more than 3% organic C. It may not exceed threshold limits for impurities, pathogens, PAH₁₆, Al and Fe. The food processing may not include animal-by products and no biocidal products may have been involved. The struvite has to be REACH registered. Struvite as a CMC material is still considered waste and all prerequisites and requirements from Waste Framework Direction and Waste Shipping Regulation apply. The EU fertilising product that is produced from struvite has to meet the criteria of an EU Product Function Category (PFC). These include minimum contents of nutrients, and threshold levels for heavy metals and arsenic. After conformity assessment procedure, involving controls from a certified 'notified body' the product may be labelled with the CE marking and has obtained the End-of-Waste status. EU fertilising products with CE marking may be traded throughout the internal EU market without any additional restrictions or requirements at the national level.

Struvite as a National fertiliser without CE marking

Struvite that does not meet all requirements of the EU 2019/1009 or for which the producers do not want to go through the conformity assessment procedure for CE marking may be brought to the market as a national fertiliser if it complies with the national fertiliser regulations. In the Netherlands, struvite from certain sources that meet requirements on P_2O_5 levels and contaminants belong to the fertiliser category 'recovered phosphates' and can be marketed and used as mineral fertilisers. In Belgium, struvite has to obtain a derogation as fertiliser which is specific for a producer and production site. Germany allows struvites to be used for the production of mineral fertilisers. In the UK high purity struvites were recognised as an EC-fertiliser under the outgoing EU Fertilising regulation 2003/1003, but it is not clear how this will be influenced by the Brexit. In France, struvite products have to obtain a producer specific derogation ("homologation") which requires an extensive application dossier. In Ireland, a derogation has to be obtained to be used as a fertiliser.



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European Regional Development Fund



Struvite from municipal wastewater processing

Struvite from municipal wastewater processing

Technology description

Struvite (magnesium ammonium phosphate ($\text{NH}_4\text{MgPO}_4 \cdot 6\text{H}_2\text{O}$)) formation is a natural phenomenon at wastewater treatment plants (WWTPs) and occurs at equimolar concentrations of $\text{Mg}:\text{NH}_4:\text{PO}_4$ (1:1:1). It is a co-precipitate when Mg, NH_4^+ and ortho-phosphate are present in concentrations above the solubility constant.

In WWTPs with enhanced biological phosphorus (P) removal, numerous examples of struvite deposition and its associated problems have been reported. Its deposition clogs pipes through encrustation and scaling, resulting in high costs for operation and maintenance. Therefore, WWTPs nowadays implement intentional struvite recovery either on the centrate or the sludge line. While struvite recovery is known to improve WWTP performance, it also provides a 'bioavailable-P' product which could be a possible substitute for synthetic P fertilisers.

Nutrients Recovery Systems (NuReSys)[®] is a Belgian company founded in 2011 which supplies in particular controlled struvite crystallisation technology. The technology is not just applicable on digested sludge and post dewatering, but also on combining both. The struvite tested in the ReNu2Farm project is obtained from the processing of wastewater from a municipal WWTP that employs the NuReSys[®] technology.

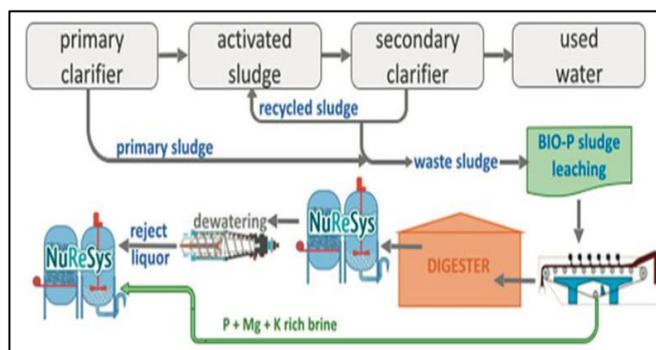


Figure 1 NuReSys[®] technology of struvite production.



Figure 2 Struvite produced from the processing of municipal waste using the NuReSys[®] technology.

Product characteristics

The struvite obtained from the processing of municipal waste (MWStruvite) was analysed for physicochemical and biological parameters (Table 1).

Physicochemical analyses

With a dry matter content of 61%, the MWStruvite has a slightly basic water-pH and very low electrical conductivity. With approximately 5% N content, MWStruvite is also a P and Mg-rich product (15% P and 10% Mg) with ~0.06 % K and a negligible S and Ca content. All heavy metals are present in low concentrations and below the prescribed legal limits (EU Fertilising Products Regulation 2019/1009).

Biological analyses

Total bacterial and fungal counts showed viable bacterial and fungal aerobic mesophiles to be present in concentrations of $10^2 - 10^3$ colony forming units per g of MWStruvite. Tests performed for detection of the pathogens *Salmonella* spp. and *Listeria* spp.

confirmed their absence per 25g of MWStruvite. Enumeration methods employed for the pathogens *Escherichia coli* and *Campylobacter* spp. exhibited <10 colony forming units per gram of MWStruvite. These results are in compliance with the EU Fertilising Products Regulation 2019/1009.

Table 1 Physicochemical and biological characteristics (expressed on fresh weight basis if not indicated otherwise) of the struvite produced by the NuReSys[®] technology from municipal waste.

Physicochemical analyses			
pH-water	7.9	Total Mg (g/kg)	105
EC (mS/cm)	0.82	Total Zn (mg/kg DM)	<4.6
Dry matter (%)	61*	Total Fe (mg/kg DM)	437
Total N (g/kg)	55	Total Cu (mg/kg DM)	0.73
C _{org} (g/kg)	0.53	Total Al (mg/kg DM)	11
NO ₃ -N (g/kg)	<0.01	Total Cr (mg/kg DM)	1.9
NH ₄ ⁺ -N (g/kg)	55	Total Mn (mg/kg DM)	31
Total P (g/kg)	148	Total Ni (mg/kg DM)	0.18
Total K (g/kg)	0.60	Total Co (mg/kg DM)	<0.093
Total S (g/kg)	0.09	Total Cd (mg/kg DM)	<0.093
Total Ca (g/kg)	0.09	Total Pb (mg/kg DM)	<0.093
Biological analyses			
Bacterial load (CFU/g)	$10^2 - 10^3$	<i>Listeria</i> spp. present or absent/25g	Absent
Fungal load (CFU/g)	$10^2 - 10^3$	<i>E.coli</i> (CFU/g)	<10
<i>Salmonella</i> spp. present or absent/25g	Absent	<i>Campylobacter</i> spp. (CFU/g)	<10

EC: electrical conductivity; DM: dry matter; CFU: colony forming unit
 *Dry matter was determined at 105°C until constant weight

Struvite from municipal wastewater processing

Agronomic impact

A field-scale agronomic trial in a sandy loam temperate grassland with a low plant available soil P level was conducted by Teagasc in Ireland. The goal was to assess the mineral P fertiliser replacement value (PFRV) and crop yield performance of MWStruvite at 40 kg P/ha in comparison to reference super phosphate mineral fertiliser at 40 kg P/ha (P40) as well as a P free control (P0 treatment). The PFRV (%) was determined by using the following equation:

$$\frac{(P \text{ uptake MWStruvite} - P \text{ uptake CON}) / \text{total P applied MWStruvite}}{(P \text{ uptake REF} - P \text{ uptake CON}) / \text{total P applied REF}}$$

where MWStruvite = struvite treatment, CON = P unfertilised treatment, REF = synthetic fertiliser reference (i.e. super phosphate). The experimental design was a randomised complete block with five replications. Grass yield and P uptake were assessed in 2019 and 2020 with 4 harvests per year.

Biomass dry biomass yield was not statistically different between mineral P40, MWStruvite and P0 control in both 2019 and 2020 harvests. However, the mean P concentrations and cumulative P uptake in herbage during 2019 trial were significantly higher in MWStruvite and P40 than the control treatment (Table 2).

Environmental impact

In order to assess the effect of MWStruvite on the environment, during the field trial duration an environmental monitoring campaign was conducted in regard to: i) soil test P levels, ii) the capacity to cycle P and iii) effect on microbial and nematode communities.

Soil test P levels

Plant available soil P (via Morgan's extracting reagent) decreased significantly for P0 treatment when pre- and post-harvest soils were compared, while this change was not different for P40 and MWStruvite (Figure 4). The results indicate that the crop removal of P (up to 34.5 kg ha⁻¹ in the 1st year) across treatments was replenished by P applications.

The apparent P recovery (APR (%)) = (P uptake treatment – P uptake CON)/total P applied treatment) increased with the duration of the trial with generally higher values for MWStruvite than mineral P40 (Figure 3). As such PFRV of MWStruvite is determined to be higher (1st harvest 110% and first-year 137%) compared to reference mineral P40. The findings indicate that MWStruvite has a superior PFRV to mineral P fertiliser in terms of growing season P availability. Hence, MWStruvite could be recommended as a potential alternative P fertiliser that can supply readily available P for crop uptake.

Table 2 P uptake and concentrations in herbage for 2019 and 2020. P0 = P unfertilised control; P40 = super phosphate at 40 kg-P ha⁻¹; MWStruvite = struvite from municipal waste. Mean values denoted by the common letter are not statistically different at the 5% probability level.

Treatment	Cumulative P uptake (kg/ha)		Mean P concentration (%)	
	2019	2020	2019	2020
P0	26.2 ^b ± 4.1	29.4 ^a ± 1.1	0.22 ^b ± 0.02	0.22 ^a ± 0.01
P40	32.3 ^a ± 3.7	30.2 ^a ± 3.2	0.25 ^a ± 0.01	0.23 ^a ± 0.02
MWStruvite	34.5 ^a ± 3.9	31.5 ^a ± 1.1	0.27 ^a ± 0.01	0.23 ^a ± 0.01

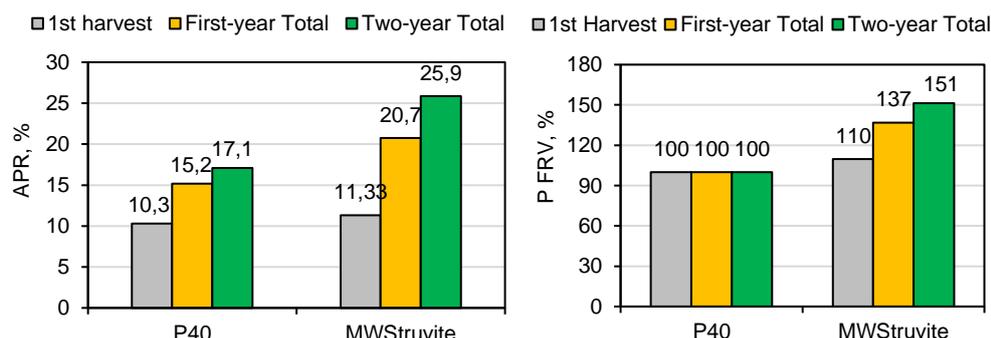


Figure 3 Apparent P recovery (APR) and P Fertiliser replacement value (PFRV). P40 = super phosphate at 40 kg-P ha⁻¹; MWStruvite = struvite from municipal waste.

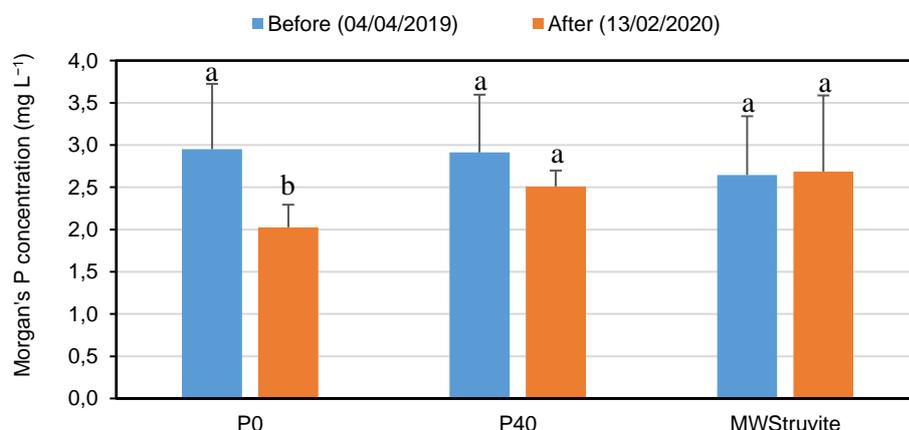


Figure 4 Pre- and post-harvest comparison of crop available Morgan's P concentrations across treatments. P0 = P unfertilised control; P40 = super phosphate at 40 kg-P ha⁻¹; MWStruvite = struvite from municipal waste. Mean values denoted by the common letter are not statistically different at the 5% probability level.

This contrasts with the P0 treatment where the plant removal of 26.2 kg ha⁻¹ caused plant available soil P reduction of 1 mg/L (33% drop) compared to their initial levels.

Struvite from municipal wastewater processing

Biological analysis – P cycling

In soils, approximately 99% of the P is not directly plant available but immobilised in either organic or inorganic forms. Soil microbes play a key role in making these P sources available. The capacity to cycle P in the fields fertilised with MWStruvite has been compared to that of the synthetic fertilised reference and unfertilised P control. This was done by assessing the soil enzymatic capacity, the ability of soil bacteria to release P, the abundance of bacterial genes, quantifying the bacteria with the capacity to release P and analysing the diversity of P cycling genes.

In the grassland field trial, the soil enzymatic activity was higher in MWStruvite when compared to superphosphate applications. Likewise, MWStruvite application increased the abundance of calcium-phosphate solubilising bacteria when compared to superphosphate. Diversity of the phosphatase genes differed between the superphosphate and MWStruvite treatments in 2020. In summary, no negative effects were identified on the natural ability of soil microbes to cycle P under MWStruvite.

Legal aspects

Struvite that is derived from treatment of municipal wastewater or sewage sludge is legally considered a waste product. It has to be authorised to be used as a recovered fertiliser product.

Struvite as an EU fertilising product with CE marking

The revised EU Fertilising Products regulation 2019/1009 (applies from 16 July 2022) allows the use of struvite as a component for the production of EU fertilising products. The criteria are laid down in the CMC 12 Precipitated phosphorus salts. The struvite has to contain at least 16% of P_2O_5 (equivalent to 7% of P) of the dry weight and no more than 3% organic C. It may not exceed threshold limits for impurities, pathogens, PAH₁₆, Al and Fe. The struvite has to be REACH registered. Struvite as a CMC material is still considered waste and all prerequisites and requirements from the Waste Framework Directive and Waste Shipping Regulation apply. The EU Fertilising product that is produced from struvite has to meet the criteria of the Product Function Category (PFC) that it belongs to. These include minimum contents of nutrients, and threshold levels for heavy metals and arsenic. After conformity assessment procedure, involving controls from a certified 'notified body' the product may be labelled with the CE marking and has obtained the End-of-waste status. EU fertilising products with CE marking may be traded throughout the internal EU market without any additional restrictions or requirements at the national level.

Struvite as a National fertiliser without CE marking

Struvite that does not meet all requirements of the EU 2019/1009 or for which the producers do not want to go through the conformity assessment procedure for CE marking may be brought to the market as a national fertiliser if they comply to the national fertiliser regulations. In the Netherlands, struvite from certain sources that meet requirements on P_2O_5 levels and contaminants belong to the fertiliser category 'recovered phosphates' and can be marketed and used as mineral fertilisers. In Belgium, struvite has to obtain a derogation as fertiliser which is specific for a producer and production site. Germany allows struvites to be used for the production of mineral fertilisers. In the UK high purity struvites were recognised as an EC-fertiliser under the outgoing EU Fertilising regulation 2003/1003, but it is not clear how this will be influenced by the Brexit. In France, struvite products have to obtain a producer specific derogation ('*homologation*') which requires an extensive application dossier. In Ireland, a derogation has to be obtained to be used as a fertiliser.

Instead, potential beneficial effects by MWStruvite may improve microbial P cycling in the medium term.

Microbial and nematode communities

The response of soil bacterial, fungal and nematode communities to the application of MWStruvite in 2020 field trial were analysed using high throughput DNA sequencing technologies, and compared against control treatments (i.e. super phosphate control and P unfertilised control). The levels of bacterial, fungal and nematode diversity were maintained in soil fertilised with MWStruvite when compared to those in the control treatment groups (Figure 5). MWStruvite can be applied by farmers, as the main source of P, without posing a threat to terrestrial microbial and nematode communities. Healthy microbial and nematode communities are indicative of healthy soils.

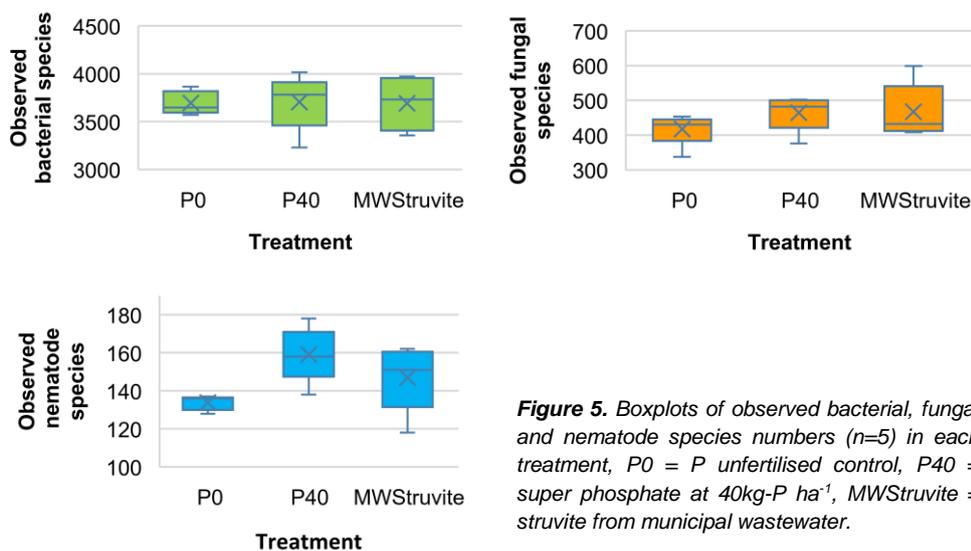


Figure 5. Boxplots of observed bacterial, fungal and nematode species numbers ($n=5$) in each treatment, P0 = P unfertilised control, P40 = super phosphate at 40kg-P ha^{-1} , MWStruvite = struvite from municipal wastewater.



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AshDec sewage sludge ash

Technology description

Metso Outotec GmbH & Co. KG, a partner in the ReNu2Farm project, is a process technology company which develops technologies and processes for the mining and metal industries.

The AshDec[®] process was developed by Outotec and the German Federal Institute for Material Research and Testing (BAM), to produce a calcined phosphate fertiliser out of the ash from sewage sludge incineration plants. The AshDec[®] process aims at removal of heavy metals from the sewage sludge ash and the conversion of non-plant available phosphate species created in the incineration step to a highly plant-available calcium (Ca)-sodium (Na)/potassium (K) phosphates (Figure 1). In the process, the ash is mixed with Na/K containing species and dried sewage sludge as a reduction additive, and thermally treated at high temperatures (~900°C) in a rotary kiln.

Some heavy metals are vapourised under reducing conditions to the gas phase and are condensed after cooling of the off-gas in the filter system, to be disposed with the filter dust. The resultant product (ash) is a P fertiliser. (Figure 2).

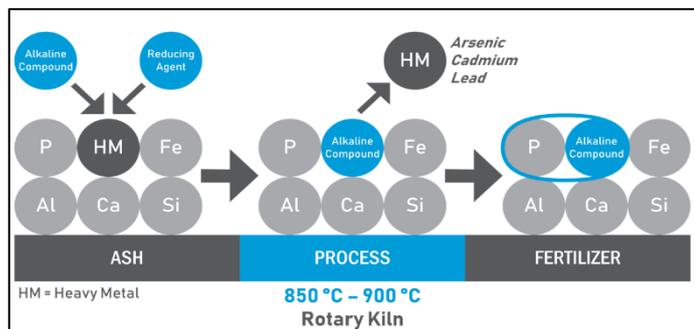


Figure 1 AshDec[®] process employed by Metso Outotec for production of the P fertiliser.



Figure 2 The calcined phosphate fertiliser produced by the AshDec[®] process.

Product characteristics

Since the ash from the AshDec[®] process has not been introduced to the market yet, the product ash (hereinafter referred to as SSAsh = sewage sludge ash) from test trials in a pilot scale testing plant was analysed for physicochemical and biological parameters (Table 1).

Physicochemical analyses

Owing to the thermochemical nature of the process, the SSAsh is entirely moisture-free with a dry matter of 100%. The product has a pH-water of 10 and a low electrical conductivity (EC). It is a P-rich product with considerable amounts of Ca and Mg, and negligible N content. Although, heavy metals of concern like Cd, Pb, As etc. are present in very low concentrations (below prescribed legal limits (EU Fertilising Products Regulation 2019/1009)), total metal content in the product of Zn, Fe, Al, etc. was found to be high. To understand the implications of the higher metal content, its plant-availability and uptake was monitored and studied by Metso Outotec.

Biological analyses

No bacterial or fungal aerobic mesophiles were found to be present per g of SSAsh, as

determined by total viable count techniques. Tests performed for detection of the pathogens *Salmonella* spp. and *Listeria* spp. confirmed their absence per 25g of SSAsh. Enumeration methods employed for the pathogens *Escherichia coli* and *Campylobacter* spp. exhibited <10 colony forming units per g of SSAsh. These results are in compliance with the EU Fertilising Products Regulation 2019/1009.

Table 1 Physicochemical and biological (expressed on fresh weight basis if not indicated otherwise) characteristics of the ash produced by the AshDec[®] process.

Physicochemical analyses			
pH-water	10	Total Zn (mg/kg DM)	1 228 - 1 797
pH-KCl	11	Total Fe (mg/kg DM)	43 626 - 59 622
EC (mS/cm)	32	Total Cu (mg/kg DM)	428 - 609
Dry matter (%)	100	Total Al (mg/kg DM)	4 523 - 52 980
Total N (g/kg)	0.25 ± 0.18	Total Cr (mg/kg DM)	73 - 112
NO ₃ -N (g/kg)	<0.01	Total Mn (mg/kg DM)	692 - 955
NH ₄ ⁺ -N (g/kg)	0.157	Total Ni (mg/kg DM)	45 - 59
Total P (g/kg)	65 - 84	Total Co (mg/kg DM)	7.6 - 12
Total K (g/kg)	10 - 13	Total Cd (mg/kg DM)	0.25 - 3.4
Total S (g/kg)	30 - 50	Total Pb (mg/kg DM)	11 - 20
Total Ca (g/kg)	76 - 103	Total As (mg/kg DM)	<1.5
Total Mg (g/kg)	15	Total Mo (mg/kg DM)	15 ± 0.63
Biological analyses			
Bacterial load (CFU/g)	0	<i>Listeria</i> spp. present or absent/25g	Absent
Fungal load (CFU/g)	0	<i>E.coli</i> (CFU/g)	<10
<i>Salmonella</i> spp. present or absent/25g	Absent	<i>Campylobacter</i> spp. (CFU/g)	<10

EC: electrical conductivity; DM: dry matter; CFU: colony forming unit

Agronomic aspects

A field-scale agronomic trial in a sandy loam soil temperate grassland with a low soil plant available P level was conducted by Teagasc in Ireland. The goal was to assess the mineral phosphorus (P) fertiliser replacement value (PFRV) and crop yield performance of SSAsH at 40 kg P/ha in comparison to reference super phosphate at 40 kg-P ha⁻¹ (P40) as well as a P free control (P0 treatment). The PFRV (%) was determined by using the following equation:

$$\frac{(P \text{ uptake SSAsH} - P \text{ uptake CON}) / \text{total P applied SSAsH}}{(P \text{ uptake REF} - P \text{ uptake CON}) / \text{total P applied REF}}$$

where, SSAsH = ash treatment, CON = P unfertilised treatment and REF = synthetic fertiliser reference (i.e. super phosphate). The experimental design was a randomised complete block with five replications. Grass yield and P uptake were assessed in 2019 and 2020 with 4 harvests per year.

Biomass dry yield was not statistically different between mineral P40, SSAsH and P0 control in both 2019 and 2020 harvests. However, P uptake was found to be more sensitive to treatment differences. The P uptake of SSAsH and the control were significantly lower than the super phosphate in 2019 (Table 2).

Environmental aspects

In order to assess the effect of SSAsH on the environment, during the field trial duration an environmental monitoring campaign was conducted in regard to: i) soil test P levels, ii) the capacity to cycle P and iii) effect on microbial and nematode communities.

Soil test P levels

Plant available soil P (via Morgan's extracting reagent) decreased significantly for P0 treatment when pre- and post-harvest soils were compared, while this change was not different for P40 and SSAsH (Figure 4). The result indicates that the crop removal of P (up to 32.3 kg ha⁻¹ in the 1st year) across treatments was replenished by P applications.

Apparent P recovery (APR) (%) = (P uptake treatment – P uptake CON)/total P applied treatment from SSAsH plots over 2019 was below 4% and therefore substantially lower than for superphosphate (15%). Importantly, the APR of SSAsH doubled in 2020 with PFRV increasing to 44% from just 22% when compared over one year (Figure 3). The findings indicate very limited P availability by SSAsH for plant uptake from immediate to first-year but potential for residual P availability over the 2nd year and perhaps further.

Table 2 P uptake and concentrations in herbage for 2019 and 2020. P0 = P unfertilised control; P40 = super phosphate at 40 kg-P ha⁻¹; SSAsH = sewage sludge ash. Mean values denoted by the common letter are not statistically different at the 5% probability level.

Treatment	Cumulative P uptake (kg/ha)		Mean P concentration (%)	
	2019	2020	2019	2020
P0	26.2 ^b ± 4.1	29.4 ^a ± 1.1	0.22 ^b ± 0.02	0.22 ^a ± 0.01
P40	32.3 ^a ± 3.7	30.2 ^a ± 3.2	0.25 ^a ± 0.01	0.23 ^a ± 0.02
SSAsH	27.6 ^b ± 3.0	31.1 ^a ± 2.4	0.24 ^{ab} ± 0.01	0.23 ^a ± 0.02

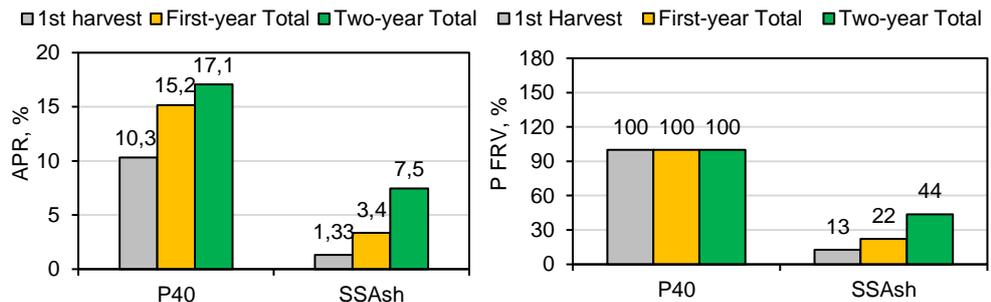


Figure 3 Apparent P recovery (APR) and P fertiliser replacement value (PFRV). P40 = super phosphate at 40 kg-P ha⁻¹; SSAsH = sewage sludge ash.

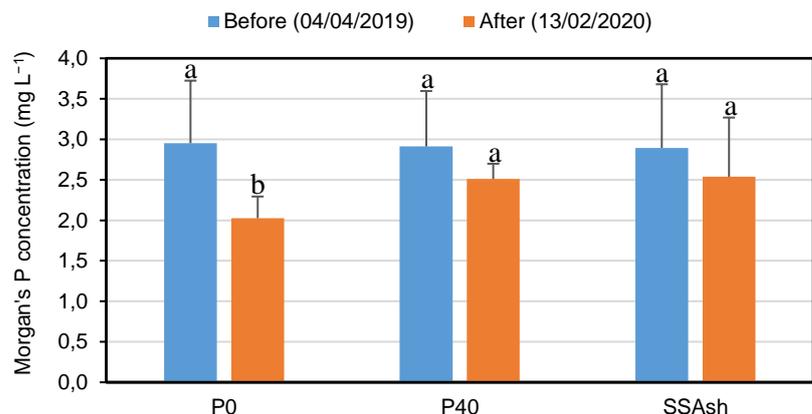


Figure 4 Pre- and post-harvest comparison of crop available Morgan's P concentrations across treatments. P0 = P unfertilised control; P40 = super phosphate at 40 kg-P ha⁻¹; SSAsH = sewage sludge ash. Mean values denoted by the common letter are not statistically different at the 5% probability level.

This contrasts with the P0 treatment where the plant removal of 26.2 kg ha⁻¹ caused plant available soil P reduction of 1 mg/L (33% drop) compared to their initial levels.

Biological analysis – P cycling

In soils, approximately 99% of the P is not directly plant available but immobilised in either organic or inorganic forms. Soil microbes play a key role in making these P sources available. The capacity to cycle P in the fields fertilised with SSAsH has been compared to synthetic fertilised reference and unfertilised P control. This was done by assessing the soil enzymatic capacity, the ability of soil bacteria to release P, the abundance of bacterial genes, quantifying the bacteria with the capacity to release P and analyzing the diversity of P cycling genes.

In the grass field trial, only minor changes were identified in the soil enzymatic activity, which was largely related to a moderate pH change caused by SSAsH. Likewise, SSAsH application increased the abundance of calcium-phosphate solubilising bacteria when compared to superphosphate. Furthermore, the diversity of the phosphatase genes differed between the superphosphate and SSAsH treatments. In summary, no negative effects were identified on the natural ability of soil microbes to cycle P when SSAsH was used. The overall

findings suggest that SSAsH use may have long-term beneficial effect on the ability to cycle P more efficiently when compared to superphosphate.

Microbial and nematode communities

The response of soil bacterial, fungal and nematode communities to the application of SSAsH in 2020 field trial were analysed using high throughput DNA sequencing technologies, and compared against control treatments (i.e. super phosphate and P unfertilised control). Diversity levels of soil bacteria remained equivalent to control treatments when SSAsH was utilised as the P source (Figure 5A). However, the order of dominating bacterial phyla was altered. Fungal diversity significantly increased in SSAsH treated soil (Figure 5B) and led to a significant shift in fungal community structure, indicating that dominant fungal species were suppressed by factors such as the high pH or metal content of the ash. This could result in the growth of fungal species more tolerant to the altered conditions. Although the levels of nematode diversity were maintained in SSAsH fertilised soil (Figure 5C), it significantly reduced the relative abundance of sensitive to environmental disturbance dorylaimids when compared with super phosphate control. Additionally, soil available P appeared to be a driving factor in shaping the nematode communities in SSAsH treatment. Due to the significant changes observed in the soil biota, it would be beneficial to further study any effects on the functionality of these organisms under this fertiliser.

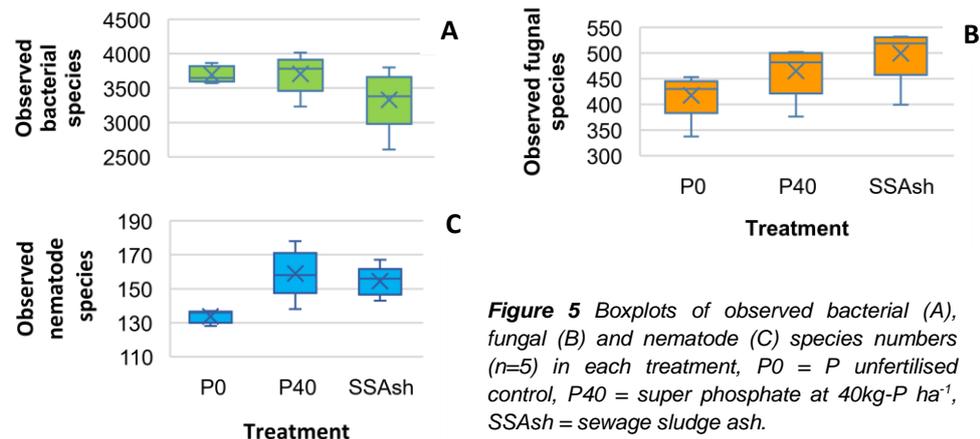


Figure 5 Boxplots of observed bacterial (A), fungal (B) and nematode (C) species numbers (n=5) in each treatment, P0 = P unfertilised control, P40 = super phosphate at 40kg-P ha⁻¹, SSAsH = sewage sludge ash.

Legal aspects

Ash that is derived from the incineration or gasification of sewage sludge is legally considered a waste product. It has to be authorised to be used as a recovered fertiliser product.

Ash as an EU fertilising product with CE marking

The revised EU Fertilising Products regulation 2019/1009 (applies from 16 July 2022) allows the use of sewage sludge ash from the incineration (but not gasification or pyrolyses) of sewage sludge as a component for the production of EU fertilising products. The criteria are laid down in the CMC 13 Thermal oxidation materials. Conditions for the processing have to be followed, and threshold levels are set for organic contaminants, hazardous properties, Cr Tl, Cl V. The ash must be REACH registered. Ash as a CMC material is still considered waste and all prerequisites and requirements from Waste Framework Direction and Waste Shipping Regulation apply. The EU fertilising product that is produced from ash has to meet the criteria of an EU Product Function Category (PFC). These include minimum contents of nutrients, and threshold levels for heavy metals and arsenic. After conformity assessment procedure, involving controls from a certified 'notified body' the product may be labelled with the CE marking and has obtained the End-of-Waste status. EU fertilising products with CE marking may be traded throughout the internal EU market without any additional restrictions or requirements at the national level.

Sewage sludge ash as a National fertiliser without CE marking

Ash that does not meet all requirements of the EU 2019/1009 or for which the producers do not want to go through the conformity assessment procedure for CE marking may be brought to the market as a national fertiliser if they comply with the national fertiliser regulations. In the Netherlands, ash does not meet criteria for heavy metals for mineral fertilisers and is not authorised. In Belgium, ash has to obtain a derogation as fertiliser which is specific for a producer and production site. Germany allows certain ashes from specific sources to be used for the production of mineral fertilisers. In France, ash products have to obtain a producer specific derogation ('homologation') which requires an extensive application dossier. In Ireland, sewage sludge is land spread, not incinerated and use of ashes is not regulated.



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Poultry litter ash

Technology description

Animal manure, like poultry litter, can be incinerated. BMC Moerdijk, a company in the Netherlands, produces green energy by incineration of approximately 420,000 tonnes of poultry manure per year (Figure 1). This is about a third of the total quantity of poultry litter produced each year in the Netherlands.

The manure that arrives at the plant from 600 poultry farms is first mixed thoroughly to obtain a homogenous feedstock prior to incineration. The incineration process is performed at temperatures reaching 1000°C. The steam generated in the turbine runs the generator, producing ~290 000 MWh electricity. The flue gases are

eventually cooled, filtered and cleaned. The produced phosphorus (P) and potassium (K)-rich poultry litter ash (Figure 2) is mainly exported to England, France and some other countries.



Figure 2 Poultry litter ash produced by BMC Moerdijk.

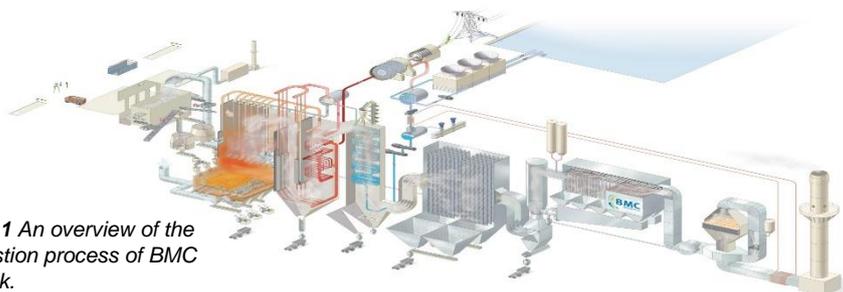


Figure 1 An overview of the combustion process of BMC Moerdijk.

Product characteristics

The poultry litter ash (PLAsh) from BMC was analysed for physicochemical and biological parameters (Table 1).

Physicochemical analyses

Owing to the thermochemical nature of processing, the PLaSh has a high dry matter content, pH-water of 12-13 and a low electrical conductivity. The PLaSh is a P-rich product with considerable amounts of other plant nutrients like K, S, Ca and Mg, and negligible N content. Although, heavy metals of concern like Cd, Pb, As, etc. are present in very low concentrations (below prescribed legal limits (EU Fertilising Product Regulation 2019/1009)), total metal content in the product of Zn, Fe, Al, etc. was found to be high. To understand the implications of the higher metal content, its plant-availability and uptake should be monitored and studied.

Biological analysis

Plate count methods showed that no bacteria or fungi of an aerobic, mesophilic nature were present in PLaSh samples. Tests performed for the detection of the pathogens *Salmonella* spp. and *Listeria*

spp. confirmed their absence per 25g of PLaSh. Enumeration methods employed for the pathogens *Escherichia coli* and *Campylobacter* spp. exhibited <10 colony forming units per g of PLaSh. These results comply with the EU Fertilising Products Regulation 2019/1009.

Table 1 Physicochemical and biological (expressed on fresh weight basis if not indicated otherwise) characteristics of the ash produced by incineration of poultry litter.

Physicochemical analyses			
pH (water)	12 - 13	Total Zn (mg/kg DM)	1 417 - 1 940
pH (KCl)	12	Total Fe (mg/kg DM)	3 490 - 4 633
EC (mS/cm)	41	Total Cu (mg/kg DM)	296 - 417
DM (%)	94 - 100	Total Al (mg/kg DM)	4 850 - 7 459
Total N (g/kg)	0.15 - 4.0	Total Cr (mg/kg DM)	14 - 20
NO ₃ ⁻ -N (g/kg)	<0.01	Total Mn (mg/kg DM)	1 417 - 1 915
NH ₄ ⁺ -N (g/kg)	<0.15	Total Ni (mg/kg DM)	17 - 22
Total P (g/kg)	53 - 55	Total Co (mg/kg DM)	2.5
Total K (g/kg)	95 - 134	Total Cd (mg/kg DM)	0.69 - 0.98
Total S (g/kg)	26 - 31	Total Pb (mg/kg DM)	7.3 - 37
Total Ca (g/kg)	153 - 166	Total As (mg/kg DM)	<1.5
Total Mg (g/kg)	29 - 35	Total Mo (mg/kg DM)	12 ± 2.4
Biological analyses			
Bacterial load (CFU/g)	n.d.	<i>Listeria</i> spp. present or absent/25g	Absent
Fungal load (CFU/g)	n.d.	<i>E.coli</i> (CFU/g)	<10
<i>Salmonella</i> spp. present or absent/25g	Absent	<i>Campylobacter</i> spp. (CFU/g)	<10

EC: electrical conductivity; DM: dry matter; CFU: colony forming unit

Agronomic aspects

A field-scale agronomic trial in a sandy loam soil temperate grassland with a low soil plant available P level was conducted by Teagasc in Ireland. The goal was to assess the mineral phosphorus (P) fertiliser replacement value (PFRV) and crop yield performance of PLash at 40 kg P/ha in comparison to reference super phosphate at 40 kg-P ha⁻¹ (P40) as well as a P free control (P0 treatment). The PFRV (%) was determined by using the following equation:

$$\frac{(P \text{ uptake PLash} - P \text{ uptake CON}) / \text{total P applied PLash}}{(P \text{ uptake REF} - P \text{ uptake CON}) / \text{total P applied REF}}$$

where PLash = ash treatment, CON = P unfertilised treatment and REF = synthetic fertiliser reference (i.e. super phosphate). The experimental design was a randomised complete block with five replications. Grass yield and P uptake were assessed in 2019 and 2020 with 4 harvests per year.

Biomass dry yield was not statistically different between mineral P40, PLash and P0 control in both 2019 and 2020 harvests. However, P uptake was found to be more sensitive to treatment differences by taking into account crop P concentration and biomass yield. P uptake and concentrations

in PLash treatment were significantly lower over the year in 2019 when compared to super phosphate (P40) and shared some overlap with P0 control results (Table 2). Apparent P recovery (APR (%)) = (P uptake treatment – P uptake CON)/total P applied treatment) from PLash plots over 2019 was up to 6% and therefore substantially lower than for superphosphate (15%). The APR of PLash increased when considering the second year of 2020 to 12% and as such the PFRV of PLash increased from 39% in the 1st-year to 71% when considering two years (Figure 3). The findings indicate that there is limited immediate P availability in PLash but potential for residual P availability over the 2nd year and perhaps longer.

Table 2 P uptake and concentrations in herbage for 2019 and 2020. P0 = P unfertilised control; P40 = super phosphate at 40 kg-P ha⁻¹; PLash = poultry litter ash. Mean values denoted by the common letter are not statistically different at the 5% probability level.

Treatment	Cumulative P uptake (kg/ha)		Mean P concentration (%)	
	2019	2020	2019	2020
P0	26.2 ^b ± 4.1	29.4 ^a ± 1.1	0.22 ^b ± 0.02	0.22 ^a ± 0.01
P40	32.3 ^a ± 3.7	30.2 ^a ± 3.2	0.25 ^a ± 0.01	0.23 ^a ± 0.02
PLash	28.6 ^b ± 5.5	31.9 ^a ± 2.8	0.23 ^b ± 0.03	0.23 ^a ± 0.02

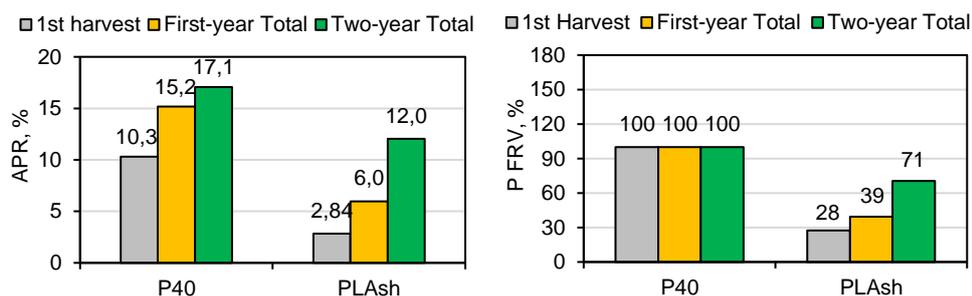


Figure 3 Apparent P recovery (APR) and P Fertiliser replacement value (PFRV). P40 = super phosphate at 40 kg-P ha⁻¹; PLash = poultry litter ash.

Environmental aspects

In order to assess the effect of PLash on the environment, during the field trial duration an environmental monitoring campaign was conducted in regard to: i) soil test P levels, ii) the capacity to cycle P and iii) effect on microbial and nematode communities.

Soil test P levels

Plant available soil P (via Morgan's extracting reagent) decreased significantly for P0 treatment when pre- and post-harvest soils were compared, while this was not different for P40 and PLash (Figure 4). The results indicate that the crop removal of P (up to 32.3 kg ha⁻¹ in the 1st year) across treatments was replenished by P applications. This contrasts with the P0 treatment where the plant removal of 26.2 kg ha⁻¹ led to plant available soil P reduction of 1 mg/L (33% drop) compared to their initial levels.

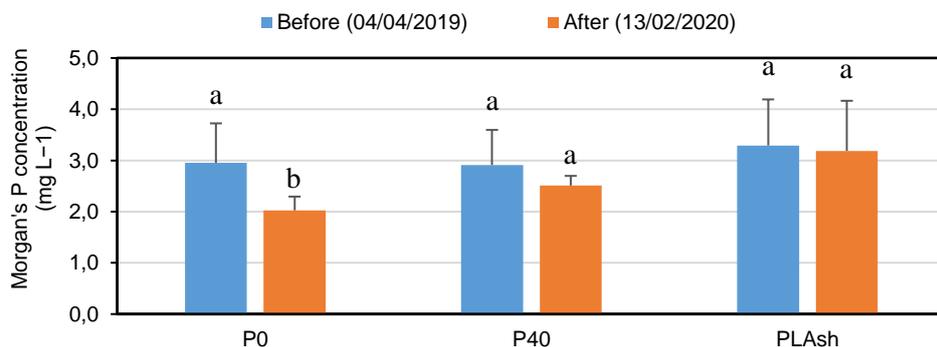


Figure 4 Pre- and post-harvest comparison of crop available Morgan's P concentrations across treatments. P0 = P unfertilised control; P40 = super phosphate at 40 kg-P ha⁻¹; PLash = poultry litter ash. Mean values denoted by the common letter are not statistically different at the 5% probability level.

Biological analysis – P cycling

In soils, approximately 99% of the P is not directly plant available but immobilised in either organic or inorganic forms. Soil microbes play a key role in making these P sources available. The capacity to cycle P in the fields fertilised with PLash has been compared to that of synthetic reference and unfertilised P control. This was done by assessing the soil enzymatic capacity, the ability of soil bacteria to release P, the abundance of bacterial genes, quantifying the bacteria with the capacity to release P and analysing P cycling genes.

Poultry litter ash

In the grassland field trial, only minor changes were identified in the soil enzymatic activity, which was largely related to a moderate pH change caused by PLAsh. Likewise, PLAsh application increased the abundance of calcium-phosphate solubilising bacteria when compared to superphosphate. Furthermore, the diversity of the phosphatase genes differed between the superphosphate and PLAsh treatments in 2020. In summary, no negative effects were identified on the natural ability of soil microbes to cycle P when PLAsh was used. The overall findings suggest that PLAsh use may have a long-term beneficial effect on the ability to cycle P more efficiently when compared to superphosphate.

Microbial and nematode communities

The response of soil bacterial, fungal and nematode communities to the application of PLAsh in 2020 grass field trial were analysed using high throughput DNA sequencing technologies, and compared against control treatments (i.e. super phosphate and P unfertilised control).

Equal levels of bacterial diversity were observed in PLAsh treated soil when compared to control treatments (Figure 5A). However, fungal species diversity significantly increased (Figure 5B), resulting in a significant shift in community structure. This indicated that optimum conditions for otherwise dominating fungal species may have changed, or suppressed their growth, allowing less competitive fungal species to survive. The order of dominating bacterial phyla was also altered in soil fertilised with PLAsh. Results showed nematode diversity was maintained in soil fertilised with PLAsh (Figure 5C) and nematode communities similar to those resulting from the application with super phosphate control. Due to the changes observed in bacterial and fungal communities, further study of any effects on microbiome functionality in soil fertilised with PLAsh would be useful to provide additional insight into its ecological safety.

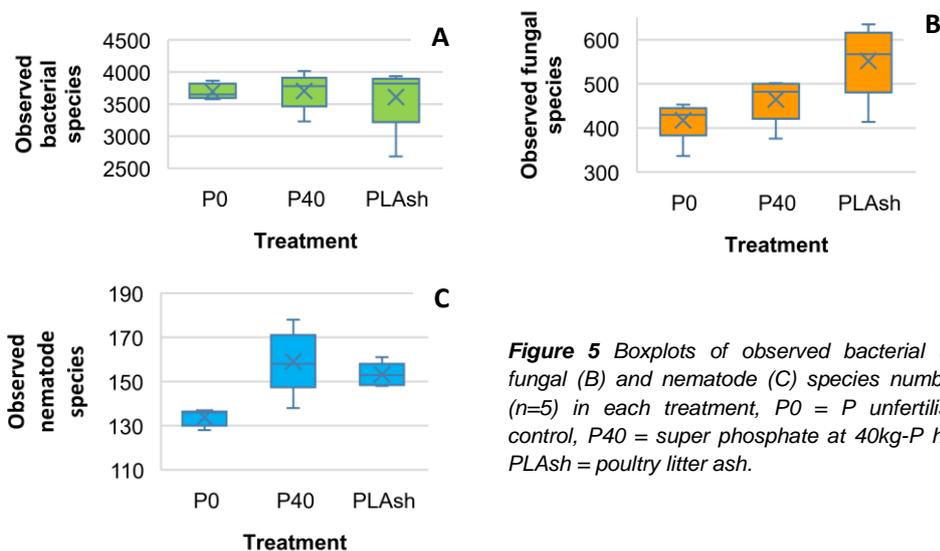


Figure 5 Boxplots of observed bacterial (A), fungal (B) and nematode (C) species numbers ($n=5$) in each treatment, P0 = P unfertilised control, P40 = super phosphate at 40kg-P ha⁻¹, PLAsh = poultry litter ash.

Legal aspects

Ash that is derived from the incineration of manure or sludge is legally considered a waste product. It has to be authorised to be used as a recovered fertiliser product.

Ash as an EU fertilising product with CE marking

The revised EU Fertilising Products regulation 2019/1009 (applies from 16 July 2022) allows the use of ash from manure incineration as a component for the production of EU fertilising products. The criteria are laid down in the CMC 13 Thermal oxidation materials. Conditions for the processing have to be followed, and threshold levels are set for organic contaminants, hazardous properties, Cr, Ti, Cl, V. The ash must have been REACH registered. Ash from manure incineration also needs to have reached an End-point of the manufacturing chain under the ABP (animal by-product) regulation, which has not yet been declared but is expected for 2022. Ash as a CMC material is still considered waste and all prerequisites and requirements from Waste Framework Directive and Waste Shipping Regulation apply. The EU fertilising product that is produced from ash has to meet the criteria of an EU Product Function Category (PFC). These include minimum contents of nutrients, and threshold levels for heavy metals and arsenic. After conformity assessment procedure, involving controls from a certified 'notified body', the product may be labelled with the CE marking and obtain the End-of-Waste status. EU fertilising products with CE marking may be traded throughout the internal EU market without any additional restrictions or requirements at the national level.

Ash as a National fertiliser without CE marking

Ash that does not meet all requirements of the EU 2019/1009 or for which the producers do not want to go through the conformity assessment procedure for CE marking may be brought to the market as a national fertiliser if they comply with the national fertiliser regulations. In the Netherlands, ash does not meet criteria for heavy metals for mineral fertilisers and is not authorized. In Belgium, ash from manure has to obtain a derogation as fertiliser which is specific for a producer and production site. Germany allows certain ashes from specific sources to be used for the production of mineral fertilisers. In the UK ashes from poultry manure can be used as a mineral fertiliser. In France, ash products have to obtain a producer specific derogation ('homologation') which requires an extensive application dossier. In Ireland, standards and norms for use as fertiliser are part of the waste management certificates of producers.



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Household biowaste compost

Household Biowaste Compost

Technology description

In the Netherlands composting of biowaste is only carried out for source separated biowaste. The input material comprises of source-separated biowaste from households but also green cuttings and catering waste as well as waste streams from the food industry.

Nowadays, about one third of the collected household biowaste volume is treated by anaerobic digestion (AD) before composting. Four of the seven installations of Attero are equipped with AD to produce biogas. At two facilities the biogas is upgraded to green gas by removing impurities and carbon dioxide.

For composting, tunnels, large indoor halls and open-air composting are in use.



Figure 1 2-Phase anaerobic digestion at a location of Attero (Venlo) in the Netherlands.

Product characteristics

Compost from household biowaste (HHB) has a high dry matter (around 60%) and organic matter content, whereas nutrient concentration is rather low (Table 1). For that reason it is considered to be a soil improver, more than an organic fertiliser. During composting, the organic matter from the HHB is stabilised, by the conversion of easily decomposable organic matter. This results in a product with a high content of stable organic matter (Figure 2).



Figure 2 Compost from household biowaste.

Mature compost does not contain a lot of nitrogen and most of it is in organic form, and not immediately plant available. At maximum, 10% of the total N is ammonium-N. Compost contains a relatively low amount of phosphorus (P) in comparison to raw animal manure. The potassium (K) content is

relatively high and fully available for plant uptake. That should be taken into account, when using compost in a fertilisation plan.

Maximum allowed contents of heavy metals, organic micropollutants and other impurities like glass, plastic and/or stones are formulated in legislation and certification schemes. In this way, a safe use of HHB compost is guaranteed.

Further innovations for potting soils

At a location of Attero (Venlo) in the Netherlands, a 2-phase digester is running: in a first step, fatty acids are extracted from the HHB, in a second step this enriched water is digested. As an in-between step, salts are washed out which makes the organic substrate a valuable peat-replacement for potting soil (Figure 3).



Figure 3 Compost of Attero being used for potting soils.

Requirements for compost to be used as an organic substrate for potting soils are that it needs to be specifically low in salt content as well as clean in terms of weed seeds, plant pathogens and impurities. Attero is the first producer internationally who is producing this type of substrate on a large scale.

Table 1 Physicochemical characteristics of compost from household biowaste reported in ranges according to analyzed batches during ReNu2Farm project.

Parameters	Result
Dry matter (%)	64 - 70
Organic matter (%)	24 - 40
Total Cl (g/kg)	0.4 - 1.5
Electrical conductivity (mS/cm)	2.8 - 3.3
pH	7.7 - 8.0
Total N (g/kg)	8.9 - 9.8
NO ₃ ⁻ -N (g/kg)	0.8
NH ₄ ⁺ -N (g/kg)	0.0
Total P ₂ O ₅ (g/kg)	2.1 - 5.1
Total K ₂ O (g/kg)	6.7 - 8
Total SO ₃ (g/kg)	3.5 - 4.4
Total CaO (g/kg)	20 - 26
Total Na ₂ O (g/kg)	1.6 - 2.0
Total MgO (g/kg)	2.7 - 5.3

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Agronomic aspects

An important agronomic aspect of HHB compost is the supply of stabilised organic matter. From scientific literature it is known that between 5 and 10% of the organic matter is decomposed in the first year after application. The consequence is that 90-95% of the organic matter supplied with the compost is still in the soil one year after its application (the so called 'humification coefficient'). The high humification coefficient of HHB compost can play a significant role in organic matter supply and carbon sequestration in the soil, which is of relevance within the scope of climate mitigation measures.

Another important aspect is the amount of N that is available for crop uptake (i.e. Nitrogen Fertiliser Replacement Value (NFRV)). From literature data it is known that the NFRV in the first year after application is about 10-15%. However, this can vary largely and depends on the C/N-ratio of the compost, the climate, and the soil type and pH. At short-term (in first weeks/months after application), N can also be immobilised, especially if the C/N ratio of the compost is high (>25:1). The net N effect in the first year can vary between -15 to +15%. Total long-term NFRV (after 5-10 years) should be assumed to be 40% but can vary as described above.

Environmental aspects

Because compost contains large amounts of ineffective N (present in the stabilised organic matter), surpluses at the N balance after the use of compost are generally high. The question is whether this ineffective N will remain in the soil or gets lost by nitrate leaching. This question has also been studied in the 3-year lasting field experiments described above (Figure 5).

The differences in residual Nmin contents between treatments were not significant due to large variations between replicates. It was concluded that the high surpluses at the N balance after the use of compost, did not lead to increased nitrate leaching within three

in field experiments that were carried out at two locations (Heelsum and Harreveld) with maize on sandy soils in the Netherlands between 2018 and 2020, the effect of several fertiliser strategies on organic matter content, crop yield and crop quality were compared. Two treatments contained HHB compost (in 2 doses) and those treatments were compared with a control treatment without organic matter supply, and treatments with cattle slurry, verge grass clippings and cattle slurry combined with verge grass clippings. The nutrient supply was kept the same in all treatments, by the addition of mineral fertilisers.

Results of the measured organic matter content in the first and last year are given per treatment for both locations in Figure 4. OM content in the treatments with the high compost dose tended to be higher than the other treatments, but differences were not significant. From a model simulation over 100 years, it became clear that the treatment with the high compost dose resulted in a higher organic matter content as compared to other treatments (Figure 4).

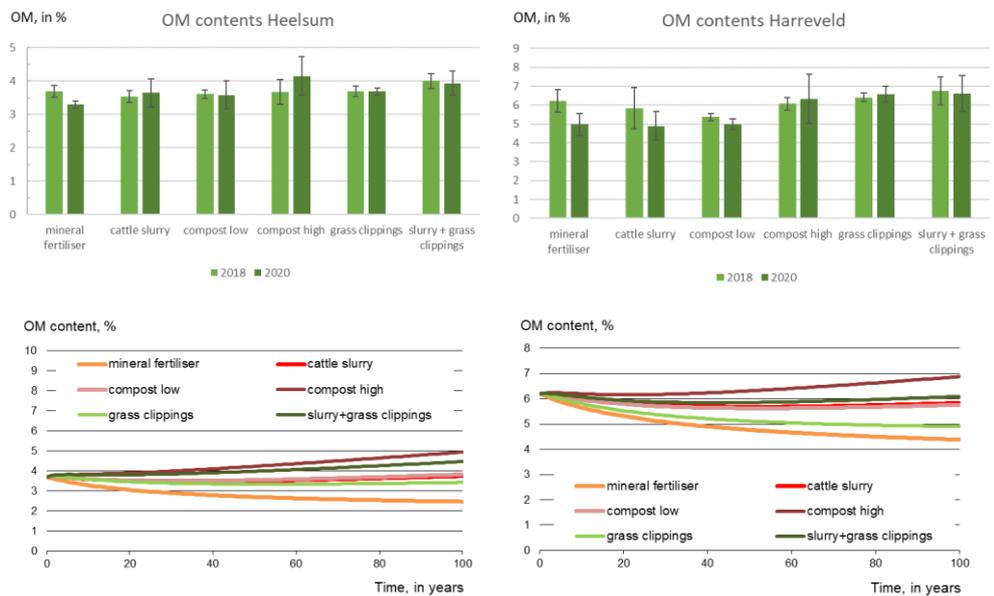


Figure 4 Measured (above) and simulated (below) organic matter (OM) contents per treatment for location 1 (left) and 2 (right).

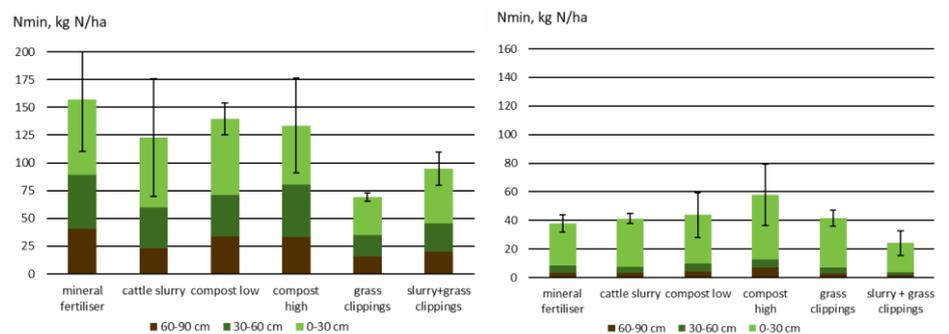


Figure 5 Measured residual nitrate contents in the 0-90 cm deep soil layer per treatment for a dry unirrigated location 1 (left) and an irrigated location 2 (right) in 2020.

years after repeated application. Differences in residual Nmin content were quite large between the irrigated and unirrigated locations, due to large differences in yield, N uptake and surpluses at the N balance between locations.

Household Biowaste Compost

Legal aspects

Compost that is produced from biowaste (including household waste) is legally still defined as a waste and has to be authorised to be used as an organic fertiliser or soil improver.

Compost as an EU fertiliser product with CE-mark

The revised EU Fertilising Products regulation 2019/1009 includes certain composts as a material for the production of EU fertilising products. Compost has to meet the requirements of the component material CMC 3 Compost. Household waste has to be source-separated (collected separately from other waste) to be used as input. The compost has to be treated aerobically according to the time-temperature regime in an approved establishment where no contact with other input or output can occur. Upper threshold levels are set for contaminants and impurities. The compost can be an EU fertilising product belonging to the product categories soil improver (PFC 3), growth medium (PFC4) or solid organic fertiliser (PFC1(A)(I)). Solid organic fertilisers have to meet minimum criteria for primary nutrients and organic carbon content, which should be of solely biological origin. EU fertilising products with organic matter may not exceed limits for pathogens and heavy metals and arsenic.

EU fertilising products with compost should have an extended conformity assessment from certified notified body. The compost can then be labelled with CE marking, by which it has reached the End-of Waste status. It can be handled and transported within the single internal market of the EU without any further restrictions or requirements at the national level.

Compost as national fertilising product without CE-mark

Compost that does not fully comply with the EU 2019/1009 or for which the producer does not want to go through the conformity compliance procedure can be put on the market as a national fertilising product. It will then have to meet the national requirements. Most countries recognise household compost as an organic fertiliser or soil improver. The procedures and criteria for compost differ between countries. For biowaste compost, a certification is obligatory in Flanders and UK. In the Netherlands, the compost has to comply with the Fertiliser Act but does not need certification. In Germany, compost may be used as soil improver if compliant with a set of rules, which can be reached with an authorised certification. In France, the compost must comply with NFU norms or have obtained derogation ("*homologation*"), otherwise it will be considered as a waste product and requires a spreading plan ("*plan d'épandage*"). In Ireland, standards and norms are part of the waste management certificates of producers.

Labelling requirements Animal By-Product (ABP) regulation

Household compost contains kitchen waste in which remains of animal foodstuffs are present. Therefore, the compost is considered an animal by-product category 3. The label should contain the following safety message for users:

- (i) 'organic fertilisers or soil improvers: no grazing of farmed animals or use of crops as herbage for at least 21 days following application'
- (ii) ABP category 3 material - 'not for human consumption'.



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Composted animal manure

Composted animal manure

(from different proportions of solid fraction of pig slurry and raw poultry manure)

Technology description

Composting is a conversion process under the influence of oxygen. The animal manure is broken down and stabilised in a process that generates heat leading to temperatures of 70°C for several days. This results in a hygienic carbon-rich product.

Currently, the Deleplanque society is prospecting in France and abroad to select compost that is the most adapted to the French farmers' needs. It commits to respect the latest standards in force, in accordance with the European and French laws. Therefore, the produced composts meet the requirements of the French standards NFU 42-001 and 44-051.



Figure 1 Composted animal manure

The produced compost (Figure 1) is commonly used as a soil improver to increase organic matter content and fertility by improving physical, chemical and biological soil fertility. The manure-based composts are very often used in organic farming (if raw materials are in compliance with organic farming regulations).

Composting animal manure gives some advantages in comparison to the raw manure: a homogeneous product, reduced sanitary risks, spreading can be done faster and transportation is less expensive in terms of nutrient content (the product is drier than the raw manure).

Composted animal manure remains under the legal status of animal manure but with specific adjustments and by respecting legal thresholds, it can be marketed.

Product characteristics

Three animal manure composts from Deleplanque were analysed for physicochemical and biological parameters (Table 1).

Physicochemical analyses

Composts are characterised by high dry matter content and high and stable organic matter content. Nutrients and heavy metals might be more concentrated than in non-composted manure. Nitrogen (N) remaining in the product is more stable: less available for crops at the short term.

Several analyses per composts were performed, highlighting some variabilities (shown via standard deviation) between batches and years (Table 1). Potassium (K) contained in compost has a good plant availability, similar to mineral fertilisers. Composts also contain sulphur (S), which might get partly lost as H₂S during the composting process.

Biological analyses

As expected, the total bacterial count method showed that 10⁴ – 10⁵ aerobic mesophiles were present per g of compost, while concentrations of fungal aerobic mesophiles ranged from 0 to 10⁴, increasing with pig slurry

content. High concentrations of aerobic microorganisms are expected in compost, given they are the main decomposers of the organic material.

Tests performed for detection of the pathogens *Salmonella* spp. and *Listeria* spp. confirmed their absence per 25g of all composts. Enumeration methods employed for the pathogens *Escherichia coli* and *Campylobacter* spp. exhibited <10 colony forming units per g in all composts. These results are in compliance with the EU Fertilising Products regulation 2019/1009.

Table 1 Physicochemical (mean and standard deviation of several analyses in period 2019-2020) and biological characteristics of three composts (expressed on fresh weight basis): compost 1 – 30% solid fraction (SF) of pig slurry and 70% raw poultry manure; compost 2 – 70% SF of pig slurry and 30% raw poultry manure; compost 3 – 100% SF of pig manure derived digestate.

	Compost 1	Compost 2	Compost 3
Physicochemical analyses			
pH water	8.6 ± 0.19	8.8 ± 0.27	9.0 ± 0.15
Dry matter (%)	38 ± 7.4	49 ± 15	42 ± 8.2
Total N (g/kg)	16 ± 2.2	21 ± 8.2	15 ± 2.9
NO ₃ -N (g/kg)	4.4 ± 1.8	4.2 ± 1.1	1.3 ± 1.1
NH ₄ -N (g/kg)	20 ± 3.5	19 ± 4.4	27 ± 6.5
P ₂ O ₅ (g/kg)	14 ± 2.8	21 ± 12	17 ± 9.1
K ₂ O (g/kg)	9.7 ± 1.0	8.6 ± 0.8	13 ± 2.6
MgO (g/kg)	26 ± 3.3	33 ± 8.7	28 ± 3.2
Organic matter (%)	50 ± 14	44 ± 2.5	69 ± 6.5
IROC (% of OM)	8.6 ± 0.19	8.8 ± 0.27	9.0 ± 0.15
Biological analyses			
Bacterial load (CFU/g)	3.6 x 10 ⁴	7.2 x 10 ⁵	4.7 x 10 ⁴
Fungal load (CFU/g)	0	3.0 x 10 ¹	4.9 x 10 ⁴
<i>Salmonella</i> spp. present or absent/25g	Absent	Absent	Absent
<i>Listeria</i> spp. present or absent/25g	Absent	Absent	Absent
<i>E.coli</i> (CFU/g)	<10	<10	<10
<i>Campylobacter</i> spp. (CFU/g)	<10	<10	<10

*IROC: indicator of remaining organic carbon; OM: organic matter; CFU = colony forming unit

Composted animal manure

(from different proportions of solid fraction of pig slurry and raw poultry manure)

Agronomic aspects

N fertiliser replacement value (NFRV) is a well-known indicator calculated to estimate N efficiency for organic products. Similarly, the phosphorus (P) efficiency of compost was investigated by determining P fertiliser replacement value (PFRV) as follows:

$$\frac{((P \text{ uptake}_{COM} - P \text{ uptake}_{CON}) / \text{total P applied}_{COM})}{((P \text{ uptake}_{REF} - P \text{ uptake}_{CON}) / \text{total P applied}_{REF})}$$

where COM = compost treatment, CON = no P applied control and REF = triple super phosphate as mineral P fertiliser reference. The aim was to express the efficiency of the P in compost in terms of a well-known reference fertiliser. The yields and the absorption of P by the crops were studied in lab trials by pot experiments and in field trials. Results from the field trials are presented in Figure 2 and results from pot trials are presented in Figure 3.

Three field trials were run on spring barley plots with soils with a low content of P₂O₅ Olsen (<25ppm). Two out of the three trials showed a response to P inputs (Figure 2). For both trials, compost application led to an increase of yield in comparison to the control (i.e. no P fertilisation). The yield increase was significant for two composts in trial 1 and for one compost in trial 2. Compost application also led to a yield improvement in comparison to the mineral fertiliser reference. In the field trials, the efficiency of P fertilisers was quite low in general. This might lead to an overestimation of the PFRV of the composts. Therefore, results from field trials are not presented here.

One pot trial was conducted in laboratory conditions, on ray grass. The efficiency of P fertiliser was better than in field condition but still quite low with apparent P recovery (= (P uptake_{REF} - P uptake_{CON}) / total P applied_{REF}) of 13% for mineral P reference. Results of

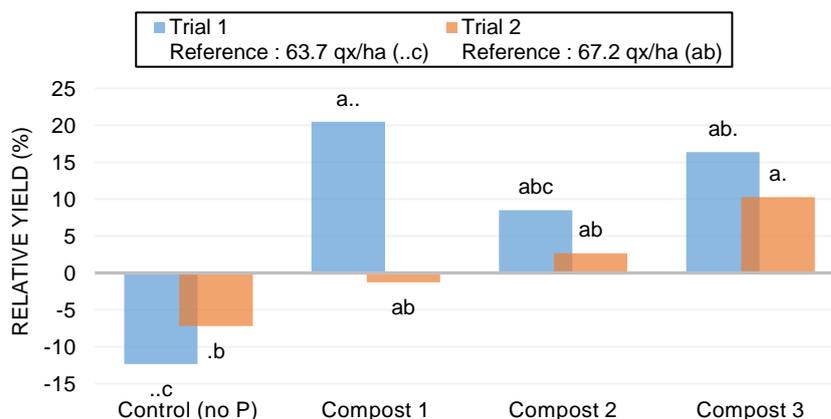


Figure 2 Relative yield of spring barley fertilised with three different composts at a dose of 100 kg P₂O₅/ha. 0 represents the yield of the reference plot where a triple super phosphate was applied. Values above 0 represent the % of yield gain in relation with the reference plot and values under 0 represent the % of yield loss. Letters above the histograms represent the statistical groups, obtained for each of the trials individually. Compost 1 – 30% solid fraction (SF) of pig slurry and 70% raw poultry manure; compost 2 – 70% SF of pig slurry and 30% raw poultry manure; compost 3 – 100% SF of pig manure derived digestate.

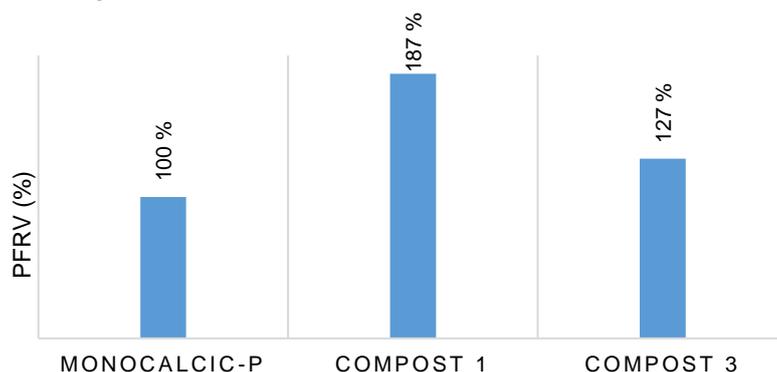


Figure 3 PFRV (%) of the composts studied in pot trials. P-FRV is calculated in comparison with monocalcic P on ray grass pot cultivation. Compost 1 – 30% solid fraction (SF) of pig slurry and 70% raw poultry manure; compost 3 – 100% SF of pig manure derived digestate.

PFRV from the pot trial are presented in Figure 3, but should not be used as is before additional validation.

As a conclusion for the different trials conducted on the composts, for an equivalent amount of P inputs, composts tend to show a good P efficiency, better than the control (without P) but it is not always significantly better than the reference mineral P fertiliser. It should also be noted that there is a variability in the composts according to the batches tested. This can be seen in the composition variability (Table 1), and is also reflected in the field results.

Environmental aspects

Organic matter

Because composts are often used to improve soil organic matter content, it is of interest to look at this effect. It is, however, not possible to measure an impact of the products on changes in soil organic carbon (SOC) in short-term field trials. Therefore, a simulation of the SOC evolution was done with the AMG model to highlight differences between products. The composition (C content) and type of carbon (stable or labile) present in composts are inputs of the model and influence the final simulation results. Figure 4 represents the results of one simulation where SOC content (in tonne ha⁻¹) evolution is shown for 30 years for the tested composts and unfertilised control in the conducted field trials. For the simulations, 5.3 tonnes of composts were applied per hectare every 4 years. This application amount was chosen as it is close to the amount of

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compost applied in the ReNu2Farm field trial. After 30 years of this application strategy, all simulations with applied composts showed a higher amount of SOC content compared to the simulation without organic product. We can see that at the long-term scale, SOC is decreasing in the no organic product strategy. The SOC content is also decreasing for the compost strategies, but to a lower extent while still managing to maintain the SOC content in the soil.

It should be noted that the absolute value of SOC stocks for the 30th years could be different for another field trial, depending on the soil type and climate; but the ranking between control (no organic product applied) and composts will remain the same. Specific simulations can be done by farmers who want to estimate the effect of their organic product application in their own field.

Heavy metal residues

In the field trials, composts were applied at the advised calculated dose (100 kg P₂O₅/ha). Nickel (Ni), Lead (Pb), Zinc (Zn), Cadmium (Cd), Chromium (Cr), Copper (Cu) and Mercury (Hg) were analyzed in soil samples (0-30cm; one month after harvest). Differences between treatments were quite low and not significant. This indicates, for the doses applied, few risks of pollution by accumulation of heavy metals in the soil, in the year of application.

Legal aspects

Composted manure is considered as a processed animal manure. The rules and prerequisites for Animal By-Product (ABP) regulation category 2 materials apply. This means that all actors, actions (transport, handling, processing, distributing) and materials (plants, vehicles, storage sites) from farm to the end user are subject to notifications, registration, approval and controls. Under the ABP regulation, the composted manure can be applied to land as an Organic Fertiliser or Soil Improver (OF&SI) provided that it has been processed and hygienised in an approved or registered establishment or plant, and that it meets the transformation parameters (time- temperature-pressure and particle size). In some countries, composted manure needs to comply with the criteria laid down in the national fertiliser regulations on nutrient contents and thresholds for heavy metals and contaminations: in France for fertilisers (NFU 42-001) or organic amendments (NFU 44-051), in Germany for organic fertilisers.

The application to land of composted manure is further regulated by the Nitrates Directive and country specific Action programmes. The use of animal manure has an application limit of 170 kg N ha⁻¹ y⁻¹ in the Nitrate Vulnerable Zones, the so-called application limit. In the country specific Nitrate Action programmes further requirements are set for the storage and time period and methods of land application.

The revised EU Fertiliser Product regulation 2019/1009 includes certain composts as a material for the production of an organic fertiliser (PFC 1) or soil improver (PFC3). However, this does not yet include composted manure or other compost from animal origin. Only animal-derived materials which have reached the so-called 'End point of the manufacturing chain' and are listed as component (CMC 10) will be allowed as input for the production of EU fertilising products with CE marking. No End-point has been defined yet in the ABP regulation for composted manure.

Labelling requirements Animal-by Product regulation

The label should contain the following safety message for users:

- i) ABP category 2 material - 'not for human or animal consumption, and
- ii) 'organic fertilisers or soil improvers: no grazing of farmed animals or use of crops as herbage for at least 21 days following application.

Soil organic carbon evolution

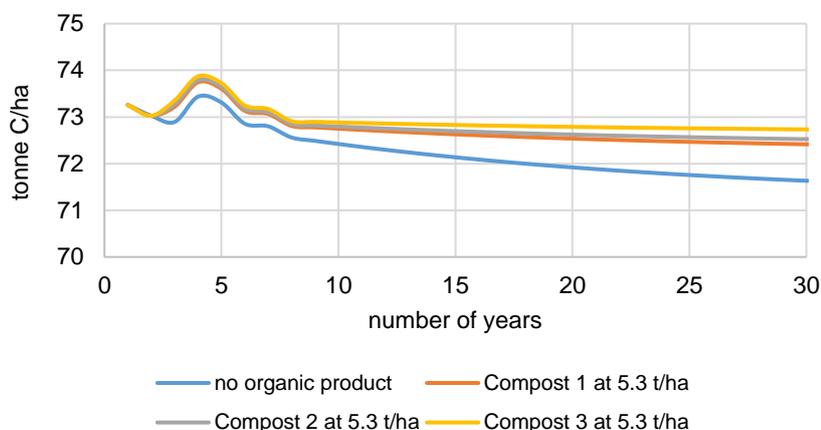


Figure 4 Results of SOC evolution (tonne C/ha) simulated with AMG model, presented for 30 years for the soil depth of 0-30cm.

The long-term effect on accumulation should be further assessed. Also, in some countries (i.e. France, Germany) thresholds for heavy metals content in composts and in fluxes are defined. Producers and users of compost should consult the thresholds before product application.



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