ifs

International Fertiliser Society

ADVANCES IN COMMERCIAL SCALE PRODUCTION OF BIO-BASED NPK FERTILISERS FROM WASTE STREAMS

by

Cinta Cazador[1], Antonio Morán[2], Isabel San Martín[2], Esteban Serrano[3], Víctor Monsalvo[3], Jaime Ezquerra[4] and Javier Brañas[1]

[1] Fertiberia S.A., Madrid (Spain).
[2] Chemical and Environmental Bioprocess Engineering Group, University of Leon, Leon (Spain).
[3] FCC Aqualia, Madrid (Spain).
[4] FCC Medio Ambiente, Madrid (Spain).

Proceedings 876

Paper presented to the International Fertiliser Society at a Conference in Cambridge, UK, on 8th December 2022.

www.fertiliser-society.org

ISBN 978-0-85310-513-8
(ISSN 1466-1314)

SUMMARY.

Turning waste into resources is key to a circular economy. The recovery of bio-waste is generating numerous possibilities to produce chemicals, fuels and valuable products. However, there are still technological and market challenges before achieving large-scale commercialisation of the developed products can be achieved. In this sense, the B-FERST project was born with the idea of developing a novel industrial process focused on establishing an innovative concept for the fertiliser industry through a new waste value chain based on nutrient recovery towards bio processes. This innovation, to be introduced into existing industrial processes is intended to replace part of the mineral raw material used currently by a biobased material with a complex matrix influence.

A number of factors have been identified as being the most important in influencing in the use of these new biowastes: quality, regulation, security, processing feasibility, logistics-availability, product stability, economic feasibility and carbon footprint.

A new versatile nutrient extraction process has been validated at pilot plant scale, and is currently being upscaled into a demonstration plant with 500 kg/h capacity at Fertiberia’s facilities in Huelva Plant (Spain). This process uses as raw material ashes produced in the combustion of sludges from Waste water treatment Plants, manure or slaughterhouses. It works in a closed circuit to be environmentally sustainable without generating liquid effluents. The designed reactor allows heat exchange that makes the application of energy to the process unnecessary.

Likewise, a new flexible coating demonstration plant is currently being built, using the results from the pilot plant scale, validating the application of biodegradable materials in the fertiliser’s surface, enhancing their agronomic efficiency.

The replacement of part of the conventional mineral raw materials with bio-based material as nutrient sources and Non-Microbial Plant Biostimulant (NMPB) or Microbial Plant Biostimulant (MPB) additives has been demonstrated in the pilot plant scale fertiliser manufacturing process.

CONTENTS

Keywords: bio-based fertilisers, circular economy, recycling, nutrient recovery.

1. INTRODUCTION.

The European Union (EU) aims to promote sustainability through the European Circular Economy Package and in this way the relationship between farmers and bio-based industries is an important objective. The EU depends strongly on non-renewable external resources for the supply of key fertilisers used in agriculture, and on the other hand EU waste management policies aim to reduce the environmental and health impacts of waste and improve resource efficiency (FAO, 2015).

Turning waste into resources is key to a circular economy. Biowaste valorisation is an attractive approach which can offer potentially useful alternatives for dealing with residues. Basic valorisation strategies, including composting, reusing and incineration, are well known and accepted worldwide practises which, however, are only able to recover/convert a fraction of the waste into useful products. Valorising biowaste components could in fact lead to numerous possibilities to produce valuable chemicals, fuels and products. Therefore, these strategies can diversify the generation of multiple products from a single feedstock. However, critical technological, political and market challenges remain before full-scale commercialisation of the developed products can be achieved.

Consequently, the fertiliser industry and farming sector must answer the challenge in a sustainable way, increasing its productivity and the efficient use of nutrients. The industry, therefore, must collaborate in this challenge by producing fertilisers that provide specialised nutrients and with a personalised dosage adapted to the needs of the farmer.

Due to concerns about the rate of consumption and limited reserves, mainly in EU countries, it is urgent to recover P from urban and industrial flows. One of the most promising recovery strategies is based on thermal treatments (e.g. incineration or sludge pyrolysis) followed by leaching, precipitation and chemical adsorption (Santos *et al.*, 2021).

Currently, a large part of the phosphorus recovery processes is based on crystallisation or precipitation of the supernatant of the Waste water treatment plant (WWTP) digester to recover struvite. The recovery rate of phosphorus from the liquid phase is lower (10–60% from the WWTP influent) than from the sludge (35–70%) and from the sludge ash (70–98%) (Chrispim *et al.*, 2019). Also, other investigated processes use Municipal Solid Waste (MSW) incineration ashes as a possible source of phosphorus using acidic leaching–precipitation or and acidic–alkaline leaching (Kalmykov and Karlfeldt, 2013).

From this foundation the B-FERST project was born.

The most important points to consider are:

i) Sustainable and more efficient use of resources. The farming and fertiliser sectors must act together to achieve more sustainable management programmes as the fertiliser sector supplies products to about 12 million farms in the EU, to fertilise approximately 175 MHa of agricultural land, directly employing around 130.000 people (EC, 2016). This situation makes it essential to ensure the availability of plant nutrients resources at affordable prices to safeguard the sustainability of the agricultural systems.

ii) Efficient sourcing, cost-effective logistics. At this moment, improved logistics are required for a green circular approach. For this issue, diversity is the key. The next generation of fertiliser plants must deal with multiple biomass feedstocks, either via a single process or through a combination of several integrated ones. Recycling and the use of wastes must be sourced in terms of collection, storage, transport, and pre-treatment, taking into account biomass volumes and location.

iii) Maintenance or improvement of soil quality and, if possible, an improvement in fertilisation through the products obtained in the new manufacturing processes. Products made using traditional inorganic fertilisers or with materials obtained from residues are improved by adding soil stimulants such as Non-Microbial Plant Biostimulant (NMPB), or by introducing beneficial microorganisms (MOs) into the soil to transform in-situ the non-available nutrients present into forms that plants can absorb by Microbial Plant Biostimulant (MPB).

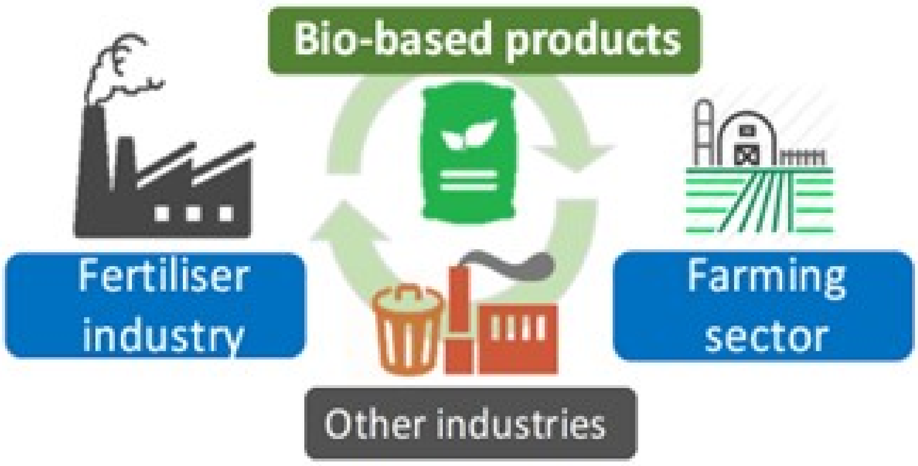

Figure 1: *New circular interaction between farmers, fertiliser and bio-based industries.*

In this sense, the new industrial process to be developed is focused on establishing a new concept of the fertiliser industry through a new waste value chain based on nutrient recovery towards bio processes. The innovation to be introduced to existing industrial processes is intended to replace part of the mineral raw material currently used by a biobased material with a complex matrix influence.

2. OBJECTIVE.

B-FERST's main objective is to integrate the valorisation of bio-wastes in agriculture management plans to create new circular and bio-based value chains from bio-waste, municipal waste management and agri-food industries into the fertiliser value chain, considering a bilateral interaction between the farming and fertiliser sectors. It is focused on a paradigm shift in the fertiliser value chain, with specialised fertilisers that combine biowastes with available nutrients, biostimulants and biodegradable coatings. For this reason, a nutrient recovery demonstration plant and a bio-coating demonstration plant are currently being built at Fertiberia's facilities in their Huelva Plant (Spain).

3. BIO-WASTES SELECTION CRITERIA TOWARDS INDUSTRIAL IMPLEMENTATION.

Europe faces great challenges: first, in the EU regions, large amounts of nutrient-rich currents are dispersing into the environment through a wide variety of both mineral residues (for example, phosphorus-P) and as organic. Second, the EU relies heavily on non-renewable external resources for the supply of key fertilisers used in agriculture.

Some of these sources of nutrients are included in secondary materials such as struvite, biowastes like ashes from different sources of agri-food industry waste and WWTP sludge and composts.

Complex NPK fertilisers often have a high nutrient concentration. Therefore, highly concentrated raw materials are also needed.

On the other hand, due to the NPK concentrated formulations, the percentage of filler material is low. This fact again reinforces the need to find nutrient concentrated biowastes or secondary materials.

As a result of considering the incorporation of new bio-based materials into the value chain of the fertiliser industry, a list of requirements has been identified as being the most influential on the success of using of these kinds of materials in conventional processes. They can be summarised as follows:

3.1. Quality.

Nutrient concentration and solubility are the main factors to consider after the identification of a potential biobased material. Nutrient concentration should be high enough to be able to incorporate at least 1-2% of N, P_2O_5 or K_2O within the NPK fertiliser. Furthermore, these nutrients must be available for plants: water soluble and/or soluble in neutral ammonium citrate, citric acid, etc. which will ensure the final nutrient quality in the new biobased NPK formulations.

3.2. Regulation.

New fertiliser regulation 2019/1009 (FPR) must also be part of the selection. Every biowaste should comply with the defined parameters depending on the kind of Component Material Categories (CMC), or even Product Function Categories (PCF).

Moreover, the national regulatory system should be also taken into account.

3.3. Security.

In this sense and having the current regulations as the basis, the importance of the absence of pathogens and a low heavy metals concentration, as well as compliance with other safety-related parameters, is clear.

3.4. Processing feasibility.

The physical and chemical properties and composition of the biobased material are highly influencing. How to handle and feed the material into the granulation process and how to keep or increase the nutrient availability in it constitutes one of the main considerations to assess.

Parameters such as moisture content, granulometry and density need to be assessed, and are directly related to the success of the implementation of a new raw material.

3.5. Logistics and Availability.

Potential new raw materials must be able to ensure a continuous supply. This means that the biobased source ought to be available in sufficient volumes throughout the year, being aware that they are biowastes or come from biowastes.

This requirement is directly related to the Regulation and it is very important that it is reviewed and updated frequently enough, given that the market and the international situation are changing.

In the same way, the location is a key parameter that directly influences the economic balance, carbon footprint and regulatory aspects: transport costs and environmental impact, regulation needs for transportation, type of transport, charge and discharge, etc.

3.6. Stability.

Linked with security and availability, the biobased material has to be stable in terms of its composition, biological activity and supply.

Regarding the physical and chemical properties and composition, the best scenario is the stable homogeneity of the biowaste. This is a challenging parameter that must be considered from the very beginning.

The absence of pathogens must be ensured within the whole fertiliser value chain.

The new material supply should be continuous or clearly defined.

3.7. Economic feasibility.

All the above factors are related to the price of the biobased material, which should not be higher than nutrient’s market prices. The exercise of comparing the conventional raw material fertilising unit cost versus biobased material fertilising unit cost must be carried out.

The avoidance of waste management costs might be applied in some cases, leading to an easily affordable material from the economic point of view.

The economic feasibility of the use of biobased material is of course required.

3.8. Carbon footprint.

The reduction of the environmental impacts and carbon footprint in the fertiliser manufacturing processes are becoming nowadays one of the main targets to reach. Therefore, the carbon footprint calculations would help in the final decision of selecting a new biowaste as part of the fertilisers, in comparison with the conventional raw materials results.

Table 1. *Guidelines for biowastes selection. All principal and secondary nutrients as well as micronutrient limits are considered as available. Blue letters: mandatory requirements under Regulation 2019/1009. Dark red letters: desirable.*

Parameter	Value range	Parameter	Value range
N* / P_2O_5 / K_2O	> 10 %	Granulometry	0.4 – 1.0 mm
MgO	> 10 %	Density	1000 kg/m^3
CaO	> 10 %	Moisture	< 1 %
SO_3	> 10 %	Supply	> 2,000 t/y
Cr	< 400 mg/L	Location	Close to fertiliser plant
Cr (VI)	< 2 mg/L	Transport costs	< 15 €/t
C_{org}	CMC12 < 3% CMC12 < 3% CMC14: ****	Cost**	< 50 €/t
Hg	< 1 mg/L	CO_2-eq	< 95% of conventional
Ni	< 100 mg/L	Pb	< 120 mg/L
ClO_4^-	< 50 mg/kg dry matter	As	< 40 mg/L
Tl^-	< 2 mg/kg dry matter	Cd***	20-40 mg/kg P_2O_5
Cl^-	< 30 g/kg dry matter	Biuret	< 12 g/kg dry matter
V	< 600 mg/kg dry matter	PAH_{16}	< 6 mg/kg dry matter
Salmonella	Absence in 25 g	PCDD/F	< 20 ng/kg dry matter
Enterobacteriaceae	M=300 in 1 g		

* N content if the biowaste material is not an ash. If it is an ash, N<0.5%.
** Depending on the cost of one fertilising unit.
*** If the biowaste contains more than 5% P_2O_5, otherwise: Cd < 3 mg/L.
**** Check Regulation 2021/2088.

4. HURDLES AND BOTTLENECKS IN INDUSTRIAL IMPLEMENTATION.

Validation of biobased materials for their incorporation within the fertiliser industry is not a simple task, as it is not a traditional business model, in which the logistics channels and the business network are not established.

Throughout the project, different barrier factors have been found as the main bottlenecks that must be assessed and overcome.

1) Nutrient concentration. Producing high nutrient concentrated NPK fertilisers means that all raw materials fed should also be highly concentrated. When working with biobased materials, this is a tricky aspect that strongly influences their use. The higher the nutrient proportion they have, the higher their incorporation within the NPK fertiliser can be. In the B-FERST project, products have been formulated with 10-65% of biobased materials in their matrix.

2) Variability. Unlike mining or chemical processes, obtaining nutrients by biological processes or from biowastes implies a high dependence on the starting waste. This effect can be clearly seen in the case of ashes and compost, for example, where the combustion or composted initial materials determine the abundance of nutrients in the final product. The lack of homogeneity in biowastes could become an issue to solve.

3) Location, Production and Quality. One of the difficulties regarding the location is the availability of sources as well as the production rates. It is not only important to find a point where the desired biobased material is produced and at the optimum distance. The quantities required for the industrial and sustainable production of fertilisers require contributions of thousands of tons per year that are not always available in just one source. For example, there are many struvite production spots in Europe, but they normally produce less than 900 t/y of struvite.

   The concepts of quality and concentration are correlated with the number of available resources. It is important that the characteristic of the biobased material meets the requirements specified by the fertiliser manufacturers to fit the quality requirements and fertiliser production process. Unsorted, uncompacted, and high hydrated biobased resources, such as compost, are usually uneconomic from a logistic point of view when long distances must be considered under the Life Cycle Analysis (LCA).

4) Regulation. Adaptation to the new European Regulation is one of the key factors, not only for the fertiliser industry, but also for all companies likely to produce potential biobased resources. Such regulation can be different between neighbour countries regarding safety and logistic measures so the international legislation frame plays an important role in the biobased material exploitation.

5) Energy consumption. The global carbon footprint would increase when higher energy consumption per fertiliser unit occurs. Furthermore, although this factor affects every part of the value chain, when the expenses due to the energy costs are related to biobased resources and therefore their price increases, the cost of every fertiliser unit also increases, making it more difficult to include in the fertiliser manufacturing process.

6) Biobased resources hot-spot selection: To support the decision-making process to evaluate when a new hot-spot / biobased material could meet the expectations of inclusion in the industrial chain, it is necessary to create a flowchart in which the main factors of the quality requirements are considered. The general flow-chart must be reviewed and adapted to the different possible scenarios, biobased resources characteristics /requests and target countries. Figure 2 represents the decision-making model followed in the B-FERST project.

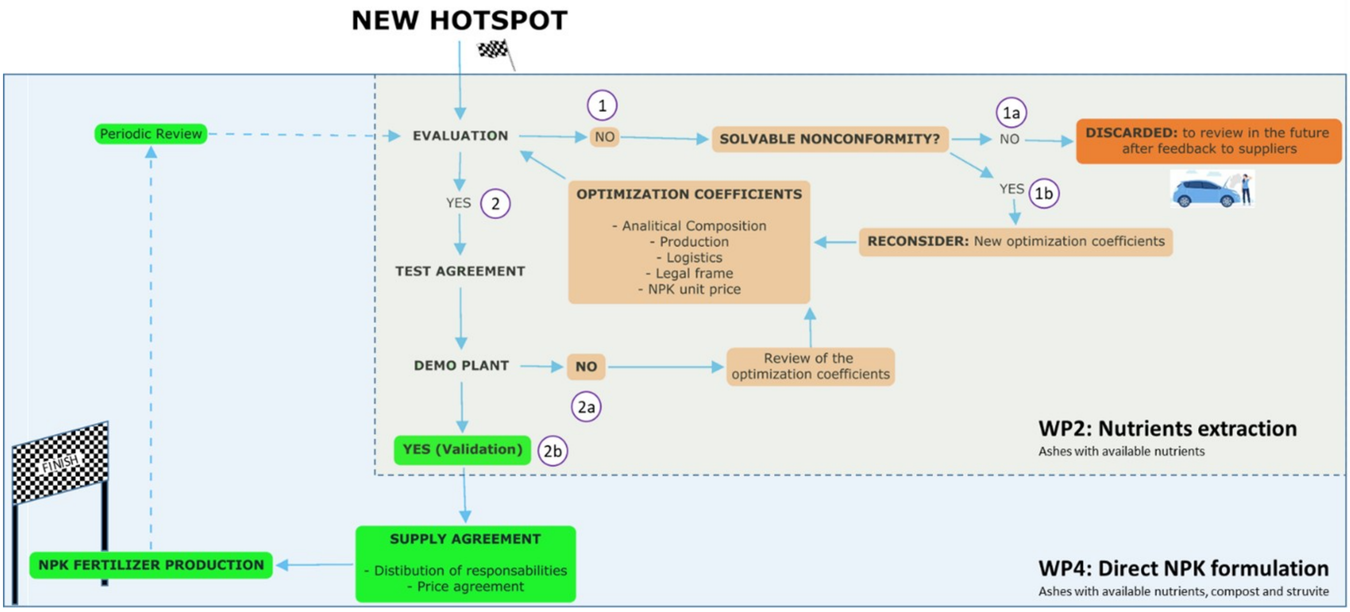

Figure 2: *Decision-making and logistics model for biobased materials implementation.*

5. SOLUBILISING NUTRIENTS FROM BIOWASTES INTO AVAILABLE NUTRIENTS: REPHOVERY PROCESS AT DEMONSTRATION SCALE.

One of the main identified factors for the success of the implementation of biobased materials in the fertiliser manufacturing process is the quality of the nutrients. The incorporation of soluble nutrients is crucial for the final fertiliser acceptance by the end-user.

Ashes produced in the combustion of sludges from WWTP, manure or slaughterhouse are abundant in Europe. Many of them contain high concentration in P_2O_5, but in insoluble forms, being only soluble in strong acid solutions.

In this sense, a novel P extraction process from ashes have been developed and validated at pilot plant scale. After finalising Basic and Detailed Engineering Packages, a demonstration plant with 500 kg/h capacity is currently being built at Fertiberia facilities in Huelva Plant (Spain).

The Rephovery Process (Figure 3) consist of 4 main stages:

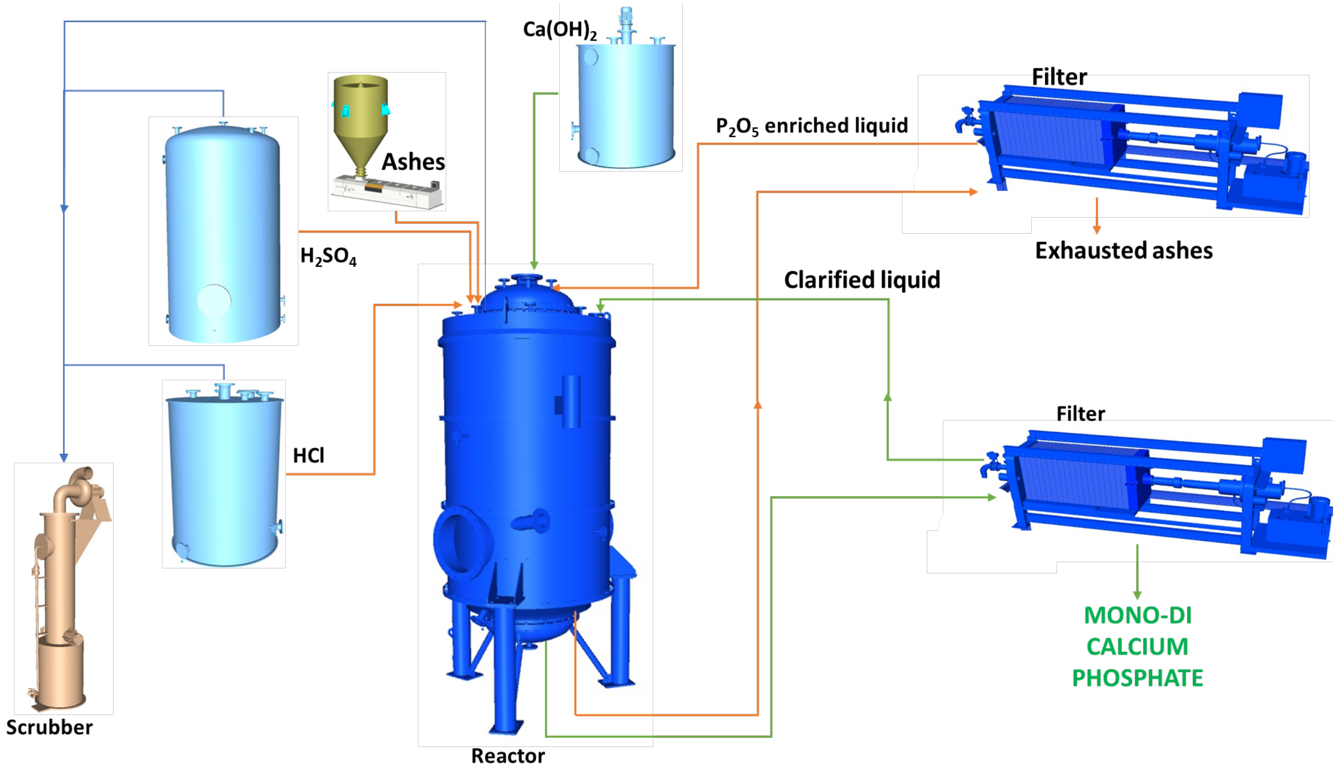

Figure 3: *Rephovery Process. Lines in red colour: streams related to Digestion (Reactor 1); Lines in green colour: streams related to Neutralisation (Reactor 2); Lines in blue colour: cleaning system.*

1) Digestion of the ashes (Reactor 1) by a phosphate, chloride, and nitrate free acid leaching liquor, which acts to form a solid phase containing the impurities, and a first liquid phase rich in phosphate ions. The use of sulphuric acid (H_2SO_4) as a digester in the leach liquor is due to its efficiency in extracting the different elements contained in the ashes, besides making the process less expensive than with other acids. The temperature used is between 60 and 75°C and HRT 1 hour.

2) Continuous separation of the solid and liquid phases with low energy consumption. This separation can be carried out by means of decantation, or filtration. The supernatant obtained contains the phosphate ions present in the ash, without most of the impurities present, now in the solid phase.

$$\text{Ash} + H_2O + \text{acid} \rightarrow \text{Solution rich in } P_2O_5 + \text{impurities}$$

3) Addition of $Ca(OH)_2$ to the liquid coming from the filtration (step 2, Reactor 2) produces a chemical precipitation of the phosphate ions contained in the liquid phase, resulting in a second acidic liquid phase and a second solid phase containing the separated phosphate ions. This precipitation is coupled thermally to the digestion of the ash (first step) in the same vessel.

$$P_2O_5 + 3H_2O \rightarrow 2\ H_3PO_4$$

$$Ca(OH)_2 + 2\ H_3PO_4 \rightarrow Ca(H_2PO_4)_2{\cdot}2H_2O$$

4) Another continuous separation of a second liquid phase and a second solid phase, rich in mono and di-calcium phosphates. As in step 2), this separation can be performed by decantation or filtration. The liquid phase is acidic and can be recirculated back to step 1). The solid phase is a mixture of monocalcium phosphate, dicalcium phosphate and calcium sulphate.

The closed circuit is an innovative advantage for this process, being environmentally sustainable without generating liquid effluents. The heat exchange between Reactor 1 and Reactor 2 makes it unnecessary to apply energy to the process, since the reactions taking place in Reactor 1 are strongly exothermic, while the reactions occurring in Reactor 2, although also exothermic, do not exceed 50°C. Thus, it is necessary to cool Reactor 1 and to heat Reactor 2 so that both reach optimum operating temperatures. This objective is achieved by the special design of the reactors.

A large number of tests were carried out at the pilot plant scale. They are summarised and divided in 5 groups, depending on the acid or proportion of acid that is used to extract the phosphorus from the ashes. The acids used were sulphuric acid (96%), hydrochloric acid (37%) and combinations of these in different proportions (Figure 4).

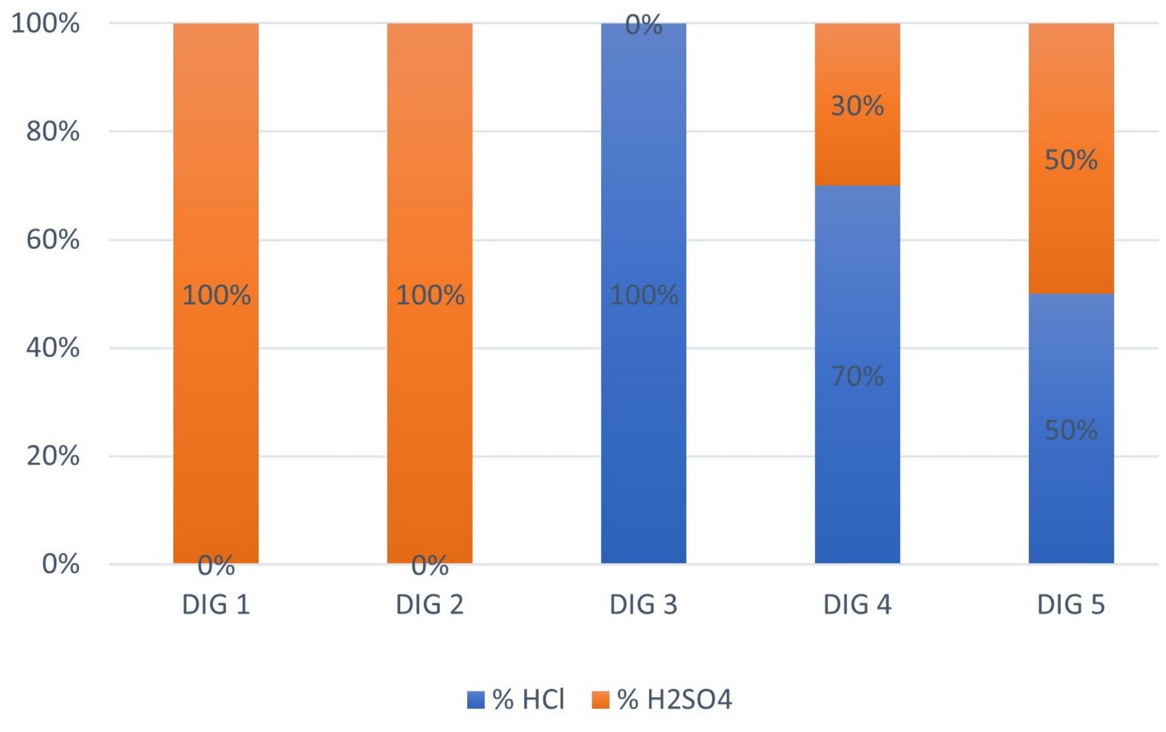

Figure 4: *Percentage of each acid in the five different types of digestion performed (DIG 1-DIG 5). The difference between DIG 1 and DIG 2 is the amount of ash and acid in the total volume of liquid phase (DIG1 has half amount of ashes and double volume of liquid phase compared to DIG2, but both were performed with 100%* H_2SO_4*)*

Based on these results obtained for the distinct types of digestions (Table 2), it was determined that DIG 1 produced a percentage of phosphorus extraction of 70%, this value being very inferior to the one obtained in the rest of the tests (>90%). In addition, the sulphate/phosphate ratio for this type of digestion is very high, leaving many sulphates dissolved in the water, which are subsequently precipitated together with the calcium added in the neutralisation stage, diluting the final product greatly in terms of phosphates (sulphate/phosphate ratio = 24). This type of digestion was therefore eliminated from the process.

Table 2: *Average result for each of the five types of digestion carried out.*

DIGESTION	P_2O_5 (mg/L)	**P_2O_5 recovery** (%)	**Sulphate/phosphate ratio**
DIG 1	12	70	24
DIG 2	58	95	4
DIG 3	67	91	0
DIG 4	71	90	0
DIG 5	74	94	0

Regarding the rest of the digestions carried out (DIG 2 - DIG 5), the results of the percentage of phosphorus extraction from the ashes are in all cases higher than 90% and very similar to each other. This indicates that both sulphuric acid and hydrochloric acid, as well as the combinations of both acids at different percentages, are optimal for carrying out the ash digestion process from the chemical point of view.

For the sulphate/phosphate ratio, as was obvious, it is higher in the case of DIG 2 digestions, in which only sulphuric acid is used, than in those digestions with a combination of acids (DIG 4 and DIG 5) or in which only hydrochloric acid is used (DIG 3). Even so, this ratio is perfectly acceptable from the point of view of the quality and concentration of phosphates in the final product. In order to determine whether the use of both types of acids independently and/or their possible combinations is acceptable from an energy point of view, temperature monitoring was carried out during the digestion process in all cases (Figure 5).

Digestion with only sulphuric acid (DIG 2) reaches a higher temperature than the rest of the digestions throughout the course of the process. In the case of the combinations of both acids (DIG 4 and DIG 5), both digestions are similar from the thermal point of view, starting and ending at very similar temperatures. And in the case of using only hydrochloric acid to conduct the digestion (DIG 3), it can be observed that both the starting temperature and the final temperature are somewhat lower than the rest of the cases. Digestion only with sulphuric acid (DIG 2) reaches a higher temperature than the rest of the digestions throughout the course of the digestion. In the case of the combinations of both acids (DIG 4 and DIG 5), both digestions were similar from the thermal point of view, starting and ending at almost the same temperatures. And in the case of using only hydrochloric acid to conduct the digestion (DIG 3), it can be observed that both the starting temperature and the final temperature are somewhat lower than in the rest of the cases. Therefore, the conditions of DIG 3 are those that were considered most appropriate.

After the validation of the four types of digestions, the neutralisation process was also tested, optimised and then validated. All neutralisations had efficiencies above 99.4%, except those carried out using ammonia as a pH raising agent, where efficiencies remained around 98.9%, regardless of the acid or combination of acids used during the digestion stage. Table 3 summarised the main results.

Figure 5. *Temperature (°C) monitoring during digestion (DIG2-DIG5).*

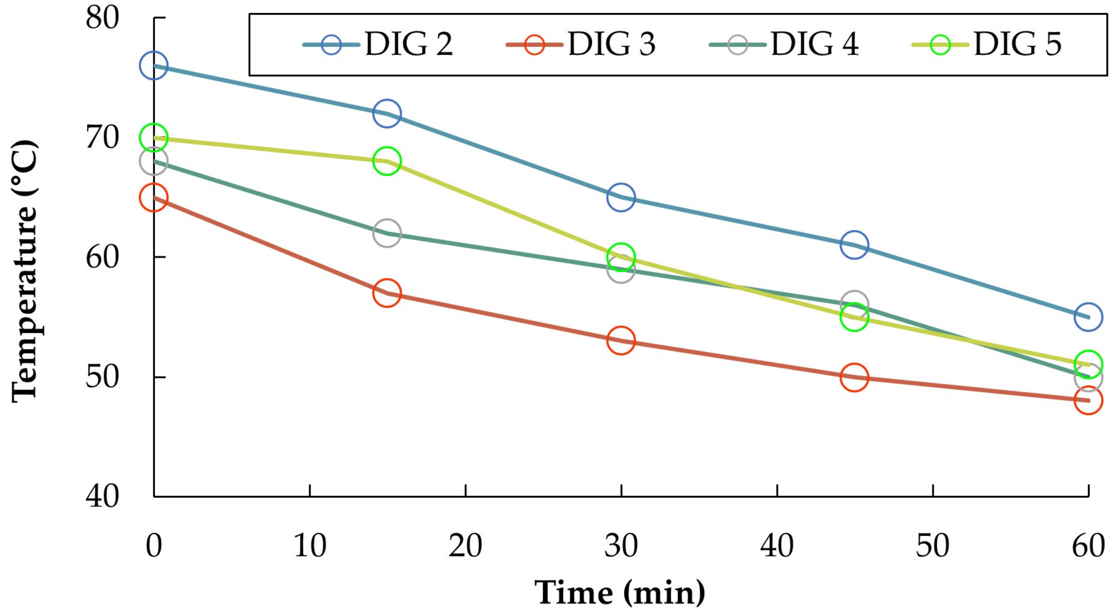

Table 3. *Average result for each of the nine types of neutralisation carried out.*

NEUT	Sample (g)	P_2O_5 total (%)	P_2O_5 avail. (%)	P_2O_5 (g)	SO_4^{2-} (%)	SO_4^{2-} (g)	Sulphate / phospate ratio
NEUT1	67.9	11.9	10.4	8.0	61.2	41.6	5.1
NEUT2	57.6	16.6	16.0	9.6	61.5	35.4	3.6
NEUT3	58.0	16.1	15.0	9.3	36.1	20.9	2.2
NEUT4	29.6	22.1	20.1	6.5	3.6	1.0	0.1
NEUT5	27.3	27.2	26.6	7.4	3.8	1.0	0.1
NEUT6	34.6	24.5	23.8	8.5	1.3	0.4	0.0
NEUT7	24.8	14.9	13.4	3.7	0.0	0.0	0.0
NEUT8	41.7	20.3	18.1	8.4	0.0	0.0	0.0
NEUT9	35.9	23.0	21.1	8.2	0.0	0.0	0.0

The NEUT5 process had the highest percentage of P_2O_5 in the final product of all those tested (27.2%). This reason, together with the fact that it is thermally suitable for the use of the reactors, made it one of the chosen processes to be upscaled.

6. BIOBASED COATINGS AT DEMONSTRATION SCALE (ECOAT PLANT).

The B-FERST project aims to demonstrate the feasibility of producing innovative biobased fertiliser products. These fertiliser products will be manufactured in one demonstration plant covering three main stages: (1) A nutrient recovery stage (mainly P and K); (2) a granulation stage, and (3) an addition of biostimulant (Non-microbial plant biostimulant (NMPB) or Microbial plant biostimulant (MPB)) with the requirement of a coating stage. It will be validated within the B-FERST project at a 1 ton/h demonstration production scale (1:15), paving the way towards full industrialisation. Figure 6 shows this global integration towards the production of biobased fertilisers.

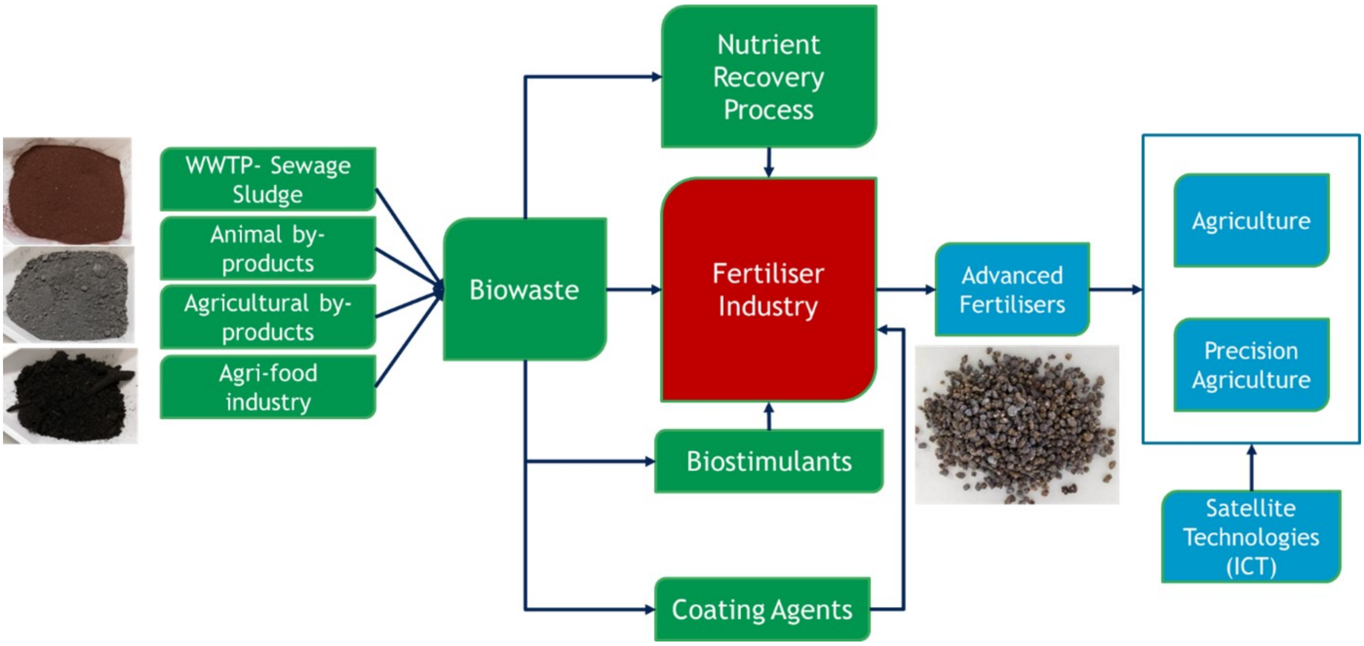

Figure 6: *Fertiliser demonstration plant integrated system.*

The demonstration Coating plant has been designed with the flexibility to coat 1.0-1.5 t/h of biobased fertilisers and organo-mineral biobased fertilisers with different coating agents (biodegradable) as well as with the addition of liquid biostimulants (NMPB or MPB).

In order to achieve the maximum operational flexibility in the coating plant, three coaters are being installed, allowing the addition of different kinds of coating agents that can be added at low or moderate temperatures, or are very viscous, or solids, even suspensions.

It will allow the successive feeding of several layers of different types of coating agents combined with the addition of biostimulants. Thus, for example, in the case of MPB, the fertiliser granules can be coated with a previous layer before adding the MPB to ensure the conservation and development of microorganisms in the soil.

The selected developed coating materials will be introduced into the respective tanks to coat the surface of the fertiliser granules by spraying systems. The properties of the biodegradable compounds (temperature, viscosity, adherence) must be such that they allow a homogeneous and good coating quality around the granule, avoiding an increase in the temperature and humidity of the fertiliser. The finished coating at room temperature will prevent compaction of the granules, allowing their good preservation during storage. Figure 7 shows a summarised flow diagram of the coating plant.

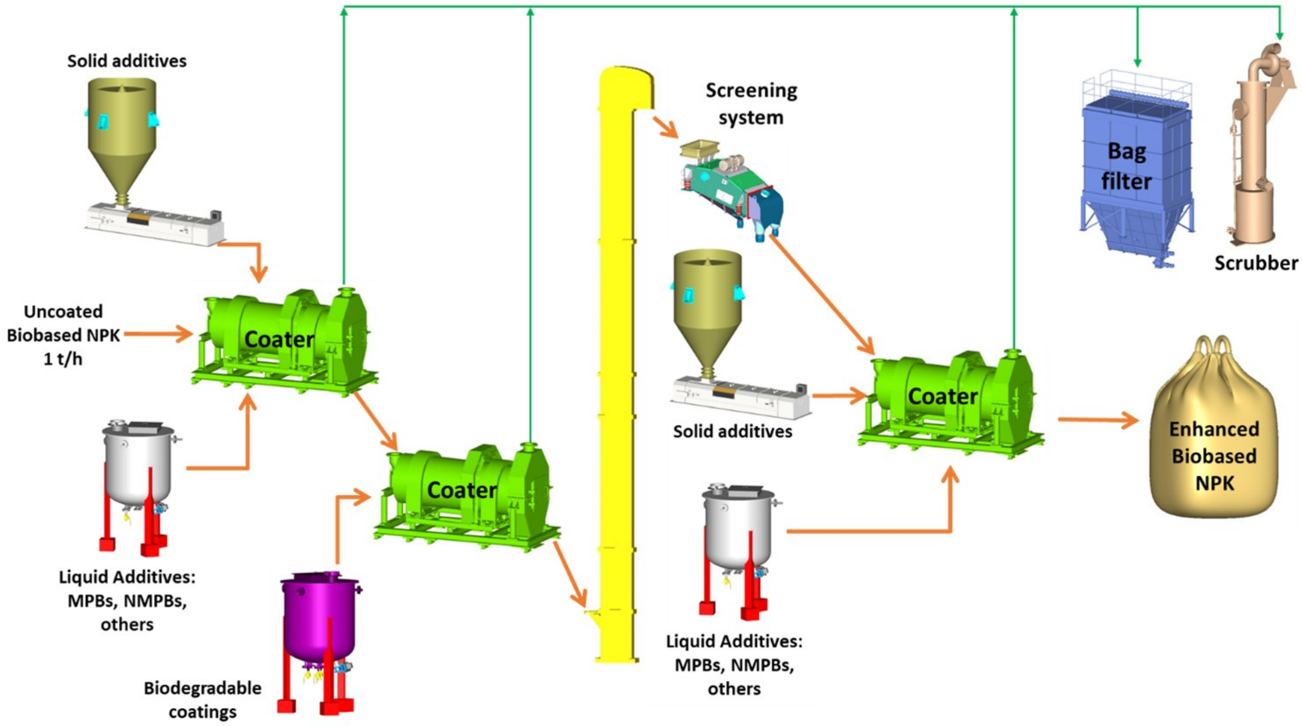

Figure 7: *Flow diagram of the coating demonstration plant.*

Trials carried out with the pilot plant have provided a basis for the development and implementation of the coating demonstration plant. These trials also helped in the final definition and optimisation of the selected additives: MPBs, NMPBs and biodegradable coatings.

7. CONCLUSIONS.

The promotion of the circular economy in the production of fertilisers from biowaste can be an interesting alternative to reduce dependence on nutrients from abroad and the C footprint.

A list of optimised selection criteria and models to identify the most promising biobased sources have been validated: biowaste quality, security, regulation, processing feasibility, logistics-availability, stability, economic feasibility and carbon footprint. A requirement table has been developed.

Composition concentration, variability and homogeneity, location, production, quality, regulatory aspects and energy consumption have been identified as the main bottlenecks for the implementation of the biobased sources within the fertiliser industry value chain.

A new versatile nutrient extraction process has been validated at pilot plant scale, and is currently being upscaled into a demonstration plant.

A new flexible coating demonstration plant is currently being built, using the results from the pilot plant scale.

Effective replacement of part of the conventional mineral raw materials by biobased material as nutrient sources and special additives has been demonstrated in the fertiliser manufacturing process at pilot plant scale, reaching the incorporation up to 65% biobased materials.

8. ACKNOWLEDGEMENTS.

This project has been financially supported by the European Commission - BBI JU project 'Bio-based Fertilising products as the best practice for agricultural management sustainability (BFERST)'. H2020-BBI-JTI-2018, Grant agreement ID: 837583.

9. REFERENCES .

Chrispim, M.C., Scholz, M. and Nolasco, M.A. (2019). Phosphorus recovery from municipal wastewater treatment: Critical review of challenges and opportunities for developing countries. *Journal of Environmental Management*, **248**, 109268.

EC. (2016). Circular economy: New Regulation to boost the use of organic and waste-based fertilisers. EC - Fact Sheet. Brussels, 17 March 2016.

FAO. (2015). World fertiliser trends and outlook to 2018, FAO, Rome.

Kalmykova, Y. and Karlfeldt, F.K. (2013). Phosphorus recovery from municipal solid waste incineration fly ash. *Waste Management*, **33**(6), Pages 1403-1410.

Santos, A.F., Almeida, P.V., Ivareng, P.A., Gando-Ferreira, L.M. and Quina, M.J. (2021). From wastewater to fertiliser products: Alternative paths to mitigate phosphorus demand in European countries. *Chemosphere*, **284**, 131258.

RELATED PROCEEDINGS OF THE SOCIETY.

219, (1983), *Utilisation of Organic Wastes as a Fertiliser,* J H Voorburg.

293, (1990), *Agro-Industrial Waste Composting and its Agricultural Significance,* J M Lopez-Real.

342, (1993), *Opportunities and Constraints for Recycling Nutrients from Organic Wastes,* G W Searle.

372, (1995), *Opportunities and Constraints in the Recycling of Nutrients,* J Lammel, Prof. H Kirchmann.

406, (1997), *Product Stewardship (Fertilisers),* D M Martin, R S N Carne

409, (1998), *Agricultural Use of Biosolids (Sewage Sludge),* T D Evans.

432, (1999), *Speciality Mineral and Organo-Mineral Fertilisers - Products and Markets,* A Rainbow.

475, (2001), *Sustainable Agricultural Production Systems,* M K Garrett.

508, (2003), *Product Stewardship Applied to Fertilisers,* H Kiiski, R J Milborne

619, (2007), *Potassium and Magnesium in Manures and Organic By-Products,* J Salomez, S De Bolle, J Bries, S De Neve, G Hofman.

623, (2008), *Food, Fertilisers and Footprints - An Environmental Essay. 25th Francis New Memorial Lecture,* C J Dawson.

624, (2008), *Relationships Between Nutrient Recycling, Environmental Impacts and Agricultural Production,* J J Schröder, J F F P Bos.

626, (2008), *'Reach' Regulations: Impact on the European Fertiliser Industry,* J Ebenhöch.

631, (2008), *Compost: Production, Use and Impact on Carbon and Nitrogen Cycles,* M P Bernal.

635, (2008), *Nutrient and Carbon Recovery from Household and Food Biowastes,* T D Evans.

636, (2008), *Industrial Symbiosis: Nationally Co-ordinated By-Product Use and Nutrient Recycling,* M R Bailey, P D Jensen, H Hitchman, A Gadd.

637, (2008), *Policies to Encourage Integrated Nutrient Management and Recycling,* Å E Sjöström.

637, (2008), *European and UK Regulatory Requirements for the Application of Waste Products to Land,* M J Davis.

640, (2008), *Non-Metallic Contaminants in Domestic Waste, Wastewater and Manures: Constraints to Agricultural Use,* B Vinnerås, J Clemens, M Winker.

642, (2008), *Assessment of Manure Transport Distances and their Impact on Economic and Energy Costs,* R Fealy, J J Schröder.

698, (2011), *Enhancing Phosphorus Recovery from Sewage Sludge Application to Arable Land,* M Pawlett, R Sakrabani, R Read, L K Deeks, M S Le, S Tyrrel.

717, (2012), *Phosphorus Fertilisers from By-Products and Wastes,* O Oenema, W Chardon, P A I Ehlert, W Rulkens, O Schoumans, K van Dijk.

727, (2013), *Phosphate Recycling in Mineral Fertiliser Production,* C P Langeveld, K W ten Wolde.

763, (2015), *Review of Promising Methods for Phosphorus Recovery and Recycling from Wastewater,* C Kabbe, C Remy, F Kraus.

790, (2016), *Crop Available Nitrogen Supply from Food-based Digestate,* A Bhogal, F Nicholson, M Taylor, A Rollett and J R Williams.

802, (2017), *Role of fertilisers for climate-resilient agriculture,* J S Angle, U Singh, C O Dimkpa, D Hellums, P S Bindraban.

832, (2019), *Production of Clean Phosphorus Products from Sewage Sludge Ash using the Ash2phos Process,* Y Cohen, P Enfält, C Kabbe.

833, (2019), *Realising Phosphorus Recycling,* S Brandjes.

834, (2019), *Circular Agriculture: Easier Said Than Done,* J J Schröder.

846, (2020), *Exploring Variations in the Demand for Fertilisers Derived from Recycling in North West Europe,* R. Postma, I. Harms, N. Power, A. Egan, L. van Schöll.

847, (2020), *Production of Phosphorus Fertiliser from Abattoir and other Industrial Wastes,* M.S.A. Blackwell, T.S. Darch, R. Dunn.

863, (2021), *Estimating Agronomic Performance of Recycled Phosphorus Fertilisers – Challenges and Possible Solutions,* S. Kratz, P. Keßeler, K. Jabs, R. Anlauf, H. Schultz, E. Wilharm, T. Potthoff, B. Steingrobe, E. Bloem.

International Fertiliser Society

The International Fertiliser Society is a scientific Society founded in 1947, with members in approximately 50 countries worldwide. Its main objectives are:

> *To provide an international forum for discussion and dissemination of knowledge of scientific, technical, environmental, economic and safety aspects of the production, marketing, use and application of fertilisers.*

Copies of past Proceedings can be obtained from the Society website:

www.fertiliser-society.org

e-mail: secretary@fertiliser-society.org