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SCOPE NEWSLETTER

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Meetings

***Struvite** 17th June Amersfoort Netherlands*

recovered struvite REACH Registration exemption, REACH dossier update, struvite EU Fertiliser Regulation criteria, struvite fertiliser value

***EU Fertiliser Regulation** 29th June Brussels*

discussion of proposed Regulation text, application to recovered nutrient products, composts, digestates

***Nutrient recycling** 11th July Denver, USA*

opening plenary session on P-recovery success stories presented by ESPP at IWA-WEF Nutrient Removal and Recovery Conference 2016 (11-14 July) plus Workshop on Nutrient Recovery at WWTPs 10th July.

Registration information and full events listing
http://www.phosphorusplatform.eu/events/upcoming-events

Nutrient recycling

US EPA Nutrient Recycling Challenge

Ten innovative manure treatments awarded covering digestion, chemical treatment, separation, stripping.

Canada nutrient removal and recycling

perspectives, technologies and economics of sewage nutrient removal, recovery and reuse

Recycling of phosphorus in Norway

Norwegian EPA proposals for national P-recycling

Policy

European Parliament

Agriculture Committee supports nutrient recycling

EU Nitrates Directive implementation

France State study of 6 Member States concludes that agricultural N and P regulation is a major challenge.

Reports and workshops

PHORWater workshop Lyon

Five full-scale struvite recovery processes compared

RISE report on nutrient recovery and reuse

Report on nutrient recycling in European agriculture

Finland nutrient recycling programme

Launch conference:12 M€ for nutrient recycling innovation

Challenges open

Flanders manure processing competition

Open to 28/10/16: 2000€ prize and promotion for innovation proposals in manure nutrient valorisation.

George Barley Prize

Everglades teams with Ontario for 11.2 million US$ nutrient removal and recovery challenge

The partners of the European Sustainable Phosphorus Platform

Fertiliser Regulation

Input to EU Fertilisers Regulation

The first deadline for comments on the published EU Fertilisers Regulation revision text closed 12th May. The European Commission has published 99 comments received. As a member of the European Fertilisers Working Group, ESPP submitted comments which are summarised below. ESPP is organising a **meeting in Brussels, 29th June**, to discuss the proposed Regulation text.

Comments received published by EU Commission: http://ec.europa.eu/transparency/regdoc/?fuseaction=feedbackreport&doc_id=3092157

Summary of Commission proposal: SCOPE Newsletter n° 120 www.phosphorusplatform.eu

ESPP welcomes the proposed Fertiliser Regulation (revised) text as **positive, balanced and pragmatic**. Its flexible and open approach will facilitate nutrient recycling and return of organic carbon to soils in Europe, and so development of the nutrient Circular Economy.

ESPP also welcomed the **subsidiarity** which will enable Member States to continue to authorise use of other recycled nutrient materials in agriculture (within their territory) as "national fertilisers" or under waste-type spreading authorisations, including appropriately treated and managed sewage sludge where Member States wish to enable this.

Confidence and effectiveness

Key comments from ESPP point to issues which are not addressed in the Fertiliser Regulation revision text as published:

- **Traceability**: the Commission proposal does not at present provide for recycled fertiliser product traceability. ESPP suggests that traceability should be obligatory for products susceptible to contain organic contaminants from certain potentially problematic sources (or perceived as such), e.g. sewage, animal manures, household food waste (unless incinerated). This is necessary to (a) ensure consumer confidence and (b) avoid exclusion of important nutrient recycling potential streams for this reason, in particular municipal sewage.

- **Effectiveness as fertilisers**: the Commission proposal specifies that products must be "sufficiently effective" but does not define what this means. ESPP proposes for P fertilisers either 80% water or neutral ammonium citrate solubility, or documented demonstration trials specifying crop and test conditions.

Additional input material categories

As summarised in SCOPE Newsletter n° 120, the Commission proposal already defines criteria for composts, digestates, some food industry by-products and (not yet defined) some animal by-products. Additionally, criteria definition is underway for struvite, ash-based materials and biochars (see *www.phosphorusplatform.eu/regulatory*)

ESPP requests that **criteria definition should also launched for several other recycled nutrient materials, which are not at present covered**: recovered "mineral" nitrogen fertilisers (e.g. nitrogen compounds extracted from digester gases), other inorganic phosphates (in addition to struvite, for which criteria definition is launched), dried / pelletised animal manures, sewage sludge derived products.

ESPP also makes a number of other comments including the need for coherence with **REACH** (confirmation of exemption of digestate and of application of Art 2(7)d to Fertiliser Regulation recycled nutrient products), **coherence of definitions** (e.g. organic content of PFC1(C) inorganic fertilisers), acceptance of food and beverage industry by-products as input materials, pertinence of contaminant limits.

EU Fertilisers Regulation proposed revised regulation text, 17/3/2016 http://ec.europa.eu/DocsRoom/documents/15949 *and summary in SCOPE Newsletter n° 120* www.phosphorusplatform.eu

EU publication of comments received by deadline of 12th May 2016: http://ec.europa.eu/transparency/regdoc/?fuseaction=feedbackreport&doc_id=3092157

ESPP comments 12th May 2016: www.phosphorusplatform.eu/regulatory

Fertiliser value of composts and digestates

The Improve-P Fact Sheet reviews current knowledge on the fertiliser and soil improvement effects of composts and digestates from urban organic wastes

A 12 page Fact Sheet published (2016) by the EU **Improve-P** network reviews current knowledge on nutrient and carbon characteristics, nutrient plant availability, contaminants, impacts on soil quality and greenhouse gas emissions of composts and digestates produced from municipal organic wastes. Regulatory questions relating to use in Organic Farming are indicated.

Urban organic waste (**UOW**) is identified as: garden and park green wastes, source separated household food wastes, food processing organic wastes, retail sector food waste (often containing high levels of plastics) and catering / institutional food waste. The last two may be classified Animal By Products under Regulation EC 1069/2009.

The **EU Organic Farming Regulation 889/2008** only specifically mentions source separated household organic waste as input, but does not explicitly exclude other UOW feedstocks, with different and contradictory interpretations in different EU Member States.

Such wastes (UOW) are estimated at **100 kg/person/year in Europe**, that is 40% of municipal solid waste. Only around 30% of this is currently separated and recycled as secondary fertilisers.

Composts are indicated to have 50-75% dry matter, compared to only 2-12% in digestate. For digestates this can be increased to 20-30% by solid-liquid separation and to 60-86% by drying.

Nutrients in composts and digestates

Both composting and processing of digestate (after the anaerobic digester) result in **high nitrogen volatisation losses**, and solid products with high P:N ratios. Liquid digestates have a higher nitrogen content, with a high ratio of ammonia to total N.

In both composts and digestates, **more than half of the phosphorus is generally present in poorly soluble, inorganic forms**. In particular, the water soluble fraction of phosphorus is considerably reduced during anaerobic digestion.

The document considers that **100% of phosphorus in composts and digestates is plant available in the long term**, but only 10-50% of municipal composts is available for plant uptake in the first year. Stable composts generally have lower water soluble phosphorus. Field experiments with digestates suggest that anaerobic digestion does not modify the phosphorus availability.

The availability to crops, in the first year, of nitrogen in composts can vary from 15% to -15% (net nitrogen immobilisation), with a net mineralisation of 2 – 8% of the remaining nitrogen over subsequent years. In the long term, around 40% of N in compost can be estimated to become plant available.

Nitrogen loss in anaerobic digestion is low, and liquid digestates from municipal organic waste are estimated to contain 2-27%N (total nitrogen, % dry matter) of which 35-75% is ammonia. Dried solid digestates have very low nitrogen fertiliser value, due to high N losses during drying and transformation of N into heterocyclic compounds (melanoids).

Soil quality value of organics

Both compost and digestate provide recalcitrant (not easily biodegradable) organic carbon forms to the soil. They will generally result in a decrease in soil acidity, because the breakdown of organic acids and carbonates they contain will consume protons.

Cited literature studies show that **both composts and digestates improve soil physical properties** by reducing soil bulk density, increasing saturated hydraulic conductivity, moisture retention capacity and aggregate stability. However, further studies are needed. There is, for example, only one field study comparing effects of digestates and composts from similar UOW feedstocks.

A summary of German data on **heavy metal levels** in a range of UOW composts and digestates is given. A specific identified issue may be zinc, both from input materials and processing equipment.

The authors consider that **data is lacking regarding levels of persistent organic pollutants** (PCBs, PAHs, PCDD/F) in digestates, whereas high quality composts can have levels lower than soil background.

Data is provided for **energy consumption in composting and anaerobic digestion**, and for energy production from methane produced in anaerobic digestion. Studies assessing greenhouse gas emissions during production and storage of composts and digestates are discussed.

Improve-P Fact Sheet on composts and digestates from urban organic wastes (2016), 12 pages, Improve-P, funded by EU FP7 ERA-net project "Core Organic II" (Coordination of European Transnational Research in Organic Food and Farming Systems). Editors: K. Möller, Universität Hohenheim, Germany kurt.moeller@uni-hohenheim.de, *A. Oberson, ETH Zurich, Switzerland, P. Mäder and S. Hörtenhuber, Research Institute Organic Agriculture (FiBL), Switzerland, A-K. Loes, Bioforsk, Norway, J. Friedel, BOKU Vienna, Austria, J. Cooper, Newcastle University, UK, J. Magrid, University of Copenhagen, Denmark.*
http://www.coreorganic2.org/upload/coreorganic2/document/moeller2016-Factsheet_compost_and_digestates.pdf

Proposed biochar fertiliser criteria

After consultation with scientists, technology suppliers and biochar associations, ESPP has published proposed outline criteria for biochars as input to the EU Fertiliser Regulation revision.

See www.phosphorusplatform.eu/regulatory

ESPP already published in 2015 draft outline EU fertiliser criteria for recovered **struvite** and for **ash-based materials**. Along with the draft biochar criteria, these are submitted to the European Commission JRC (Joint Research Centre). JRC has been mandated by DG GROW to draft official Commission criteria proposals to submit to EU consultation and then **integration into the revised EU Fertilisers Regulation** (once this has been promulgated, expected in 2017-2018).

ESPP and DPP selected in expert group

ESPP and the German Phosphorus Platform (DPP) have been selected by the European Commission as **members of the expert group to advise JRC in writing proposed Fertiliser Regulation criteria for recovered struvite, ash-based products and biochars**. The first meeting of this expert group takes place 6-7 July.

Flexibility, innovation, safety, confidence

The objectives of the proposed ESPP biochar criteria:

- Specify that eligible biochars must be **produced principally from bio-materials** (biological origin of input materials), and define what this means in practice
- Aim to be open and flexible to **anticipate innovation in technologies and encompass production from a wide range of input materials**, including manures, sewage biosolids, municipal/household food wastes, crop by-products, food industry and slaughterhouse wastes…
- Ensure **complete safety of biochars** produced from all such input materials, and enable farmer, food-chain and consumer confidence

Ensuring pyrolysis of organic contaminants

Biochar **hydrogen/organic carbon ratio H/C_{org} < 0.7** (in the biochar) is proposed as a simple, clear and sufficient criterion to guarantee that all organic inputs have been fully pyrolysed (e.g. pharmaceuticals or pathogens eliminated). This avoids process temperature criteria which can be complex to control and verify.

To further improve consumer and user confidence, ESPP proposes obligatory **labelling and traceability** if biochars contain as input materials municipal sewage biosolids, manure or other animal by-products.

Carbon and contaminants

ESPP proposes a **minimum 30% carbon content** (total carbon/dry matter) to distinguish biochars from ash materials. Contaminant levels for PCBs (sum PCBs < 0.2 mg/kgDM) as a default criterion, considered a sufficient indicator for dioxins/furans.

For heavy metals, pathogens, macroscopic impurities and PAH it is proposed to **use the same limit levels as specified in the draft Fertiliser Regulation revision text for other CMCs** (Component Material Categories, e.g. compost, digestate) or PFCs (Product Function Categories).

However, for PAH (proposed limit PAH_{16} < 6 mg/kgDM, as for composts and organic fertilisers in the Fertiliser Regulations proposal) it is recommended to specify extraction with toluene, because PAHs can be strongly adsorbed to the biochar carbon matrix. Although such adsorbed PAHs may not be readily bio-available in the environment, ESPP considers that user confidence suggests to ensure that there are not "hidden" PAHs not taken into account.

ESPP's proposed criteria for struvite, ash-based products and biochars have been **submitted to the European Commission, JRC**, for consideration in the official criteria definition process.

ESPP proposed outline criteria for integration of biochars, struvite and ash-materials into the EU Fertiliser Regulation revision process: www.phosphorusplatform.eu/regulatory

Struvite as an effective fertiliser

Many further published tests confirm that recovered struvite is an effective fertiliser for a range of crops

Precipitation of **struvite (magnesium ammonium phosphate)** has emerged as an effective route for recycling phosphorus from liquid waste streams, including in sewage treatment, manure processing, food industry and other industries. **The recovered struvite is sold, as such or blended with other nutrients, as an agricultural or specialist fertiliser**.

In sewage treatment, **struvite recovery is now a proven, effective nutrient recovery technology in plants operating biological phosphorus removal and sewage sludge anaerobic digestion** (biogas production), enabling nutrient recycling and also improving operation (problem deposit avoidance, improvement of P-removal and N-removal, better sludge dewatering …). Companies are also operating struvite recovery full scale in the food processing industry and pilot in manure processing, pharmaceutical and semi-conductor production … For a map of operating struvite production units see *http://e-market.phosphorusplatform.eu/*

Fertiliser value of struvite

Struvite is not readily water soluble like many conventional mineral phosphorus fertilisers (e.g. superphosphates SSP or TSP, mono- or di- ammonium phosphates MAP or DAP) and therefore its plant availability and effectiveness on crops is sometimes questioned.

However, not only industry and field experience, but also many science and technical publications confirm that recovered struvite is an effective fertiliser. Further recent publications, with fertiliser tests on a range of crops and in different conditions, add to this body of evidence.

Already in 1968, **Bridger ("New Fertilisers Manuel", see SCOPE Newsletter n°43, 2001)** reviewed a number of papers showing the fertiliser value of struvite, on crops including ryegrass (eight successive crops), blue grass, buckwheat, wheat, tobacco, strawberries, mangel beets, potatoes, tomatoes, fruit trees and a number of ornamental plants. This review also covered K-struvite (magnesium potassium phosphate).

A significant number of further, more recent studies showing the fertiliser effectiveness of struvite are summarised below. A number of these are also covered in the recent review on struvite recovery by Kataki (2016).

If you are aware of other fertiliser tests of struvite not indicated here, please send details to ESPP info@phosphorusplatform.eu and we will also reference this.

Field trials of struvite

ESPP underlines, however, that, although there are a large range of pot trial data, **there are still very few published field trial results of struvite fertiliser testing**. Other than the 1960's studies indicated in **Bridger 1968 above**, we are aware only of the following published field trials of struvite:

- **Hammond & White (2005, SCOPE Newsletter 60)** and **DEFRA (2008)** compared commercially manufactured fine powder struvite (Budenheim Budit 370) to Triple Super Phosphate (TSP) in **four years of field trials on potatoes in the UK** (low P status soil, soil pH not specified). The project concludes that struvite is an effective a fertiliser (crop yields, nutrient uptake) as TSP. Lower growth on some struvite plots was attributed to potassium uptake deficiencies in struvite fertiliser potatoes.

- **Gell (2011)** carried out field **20 m^2 plot trials of two different recovered struvites compared to triple super phosphate, in the Netherlands**, soil pH 4.5, tilled into soil before planting maize, maize harvested after 135 days. Results were not informative, as all fertiliser treatments showed similar yield to control (no fertiliser).

- **Thompson (2012 and thesis 2013, SCOPE Newsletter 97)** presented pot trials on rye grass and **two-year field trials on maize and soybean in Iowa**, low phosphorus soils pH 5.5 – 6.4, showing that struvite was comparable as a phosphorus fertiliser to TSP (triple super phosphate)

- **Ruiz Diaz (2010, SCOPE 90)** presented pot trials and **field trials of struvite recovered from cattle manure**, marketed by **TerraPhos** *www.kemallc.com* on corn, soybeans, and horticultural plants, in Kansas, on low phosphorus soils, pH 6.3 – 6.7.

- **STOWA (2016)** report, in Dutch, summarises pot trials (soil pH 5.0) of iceberg lettuce, dike grass, gladiola flowers and the garden shrub *Elaeagnus ebbingei* and **field trials with gladiola** (soil pH not indicated), concluding that struvite was as good or better fertiliser than commercial fertiliser (including triple super phosphate)

Other field studies are not published because

- Field trials are carried out by struvite producer companies and are not published
- In order to show a yield effect, trials have to be carried for a number of years at fields with very low P content which are difficult to find in Europe.
- Field trial data, including from several recent EU projects, are still underway and not yet publishe: e.g. **IASP - P-REX** (see SCOPE Newsletter 108), **Naskeo** (SCOPE 120), **University of Bonn** (see SCOPE 88), **PHORWater** LIFE+ (see SCOPE 97 and in press)

https://www.flickr.com/photos/gtzecosan/albums/72157624540490811/

Struvite is now widely recognised to be an effective fertiliser

Because struvite is not readily water soluble (see below) and is not soluble using the standard P-Olsen solubility test, **this led some poorly-informed agronomists to state that it is not an effective fertiliser** or is only very slowly plant available.

However, the fertiliser effectiveness of struvite has now been demonstrated by many tests (some of which are cited here), in different conditions and using different crop plants. Therefore, the fertiliser value of struvite is now generally recognised, **including for crops needing rapidly available phosphorus such as maize or wheat**. This is maybe partly because plants and microbes in soil are highly efficient in "accessing" insoluble forms of phosphorus (see **Rothbaum** below), because phosphorus is often the critical limiting element in soil systems.

Nonetheless, the low solubility of struvite does have **specific advantages, in particular run off from soils is less likely,** because the phosphorus is only mobilised as and when it is actually needed by plants (see SCOPE 99).

Regarding the solubility of struvite, **Crutchik (2016)** recently published results showing a solubility product Ksp of around 5.5×10^{-14} at pH 8.5 (with solubility increasing with higher temperatures) and summarising previous literature solubility data at pH 7.6 – 9.

Factors which impact struvite fertiliser performance

The rate of plant uptake of P and N from struvite is (predictably) impacted by **particle size** (**Nelson 2000 Goto 1998**, see SCOPE 42).

It is however also useful to produce struvite products in a form which can be handled, stored and spread by farmers, using their current equipment, and fine powders may not be appropriate. **Latifian (2012)** investigated **producing pellets from wastewater-recovered struvite**, and handling properties and nutrient release from these pellets (plant tests were not carried out).

Struvite can offer the advantage over some commercial phosphorus fertilisers of having **lower toxicity to seedlings** (e.g. **Katanda 2014, Katanda 2016** below). Inhibition of seedling emergence by commercial fertilisers may explain why struvite shows higher fertiliser performance results in some studies.

Rothbaum (1976) showed that struvite nutrient availability is **enabled by aerobic microbial action in the soil**. They tested soil water leaching for 3-6 months of a pellet fertiliser made by bonding struvite to potassium sulphate. Results showed that phosphorus release was progressive over 2-3 months, was strongly inhibited at 53°C and was increased several-fold by aeration. Inclusion of 1.5% iron in the pellets did not reduce the phosphorus leaching.

Talboys (2016) showed that buckwheat *Fagopyrum esculentum*, which **exudes high levels of organic acids**, was more effective at using struvite phosphorus than spring wheat *Triticum aestivum* (pot trials 30, 36 and 90 days, soil pH 6, comparing wastewater recovered struvite **Ostara CrystalGreen**® to di-ammonium phosphate DAP and triple super phosphate TSP). They conclude that struvite acts as a slow-release fertiliser, providing equivalent rates of P uptake and yield at harvest. Their results showed slower P uptake from struvite in initial plant development (first month), but this may be because the struvite pellets were quite large (c. 2.4 mm granules) and were placed in one location in the pot, not mixed into soil.

The magnesium and ammonium present in struvite (or other chemicals such as calcium if recovered struvite is not pure) may impact plant availability and plant uptake of phosphorus, both because of the fertilising effects of these nutrients, by chemical interactions in the soil, and by other possible actions on soil organism or plant root activity.

Vaneeckhaute (see below) suggests that **uptake of NH_4 from struvite by roots and nitrification of NH_4 to NO_3** are acidifying processes, causing a soil pH reduction, so making soil phosphorus more available to plant roots.

Ahmed (2016) studied dissolution of struvite in soil in **interaction with plant roots**, comparing granules of wastewater-recovered struvite (**Crystal Green®**) to triple super phosphate, in soil columns 110mx500mm, soil pH 5.9 using spring wheat (*Triticum aestivum*) over 14 weeks. 3 dimensional micro-focus X-ray tomography (µCT) imaging showed that roots grew faster when they reached within a few mm of fertiliser granules and that there was a strong relationship between root length and struvite granule dissolution. The average struvite dissolution rate in these conditions showed to be 0.75 mm^3/week.

Soil pH

There has been discussion as to whether struvite is an effective fertiliser in neutral or slightly alkaline soils, see e.g. **Ackerman 2013** below. However, it should be noted that **most of the EU's soils are naturally acidic, mostly pH < 5.5,** with soil pH > 7 limited principally to Eastern Spain, Eastern Italy and small areas of Greece, Hungary, Austria. *http://eusoils.jrc.ec.europa.eu/library/data/ph/* However, agricultural arable soils will often be limed to increase pH to at least 6.

Ackerman (2013) found that swine manure recovered struvite and pure struvite showed lower fertiliser effectiveness (biomass production, phosphorus uptake) in pot trials using Canola (spring colza/rapeseed *Brassica napus*) in **prairie soils pH 7.7,** suggesting that this lower performance than commercial fertilisers in alkaline soil (see SCOPE 90). However, according to Katanda 2016, this may be because the soils used by Ackerman (sandy loam, 12 mg/kg bicarbonate extractable = Olsen P) were not very low in P which may have resulted in slower dissolution of struvite. Another possible explanation is that soil magnesium reduces struvite solubility.

Also the **IMPROVE-P project** (assessment of options for recycling phosphorus to Organic Farming) *https://improve-p.uni-hohenheim.de/* is currently compiling data on struvite as a fertiliser across different soil pH values.

The data does not indicate a pH dependency for the P fertilizer value of struvite. The overall mean value is nearly the same as for triple super phosphate TSP (struvite 95-100 % effectiveness of TSP), ranging from 60 to 125 % effectiveness of TSP. This will be published later in 2016.

Struvite fertiliser performance in non-acid soils

A number of authors have shown fertiliser performance of struvite in neutral/alkaline soils:

- **Cerillo (2014)** tested struvite recovered from pig manure in a 20-litre laboratory test reactor, in pot trials on lettuce, Barcelona, soil pH 8.1, Olsen P 29 mg/kg, showing that **struvite was as effective (biomass yield) as diammonium phosphate**.

- **Johnston (2003)** carried out pot trials of struvite, calcium phosphate and iron phosphate, with rye grass, in **soils pH 6.6 and 7.1.** All showed P **fertiliser effectiveness comparable to monocalcium phosphate**.

- **Katanda (2016)** tested struvite recovered from hog manure (ground, pasted, dried then cut into granules of comparable size to those of mono ammonium phosphate), compared to granular and polymer-coated mono ammonium phosphate. Two **soils of pH 7.6 and 8** were used. Canola (*Brassica napus*) and spring wheat (*Triticum aestivum*) was grown in pots in greenhouses, over three crop phases (C-SW-C and SW-C-SW). Struvite's fertiliser performance for canola, was similar to commercial monoammonium phosphate fertiliser for the first crop (for dry matter yield and for phosphorus uptake) and **superior to monoammonium phosphate** in the second and third crops of canola. Even though neither source of phosphate provided a dry matter yield response for wheat in any of the three crop phases, wheat uptake of P from monoammonium phosphate was greater than uptake from struvite in the first crop phase. **Katanda's 2014 thesis** also assesses the effects of struvite and mono ammonium fertiliser application on canola seedling emergence: mono ammonium phosphate reduced final seedling emergence for all tested application levels, with reductions up to 50%; polymer coated mono ammonium phosphate showed less negative impacts, and there were **no significant reductions in seedling emergence for struvite application**.

- **Liu (2016)** tested struvite recovered from urine in 42 day pot trials with bird rapeseed (*Brassica campestris*) in acid and neutral soils (**pH 6.0 and 7.3**) and irrigation waters (**pH 6.0 and 7.5**). Struvite showed fertiliser efficiency (biomass production, leaf P concentration, leaf chlorophyll) **as good as commercial calcium superphosphate** (i.e. single superphosphate) with alkali soil/water and better in the acid soil/water.

- **Massey (2009)** tested struvite and dittmarite (struvite mono-hydrate) in 120 day pot trials on spring wheat (*Triticum aestivum*) using slightly acidic rangeland soil (pH 6.5) and the same soil **limed to pH 7.6**. Two struvites were tested, recovered from dairy wastewater, and dittmarite which had precipitated spontaneously in a food processing plant. The struvites and dittmarate showed **fertiliser performance comparable to triple super phosphate in both acid and limed soils**, whereas rock phosphate did not in all cases. The authors note that liming may result in higher available P and may not give results comparable to naturally alkaline soils.
- **Uysal (2010,** SCOPE 95) tested struvite, recovered from sewage sludge and potato processing effluent in pot trials on corn and tomatoes, **soil pH 7.9, showing effectiveness comparable to commercial mineral fertilisers** (ammonium and potassium phosphates).
- **Vaneeckhaute (2015, 2016)** compared **NuReSys** struvite recovered from potato processing plant wastewater, pig manure, digestate and iron phosphate sludge from piggery manure dephosphatation to triple super phosphate (TSP) in 40-day maize pot trials, in two **soils pH 5 and pH 7.9**. Yield results were not significantly different from control for any of the treatments in both soils (except for a lower yield with TSP in the acidic soil). Based on soil P solubility analysis and Rhizon soil moisture samplers, the authors conclude that **struvite stimulates release of P from the soil complex, providing high P availability at the start of the growing season and a stock of P for later release**, whereas iron phosphate was not useful for short term P release.
- **Wilken (2015),** demonstrated in pot trials that wastewater derived struvite products from different recovery processes had comparable fertilization performances to TSP on acidic and neutral soils (**soil pH 4.9 and 7.1**). Field trials showed no significant differences between all fertilizers including TSP and the unfertilized plots. This was due to the high phosphorus content of the soils.

Many tests show struvite fertiliser effectiveness in acidic or unspecified soils

Achat (2014 - I, 2014 - II) tested pure struvite, pure hydroxyapatite (calcium phosphate) and four phosphates recovered from pig manure, containing struvite and poorly crystallised calcium phosphates and magnesium oxide (see Morel in SCOPE 101), in 2 month pot trials, soil pH 6.5, P deficient soil (P-Olsen 14 mg/kg soil) on both on a mixture of rye grass (*lolium perenne*) and fescue (*Festuca rubra*). These pot trials were completed (Achat 2014 – II) with soil incubation tests, with soils pH 5.2 – 8.1 (isotopically exchangeable inorganic phosphate after 28 days incubation at 28°C, looking also at soil calcium carbonates and iron and aluminium oxyhydroxides). All four tested products were as effective fertilisers as triple super phosphate (biomass production, P uptake) at soil pH 5. Pure and recovered struvite were also of similar fertiliser efficiency as triple super phosphate at soil pH 8, whereas hydroxyapatite was of lower efficiency at soil pH 8.

Antonini (2012, SCOPE 88) carried out pot trials using rye grass and maize (soil pH not specified) on six urine derived struvites, showing fertiliser performance comparable or better than superphosphate.

Barak (2006) tested struvite in 6 week pot trials with maize (soil pH not specified), showing higher fertiliser performance than mono ammonium phosphate.

Bonvin (2015, SCOPE 112) used 33P and 15N radioisotope-labelled struvite to assess P and N uptake by rye grass in pot trials, soil pH 5.4. The struvite N and P were as for soluble ammonium nitrate and monopotassium phosphate.

Cabeza (2011, SCOPE 85) tested struvite in 2-year pot trials on maize, in soils pH 4.7 and 6.6, concluding that struvite was as effective a fertiliser as TSP and that water and 2% citric acid P-solubility were not good indicators of phosphorus crop availability.

Ganrot (2006 and 2007) carried out pot trials on spring wheat in sand and water, using struvite and nutrient-loaded zeolites, both from urine nutrient recovery. Results do not provide relevant information regarding struvite fertiliser effectiveness.

Ghosh (1996, SCOPE Newsletter 37), India, tested struvite, brushite, strengite and variscite, compared to diammonium phosphate and single super phosphate in pot trials of chick peas, soil pH 5.1, showing that struvite was as effective as the commercial fertilisers at 12 mgP/kg soil application.

Gonzalez Ponce (2007 and 2009) carried out 98 day pot trials of wastewater recovered struvite ground <0.15mm, with ryegrass, soil pH 5.7 and three month pot trials with lettuce in soil pH 5.9 (grinding of struvite not specified). For the ryegrass, struvite applied and dug into soil four months before planting showed to be as or more effective than MAP (mono ammonium phosphate) and calcium superphosphate applied two days before sowing. For the lettuce, struvite mixed into soil 4 days before planting showed to be a more effective fertiliser than single superphosphate (the authors suggest that this may be the result of the magnesium supplied in the struvite).

Goto (1998, SCOPE 42) reported pot trials with *Brassica campestris*, soil pH 5.8, showing that struvite was as effective as superphosphate.

Li & Zhao (2003) tested struvite recovered from landfill leachate in 33 - 35 day pot trials using two cabbage / chard species (*Brassica parachinensis*, *B. rapa*), water spinach (*Ipomoea aquatica*) and water convolvulus (*I. reptans*) in soil pH 6.2, showing fertiliser performance better than monocalcium phosphate.

Liu (2011, SCOPE 94) tested struvite recovered from piggery waste on maize in 56-day pot trials, soil pH 6, showing better performance than fused superphosphate.

Manning (2006, SCOPE 69) tested struvite in pot trials on hard and soft wheat, soil pH not specified, showing plant growth and uptake comparable to DCP (di calcium phosphate).

Plaza (2007) tested struvite recovered from sludge digestate in pot trials with ryegrass, soil pH 5.7, showing growth and P uptake as effective as for single super phosphate.

Prater (2014) tested recovered struvite in pot trials of maize and kale. Soil pH is not indicated. Struvite was not as effective a fertiliser as 'MiracleGro' 10-10-10) but this may be because nitrogen was not dosed. Phosphorus uptake was as good with struvite as with MiracleGro.

Römer (2013, SCOPE 97) summarised results from several published pot trials of struvite (**Cabeza Perez 2010, 2011 see below SCOPE 85; Waida 2011**) showing that struvite is as effective a phosphorus fertiliser as TSP (triple super phosphate), on condition that there is not significant iron contamination. **Römer (2006**, SCOPE 68) tested 26 phosphate compounds (calcium, magnesium, ammonium, iron, aluminium phosphates), four commercial phosphate fertilisers, two phosphate slags and two recovered struvites in 21-day pot trials using rye grass in quartz sand: the recovered struvites showed to be as effective or better fertilisers than superphosphate.

Ryu (2009, 2011, SCOPE 88 and 2012) tested struvite recovered from semiconductor factory discharge on lettuce in pot trials (soil pH 5.3), showing performance comparable to TSP. **Ryu (2016)** published further tested struvite recovered from swine wastewater in pot trials with lettuce (soil pH 5.3) showing that struvite was a more effective fertiliser than mineral ammonium phosphate $(NH_4)_2HPO_4$.

Sigurnjak (2016, but see also SCOPE 100, SCOPE 102) has published results from the ARBOR project (biomass for energy). Field trials were carried out maize with manure, manure digestate, liquid fraction of digestate and ammonium sulphate recovered from anaerobic digester gas, as well as 10 m^2 greenhouse trials (34 days, lettuce plants) on these products and also struvite. The greenhouse soil pH was 6.2 - 6.3 and nutrient poor (1.3 - 1.7 mgP/kg). Phosphorus NUE (nutrient use efficiency) has higher for struvite than for triple super phosphate. Information is included in the **ARBOR** "Case study report. Nutrient recovery from digestate", June 2015, *http://hdl.handle.net/1854/LU-7018542* and full results and test details (e.g. soil pH) are published in the cited paper.

Vogel (2015) tested wastewater-recovered struvite from **Berlin Wasserbetriebe**, dried sewage sludge and several treated sewage sludge incineration ashes, compared to triple super phosphate (TSP) in pot trials on maize, forage rye (*Hordeum vulgare*), sorghum (*Sorghum bicolor*), amaranth (*Amaranthus hypochondracus*) and sunflower (*Helianthus annuus*) in soil pH 5.2. Plant growth with struvite was in most cases as good or better than with TSP, and better than with the sewage sludge incineration ashes.

Yetilmezsoy (2009) tested struvite recovered from UASB treated poultry manure as fertiliser for purslane, garden cress and grass in pot trials using garden soil (pH not specified), showing higher growth than control (mineral fertiliser was not compared). Yetilmezsoy (2013) further tested struvite from the same source for four fast-growing medicinal plants (herbs: rocket, dill, fennel, parsley) in pot trials soil pH 5.5-6. Commercial fertiliser was not tested for comparison but plant weights increased by +22% to +400% compared to control. The struvite-produced rocket (*Eruca sativa*) was fed to guppy fish for 170 hours (*Lebistes reticulatusus*) showing no signs of toxicity and confirming that use as animal feed would be acceptable.

Kataki (2016) provides a **review of recent publications** on struvite precipitation techniques (including alternative magnesium sources, use of seed materials), struvite precipitation as a route for nitrogen conservation and struvite as a fertiliser.

Magnesium accumulation

She poses the question of **possible soil magnesium accumulation** through use of struvite as a fertiliser. If soil magnesium were to become higher than soil calcium, this could affect soil quality (clay swelling, impacting porosity, aggregation) and could impact plant calcium uptake. This should be taken into consideration before repeated struvite application to the same field, or struvite should be blended with other fertiliser materials, or should be applied to crops with significant magnesium requirements and offtake.

Achat (2014 - I) "Plant-availability of phosphorus recycled from pig manures and dairy effluents as assessed by isotopic labeling techniques", Geoderma 232–234 (2014) 24–33 http://dx.doi.org/10.1016/j.geoderma.2014.04.028 *D. Achat (a,b,c), M. Sperandio (c,d,e), M-L. Daumer (f), A-C. Santellani (f), L. Prud'Homme (a,b), M. Akhtar (g), C. Morel (a,b). a = INRA, UMR 1391 ISPA, F-33140 Villenave d'Ornon, France. b = Bordeaux Sciences Agro, UMR 1391 ISPA, F-33170 Gradignan, France. c = Université de Toulouse, INSA, UPS, INP, LISBP, F-31077 Toulouse, France. d = INRA, Ingénierie des Systèmes Biologiques et des Procédés, UMR792, F-31400 Toulouse, France. e = CNRS, UMR5504, F-31077 Toulouse 04, France. f = IRSTEA/Cemagref, UR GERE, 17 Avenue de Cucillé, CS 64427, F-35044 Rennes Cedex, France. g = Nuclear Institute for Agriculture and Biology, P.O. Box 128, Jhang Road, Faisalabad 38000, Pakistan.*

Achat (2014 – II) "Solubility and mobility of phosphorus recycled from dairy effluents and pig manures in incubated soils with different characteristics", Nutrient cycling in agroecosystems 99, 1-15, 2014 http://dx.doi.org/10.1007/s10705-014-9614-0

Ackerman (2013) "Evaluation of manure-derived struvite as a phosphorus source for canola", Can. J. Plant Sci. (2013) 93: 419-424 http://dx.doi.org/10.4141/CJPS2012-207 *J. Ackerman, F. Zvomuya, N. Cicek, D. Flaten, University of Manitoba, Winnipeg, Manitoba, Canada R3T 2N2* joe.ackerman@gmail.com

Ahmed (2006) "Use of Struvite, a Novel P Source Derived from Wastewater Treatment, in Wheat Cultivation", 18th World Congress of Soil Science, 9-15 July 2006, Philadelphia USA https://crops.confex.com/crops/wc2006/techprogram/P16683.HTM *S. Ahmed, R. Shiel, D. Manning. University of Newcastle, Newcastle upon Tyne, United Kingdom*

Ahmed (2016) "Imaging the interaction of roots and phosphate fertilizer granules using 4D X-ray tomography", S. Ahmed, T. Klassen, S. Keyes, M. Daly, L. Jones, M. Mavrogordat, I. Sinclair, T. Roose, Plant Soil 401:125–134 http://dx.doi.org/10.1007/s11104-015-2425-5

Antonini (2012, SCOPE 88) "Greenhouse evaluation and environmental impact assessment of different urine-derived struvite fertilizers as phosphorus sources for plants", Chemosphere 89, 1202–1210, 2012 http://dx.doi.org/10.1016/j.chemosphere.2012.07.026

Bonvin (2015, see SCOPE 112) "Plant uptake of phosphorus and nitrogen recycled from synthetic source-separated urine", C. Bonvin, B. Etter, K. Udert, E. Frossard, S. Nanzer, F. Tamburini, A. Oberson. AMBIO (2015) 44:217-227 http://dx.doi.org/10.1007/s13280-014-0616-6

Barak P, 2006 & Stafford A. "Struvite: a recovered and recycled phosphorus fertiliser", Proceedings of the 2006 Wisconsin Fertilizer, Aglime and Pest Management Conference, 17-19 January 2006, Wisconsin http://extension.soils.wisc.edu/wp-content/uploads/sites/47/2014/02/2006_wfapm_proc.pdf

Cabeza (2011) "Effectiveness of recycled P products as P fertilizers, as evaluated in pot experiments", http://link.springer.com/article/10.1007%2Fs10705-011-9454-0

Cerillo (2014) "Struvite precipitation as a technology to be integrated in a manure anaerobic digestion treatment plant – removal efficiency, crystal characterization and agricultural assessment", J Chem Technol Biotechnol 2014 http://dx.doi.org/10.1002/jctb.4459 *M. Cerrillo, J. Palatsi, A. Bonmatí, IRTA, GIRO Joint Research Unit IRTA-UPC, Torre Marimon. E-08140, Caldes de Montbui, Barcelona, Spain.* august.bonmati@irta.cat *J. Comas, Universitat Politècnica de Catalunya (UPC), Dep. d'Enginyeria Agroalimentària i Biotecnologia, Esteve Terradas 8 08860 Castelldefels, Barcelona, Spain. J. Vicensc, Apergas Paratge Bosc de Sant Mer s/n, Sant Esteve de Guialbes (Vilademuls), Girona, Spain*

Crutchik (2016) "Kinetics of the reversible reaction of struvite crystallisation", D. Crutchik & J. Garrido, Chemosphere vol. 154, 567-572, July 2016 http://dx.doi.org/10.1016/j.chemosphere.2016.03.134

DEFRA (2008), SID5 Research Project Final Report HH3504SPO Sustainable Phosphorus Fertilisation of Potatoes, Hammond & White, Warwick HRI, http://randd.defra.gov.uk/Document.aspx?Document=HH3504SPO_8121_FRP.doc

Gell, K., Ruijter, F.J., Kuntke, P., Graaff, M., Smit, A.L., 2011. Safety and effectiveness of struvite from black water and urine as a phosphorus fertilizer. J. Agric. Sci. 3, 67–80 http://www.ccsenet.org/journal/index.php/jas/article/view/7677

Ganrot (2007) "Plant availability of nutrients recovered as solids from human urine tested in climate chamber on Triticum aestivum L.", Z. Ganrot, D. Göran, E. Nilsson, B. Li, Bioresource Technology 98 (2007) 3122-3129 http://dx.doi.org/10.1016/j.biortech.2007.01.003

Ganrot Z., 2008 "Nutrient Recovery from Human Urine Using Pretreated Zeolite and Struvite Precipitation in Combination with Freezing-Thawing and Plant Availability Tests on Common Wheat", Clean 36(1) 45-52 http://dx.doi.org/10.1002/clen.200700074

Ghosh G 1996 (see SCOPE 37° "Characterization of soil-fertilizer P reaction products and their evaluation as sources of P for gram (Cicer arietinum L.)" Nutrient Cycling in Agroecosystems 46, 71-79, 1996

Gonzalez Ponce (2007) "Evaluation of struvite as a fertilizer: a comparison with traditional P sources", R. Gonzalez Ponce, D. Garcia Lopez, 2007, Agrochimica 51, 301-308, 2007

Gonzalez-Ponce (2009) "Lettuce Response to Phosphorus Fertilization with Struvite Recovered from Municipal Wastewater, R. Gonzalez Ponce, D. Garcia Lopez, C. Plaza, Hort Science 44(2) 426-430 http://hortsci.ashspublications.org/content/44/2/426.full

Hammond (2005) "Entrust project 675382.006 Is struvite a valuable phosphate source for agriculture?", Warwick HRI, 29th March 2005 http://www.hutton.ac.uk/sites/default/files/files/staff/white/Struvite%20Final%20Report%20March%202005%20v02.pdf

Johnston (2004) "Effectiveness of different precipitated phosphates as phosphorus sources for plants", Soil Use and Management (2003) 19, 45-49. Phosphorus Research Bulletin 15, 52-59, 2004, A. Johnston, I. Richards, http://www.sswm.info/library/4095

Kataki (2016) "Review. Phosphorus recovery as struvite: Recent concerns for use of seed, alternative Mg source, nitrogen conservation and fertilizer potential", S. Kataki, H. West, M. Clarkec, D. Baruah, Resources, Conservation and Recycling 107, 142–156 http://dx.doi:10.1016/j.resconrec.2015.12.009

Katanda (2014) "Hog manure-recovered struvite as a phosphorus source for enhanced phosphorus use efficiency and reduced seedling toxicity in Canola", Y. Katanda, University of Manitoba thesis, 2014 http://mspace.lib.umanitoba.ca/handle/1993/25155

Katanda (2016) "Hog-Manure-Recovered Struvite: Effects on Canola and Wheat Biomass Yield and Phosphorus Use Efficiencies", Soil Sci. Soc. Am. J., 22nd January 2016, Y. Katanda, N. Cicek, F. Zvomuya, D. Flaten, Dep. of Soil Science, 362 Ellis Bldg, Univ. of Manitoba, Winnipeg, MB, R3T 2N2, Canada. Biosystems Engineering, Univ. of Manitoba, Winnipeg, MB, R3T 2N2, Canada. * now Environmental and Life Sciences, Trent Univ., 1600 West Bank Drive, Peterborough, ON, K9J 7B8, Canada.* http://dx.doi.org/10.2136/sssaj2015.07.0280

Latifian (2012) "Struvite-based fertilizer and its physical and chemical properties", M. Latifian, J. Liu, B. Mattiasson, Environmental Technology 33:24, 2691-269, 2012 http://dx.doi.org/10.1080/09593330.2012.676073

Li X. & Zhao Q. (2003) "Recovery of ammonium-nitrogen from landfill leachate as a multi-nutrient fertilizer", Ecological Engineering, Volume 20, Issue 2, May 2003, Pages 171–181 http://dx.doi.org/10.1016/S0925-8574(03)00012-0

Liu X. (2016) "Influence of Soil and Irrigation Water pH on the Availability of Phosphorus in Struvite Derived from Urine through a Greenhouse Pot Experiment", J. Agric. Food Chem. 2016, 64, 3324−3329 http://dx.doi.org/10.1021/acs.jafc.6b00021

Massey (2009) "Effectiveness of recovered magnesium phosphates as fertilizers in neutral and slightly alkaline soils", M. Massey, J. Davis, J. Ippolito, R. Sheffield, vol. 101, issue 2, 323–329, 2009, doi:10.2134/agronj2008.0144 http://naldc.nal.usda.gov/download/28305/PDF

Nelson (2000) "Phosphorus removal from anaerobic swine lagoon effluent as struvite and its use as a slow-release fertilizer", Masters Thesis, Dept. of Soil Science. North Carolina State University, Raleigh, NC, USA – not available.

Plaza C. (2007) "Greenhouse Evaluation of Struvite and Sludges from Municipal Wastewater Treatment Works as Phosphorus Sources for Plants", C. Plaza, C. Sanz, C. Clemente, J. Fernández, R. González, A. Polo, and M. Colmenarejo, J. Agric. Food Chem. 2007, 55, 8206–8212 http://dx.doi.org/10.1021/jf071563y

Prater, J., 2014. Improved Production of Magnesium Ammonium Phosphate (Struvite) from Landfill Leachate. Final Report. Solid Waste Research Program, University of Wisconsin System, https://www.wisconsin.edu/waste-research/download/final_reports/2014_final_reports/14%20SPT%20Prater%20stuvite(2).pdf

Rothbaum H. (1976) "Long-term leaching of nutrients from magnesium an1monium phosphate at various temperatures", N.Z. Journal of Experimental Agriculture 4: 405-13

Ruiz Diaz D. (2010), see SCOPE 90, "Phosphorus Recovered from Feedlot Manure as Fertilizer Source for Corn and Soybean", Kansas Fertiliser Research 2010 (Kansas State University), pages 8-11 http://www.agronomy.k-state.edu/research/research-reports/

Ryu (2012) "Evaluation of struvite obtained from semiconductor wastewater as a fertilizer in cultivating Chinese cabbage", Ryu Journal of Hazardous Materials 221– 222 (2012) 248– 255 http://dx.doi.org/10.1016/j.jhazmat.2012.04.038

Sigurnjak I. (2016) "Utilization of derivatives from nutrient recovery processes as alternatives for fossil-based mineral fertilizers in commercial greenhouse production of Lactuca sativa L." Scientia Horticulturae 198 (2016) 267–276 http://dx.doi.org/10.1016/j.scienta.2015.11.038

STOWA (2016). Struviet en struviethoudende producten uit communaal afvalwater. Stichting Toegepast Onderzoek Waterbeheer (STOWA), Amersfoort, Netherlands, 2016. ISBN 978-90-5773-731-2. Report number 2016-12. http://www.stowa.nl/publicaties/publicaties/marktverkenning_en_gewasonderzoek_struviet_en_struviethoudende_producten_uit_communaal_afvalwater (in Dutch)

Talboys (2016) "Struvite: a slow-release fertiliser for sustainable phosphorus management?", P. Talboys, J. Heppell, T. Roose, J. Healey, D. Jones, P. Withers, Plant Soil (2016) 401:109–123 http://dx.doi.org/10.1007/s11104-015-2747-3

Thompson L. (2013), "Field evaluation of the availability for corn and soybean of phosphorus recovered as struvite from corn fiber processing for bioenergy" Iowa State University agronomy thesis, http://lib.dr.iastate.edu/etd/13173/

Thompson (2012 - I) "Plant availability of phosphorus from struvite produced during corn bioenergy processing", L. Thompson & A. Mallarino, p. 104 in 42nd North-Central Extension-Industry Soil Fertility Conf. Proceedings,14-15 Nov. 2012, Vol. 28, Des Moines, IA. International Plant Nutrition Institute, Brookings, SD.

Thompson (2012 – II) "Crop Availability of Phosphorus Recovered As Struvite From Corn Processing for Bioenergy in Corn-Soybean Rotations", Poster n° 2209, L. Thompson & A. Mallarino, ASA – CSSA – SSSA 21-24 Oct 2012, Cincinnati https://scisoc.confex.com/crops/2012am/webprogram/Paper75016.html

Veneeckhaute (2016) "Phosphorus Use Efficiency of Bio-Based Fertilizers: Bioavailability and Fractionation", C. Vaneeckhaute, J. Janda, P. Vanrolleghem, F. Tack, E. Meers, Pedosphere 26(3): 310–325, 2016 http://modeleau.fsg.ulaval.ca/fileadmin/modeleau/documents/Publications/pvr1217.pdf

Vaneeckhaute (2015) "Efficiency of Soil and Fertilizer Phosphorus Use in Time: A Comparison Between Recovered Struvite, FePO4-Sludge, Digestate, Animal Manure, and Synthetic Fertilizer", C. Vaneeckhaute in A. Rakshit "Nutrient use efficiency: from basics to advances", Springer India 2015 http://link.springer.com/chapter/10.1007%2F978-81-322-2169-2_6

Vogel (2015) "Phosphorus application with recycled products from municipal waste water to different crop species", T. Vogel, M. Nelles, B. Eichler-Löbermann, Ecological Engineering 83 (2015) 466–475 http://dx.doi.org/10.1016/j.ecoleng.2015.06.044

Westerman (2009) "Struvite crystallizer for recovering phosphorous from lagoon and digester liquid". NC State University collaborative Extension program, USA 10/2009, P. Westerman, K. Zering, D. Rashash, https://www.bae.ncsu.edu/extension/ext-publications/waste/animal/ag-724w-struvite-westerman.pdf

Waida (2011) "Untersuchung der in der Förderinitiative erzeugten Produkt" in: Abschlussbericht: Phosphorrecycling – Ökologische und wirtschaftliche Bewertung verschiedener Verfahren und Entwicklung eines strategischen Verwertungskonzeptes für Deutschland (PhoBe), Aachen, 2011, 97–162 http://www.isi.fraunhofer.de/isi-wAssets/docs/n/de/publikationen/Abschlussbericht_PhoBe-1.pdf

Wilken (2015) "Product quality: fertilizing efficiency, results of pot and field tests", P-REX presentation, V. Wilken, O. Zapka, A. Muskolus http://p-rex.eu/uploads/media/3_P-REX_pot_tests_and_field_trials_Wilken.pdf

Yetilmezsoy K. & Sapci-Zengin Z. (2009) "Recovery of ammonium nitrogen from the effluent of UASB treating poultry manure wastewater by MAP precipitation as a slow release fertilizer", J. Hazard. Materials 166, 260-269, 2009 http://dx.doi.org/10.1021/jf071563y

Yetilmezsoy K. (2013) "Medicinal plants grown in soil amended with struvite recovered from anaerobically pretreated poultry manure wastewater", J. Animal & Plant Sciences 23(1): 2013, page: 261-270, http://www.thejaps.org.pk/docs/v-23-1/40.pdf *K. Yetilmezsoy, F. Turkdogan, A. Gunay, M. Kaleki, Yildiz Technical University, 34349, Besiktas, Istanbul, Turkey* yetilmez@yildiz.edu.tr

Nutrient recycling

US EPA Nutrient Recycling Challenge

Ten innovative manure treatments awarded covering digestion, chemical treatment, separation, stripping.

The **US EPA manure Nutrient Recycling Challenge** received 75 entries, of which 34 were selected to proceed to the next phase and ten were awarded on 30th March in Washington DC cash prizes of 1 000 – 6 000 US$ prizes. The EPA and the 19 Challenge partners (companies, NGOs, research institutes, government agencies) will support the development of these promising technologies ideas in subsequent phases of the Challenge.

The SCOPE Newsletter presents below information about the award winning technologies, validated with the technology developers:

Winners:

- **Bravespec Systems** (no website) – centrifuge technology using Coandă effect for separation of small solid particles with reduced energy and costs. No further information available.

- **Paulee Cleantec, Israel** *www.pauleecleantec.com* – an oxidising chemical is mixed with manure or other organic material, generating heat, and rapidly converting the manure to a "dry, ash like" powder which can be used as an NPK fertiliser (fertiliser trials have been carried out under a Bill and Melinda Gates Foundation grant: results not published). The *patent* indicates that oxidising agents such as peroxides, persulphates, ozone or halogens can be used, with the reaction generating heat, and that a neutralising agent is also required. Running water is not required.

- **AnSBEARs, University of Minnesota** - anaerobic digestion combined with enhanced solid-liquid separation to generate N& P fertilizer (see "Evaluation of anaerobic co-digestion of dairy manure with food wastes via bio-methane potential assay and CSTR reactor" *https://dx.doi.org/10.1080/03601234.2015.982432* and "Phosphorus Removal and Recovery from Digestate after Biogas Production" *http://dx.doi.org/10.5772/60474*)

- **CNP-Technology Water and Biosolids Corp. and Centrisys Corp.** *http://cnp-tec.com/* and *http://centrisys.com/* - CO2 stripping to produce struvite from manure digestate. Achieving high phosphate removal and partial ammonia removal from manure liquid by placing AirPrex® struvite precipitator before a decanter centrifuge.

- **Tulika Arora, Wallenberg Laboratory, University of Gothenburg, Sweden** – using Azolla (aquatic fern) for biological nutrient recovery

- **PRD Tech Inc** *www.prdtechinc.com* and **Ocean Foresters** *http://oceanforesters.org* Ammonia+ Recovery Unit (A+RU) – recovers phosphorus as calcium phosphate and nitrogen as ammonia gas (90% ammonia gas with water vapour), which can be converted to ammonia-water or ammonium salts. The A+RU can be applied to municipal wastewaters, anaerobic reactor digestates and any liquid streams rich in N and/or P. To date, two pilot-scale Ammonia+ Recovery Units have been built and operated for recovery of N and P from municipal wastewater.

- **DVO Inc** *www.dvoinc.com* – **Advanced Phosphorus Recovery System,** details *27th May 2015* - manure wastes that are pre-processed using a specific 2-Stage Mixed Plug-Flow™ anaerobic digester, then a bio-degradable polymer used, resulting in up to 95% phosphorus removal and up to 50% total nitrogen removal from the digestate. These nutrients are recovered in a stable, stackable and potentially saleable organic fertilizer that can be economically transported away from sensitive watersheds to farmland that can benefit from it.

- **KU Leuven – University of Leuven, Belgium, Power and Water Corporation, Darwin and Flinders University, South Australia** – lime is dosed to increase pH, so precipitating calcium phosphates and ensuring sanitisation, and ammonia is stripped for N recovery. A specific flocculation technology is used to separate solids and calcium phosphate, then CO2 to restore liquid pH before effluent water reuse. The phosphate sludge can be used as is, dewatered or chemically treated to produce a soluble fertiliser product. A proof-of-concept pilot test has been performed with municipal wastewater with chemical costs of 15 €/ million litres. See abstract on *www.phosphorusplatform.eu* under downloads

- **AWS Ag Waste Solutions** *www.agwastesolutions.com* and **Scott Dairy Farms** *www.scottbrothers.com* – *processing* to pyrolysis to biochar (fertiliser) and diesel fuel

- **Trident Processes** *www.tridentprocess.com* and **Soil Net** *www.soilnetllc.com* – anaerobic digestion, rotary screen to separate fibre (can be used for animal bedding), then solid/liquid separation by flotation and skimming, and finally a press system to generate a dry solid organic fertiliser product, see *2013 article* and *2015 Fair Oaks Dairy Farm article* R&D developments proposed include granulation of the fertiliser product, ammonia recovery, clarification of the liquid effluent to enable stream discharge, use of the fibre for ethanol or organic polymer production.

US EPA press release 30th march 2016 https://yosemite.epa.gov/opa/admpress.nsf/3881d73f4d4aaa0b85257359003f5348/a0a071cad98f1cef85257f85007d21e5 *List of 10 award winners* https://www.challenge.gov/challenge/nutrient-recycling-challenge/ *List of 34 phase II pre-selected submissions* https://www.challenge.gov/files/2015/10/Nutrient-Recycling-Challenge-Phase-I-Selections.pdf

Recycling of phosphorus in Norway

In May 2015, the Norwegian EPA issued a Report on phosphorus recycling in Norway, based on a task given by the Ministry of Environment.

In the Report the following recommendations were given:

- The Ministry should start a process in order to **establish a goal/an ambition level for recycling of phosphorus** from sewage, animal manure, aquaculture and organic waste

- The EPA should continue to look into the potentials for **increased recycling** from these sources

In addition, conclusions and recommendations from the Report are:

- The largest **secondary sources of phosphorus** in Norway are; manure with 11.600 tonnes P per year, aquaculture with 9.000 and sewage with 3.000 tonnes
- **More than 50% of the phosphorus spread on farmland is not utilized by crops**, and some 5% will end up as run off. The remaining will be stored "forever"
- **Plants are only partly able to make use of phosphorus from sewage sludge, because of aluminum and iron use at high concentrations for chemical P removal in sewage works**
- Norway will have to consider to reconstruct the wastewater treatment industry in order to **produce a sludge that will increase the recycling**
- Primary treatment is under enforcement in Norway and hence **more sludge will be produced in the future, containing more phosphorus**. This will take place in areas were the phosphorus demand is low and alternative uses to spreading on farmland should be found
- **Phosphorus from aquaculture is not recycled**. This is Norway's second biggest source, 9.000 tons P per year and expected to increase to some 40 000 tons P within the next 10 years
- **More treatment for aquaculture discharges will be introduced in the future**, often in the rural areas cited above, and the aquaculture sludge production could be treated in combination with sewage sludge
- There is today **not enough information** to define a realistic ambition level for P-recycling in Norway
- It is **too early to initiate a phosphorus platform in Norway**. This should be considered after an ambition level is decided
- Phosphorus in waste is not a ready-to-use fertilizer and **cooperation with producers of fertilizers is needed** to find good practice for utilizing this phosphorus in combination with nitrogen, potassium and soil.
- If farmers continue to use more phosphorus than needed one strategy could be to **use recycled phosphorus in other areas**, like compost or other soil based products

New EPA task launched

In March 2016 another task was given to the Norway EPA according to these recommendations. The Agency will in June start a new activity with the following ambitions:

- **Investigate the cost and benefits** connected to increase recycling phosphorus from agriculture, aquaculture, sewage sludge and other sources

- Develop a **strategy for phosphorus recycling** in general and for each sector concerned

A final report should be ready before end 2016

The report can be found here, but is available only in Norwegian.
http://www.miljodirektoratet.no/no/Publikasjoner/2015/Juni/Bedre-utnyttelse-av-fosfor-i-Norge/

Policy

EU Parliament Agriculture Committee supports manure nutrient recycling

Netherlands Member of the European Parliament, Jan Huitema's, text calls on the European Commission to revise the EU Fertiliser Regulation, remove barriers in the Nitrates Directive and implement special rural development programmes to stimulate the recycling of nutrients as mineral concentrates from animal manure.

This was voted in April 2016 by a large majority of the Parliament Agriculture Committee, in Mr Huitema's *report* on innovation and economic development in European farm management (2015/2227). The voted text notes concern that the EU is highly dependent on the import of minerals for fertilisers and underlines the **possibility to recover nutrients from animal manures to produce 'green fertilisers'**.

Mineral concentrates

Mr Huitema's *website* notes that mineral concentrates from manures can make a major contribution to the **circular economy**, are good for the environment, and avoid natural gas consumption and mineral import for fertiliser manufacture.

ESPP note: the EU Fertiliser Regulation revision proposals published 18th March and open to consultation (see SCOPE Newsletter 120) cover digestate and compost produced from manure, but phosphate minerals recovered from manure are not covered (work on struvite is underway) and nitrogen concentrates or chemicals recovered from manure are not yet taken into account. The Nitrates Directive issues with nitrogen minerals recovered from manures are discussed in SCOPE Newsletter 100.

Jan Huitema website "Huitema's initiative for green fertiliser widely supported" http://www.janhuitema.nl/initiatief-huitema-voor-groene-kunstmest-breed-gesteund/

European Parliament Committee on Agriculture and Rural Development "Draft report on enhancing innovation and economic development in future European farm management", Rapporteur Jan Huitema, 2015/2227(INI), vote in Committee 21st April 2016
http://www.europarl.europa.eu/sides/getDoc.do?type=COMPARL&mode=XML&language=EN&reference=PE569.493

EU Nitrates Directive implementation

France's Agriculture and Environment Ministries have published a 160 page study of EU Nitrates Directive implementation and manure spreading limitations in six EU Member States. The report concludes by proposing the organisation of a workshop to bring together the six States concerned to exchange on experience of designing and implementing regulation and its effectiveness.

The six EU Member States studied are **Germany, Belgium - Flanders, Denmark, Spain – Catalonia, Ireland and The Netherlands**, each of which was visited to meet competent regulatory authorities.

Questions addressed and different countries' approaches compared include: definition of Nitrate Vulnerable Zones and Action Programmes ; issues such as manure spreading limits, manure storage, balanced fertilisation calculation ; financial and technical support ; appreciation of effectiveness of programmes ; coherence with other EU regulation. Detailed summaries for each of the six countries are provided in annex.

All the countries visited (except Denmark) have faced European Commission infraction proceedings for failure to respect the Nitrates Directive, though in most cases these were resolved some years ago, whereas France was condemned in 2013 and 2014 (see SCOPE Newsletter n° 107).

The report includes:

- Approaches to defining the geographical coverage of **Nitrate Vulnerable Zones**
- National **transposition** of the Nitrates Directive and regionalised Action Programmes
- Acceptance of Programmes by the European Commission and list of infraction procedures (p20)
- **Contents of Action Programmes**, by country
  - types of fertilisation
  - spreading dates, for different manures, on different crops / land uses
  - spreading limits related to climate and soil, slope
  - manure storage capacities and types
  - minimal distance from water courses for fertilisation
  - nutrient spreading (dose) limits for different crops, production levels, irrigation, types of nutrient used
  - derogations, with a table for different Member States (p40)
  - nitrogen production coefficients for different livestock
- Control and monitoring systems

The use of different Programme **tools to limit nutrient spreading** is assessed, including manure treatment processes, nutrient dosage limits and derogations to the 170 kgN/ha for manure based nitrogen, grass bands alongside watercourses, cover crops for N uptake, farmer support and advice.

Defining and achieving environmental objectives

The Nitrates Directive does not fix water quality objectives (*Editor's Note: the Water Framework Directive very clearly does, however*) and **environmental objectives, measurement and progress assessment methods vary significantly between the different Member States**.

Once basic obligatory measures are put in place, reductions in water resource nitrate concentrations in response to further actions become slower. **"Legacy" nitrates continue to migrate into groundwater for many years.**

Measures also vary considerably between different regions in Member States which have designated large Vulnerable Zones, in order to adjust to varying climate, livestock systems, water quality issues.

Five of the six Member States studied have obtained **derogations to the Nitrates Directive ceiling of 170 kg manure-derived nitrogen per hectare**. In exchange, their **Action Programme obligations are considerably stricter in regions where the derogation applies**, and become even stricter as derogations are repeated.

Balanced fertilisation

The Member States have a holistic approach to fertilisation and manure spreading, **covering both phosphorus and nitrogen**, water quality (EU Water Framework Directive) and air quality (National Emissions Ceilings Directive), soil quality, agricultural practices and nutrient recycling. Measures tend to be geographically targeted, particularly strict in identified highly sensitive zones.

Denmark, The Netherlands and Flanders have detailed systems for **calculating balanced fertilisation**, including data input directly online by farmers and other actors. Data on fertilisation is compounded with CAP data (hectares, crops), animal identification data and other regulatory obligatory declaration data. These systems can support farmers in defining appropriate fertilisation, input to nutrient accounting and enable controls.

The study notes that **pressure on manure management**, which is intensifying with the end of milk quotas, is leading the Member States to innovate in regulatory and social techniques, and to wish to negotiate new regulatory tools with the European Commission.

Need for research, support and exchange

The report notes that in the different Member States scientific expert assessment, R&D and consulting support to farmers are in place, often combined with assistance to farmers to optimally use EU farm support funds and to prepare for regulatory changes.

The authors identify a need to work in each Member State to establish and **improve modelling of impacts of Action Programmes** and to estimate when these are susceptible to result in achieving Water Framework Directive quality objectives for surface and ground water.

They conclude with the **proposal to organise a meeting between the different Member States** concerned to discuss the report conclusions and a prospective vision of Nitrates Directive implementation.

"Analyse de la mise en oeuvre de la directive nitrates par d'autres Etats membres de l'Union européenne. Allemagne, Belgique (Flandre), Danemark, Espagne (Catalogne), Irlande, Pays Bas" (Analysis of implementation of the Nitrates Directive by other European Member States: Germany, Belgium (Flanders), Denmark Spain (Catalonia), Ireland, The Netherlands. J. Gault, M. Guillet, C. Hubert, F. Paulin, M-C. Soulié, CGEDD n° 010012-01 – CGAAER n° 14123, September 2015, 154 pages, in French http://www.ladocumentationfrancaise.fr/rapports-publics/164000006-analyse-de-la-mise-en-oeuvre-de-la-directive-nitrates-par-d-autres-etats-membres-de

Canada nutrient removal and recycling report

The Canadian Water Network (Municipal Water Consortium) has published a 560 page report (5 page action summary) on nutrient removal, recovery and reuse from sewage. Emerging technologies, practical implementation constraints, discharge consents and economics are assessed, covering biological and chemical P-removal, nitrogen removal, nutrient recovery, nutrient reuse in biosolids treatment and recycling. Policy and research recommendations are proposed, particularly targeting sewage treatment plant upgrades.

The report is based on a literature review of 400 papers (mostly post 2004), online survey with 69 North America municipalities response and expert interviews.

Phosphorus removal

Over 60% of the survey responding sewage works use enhanced biological phosphorus removal (EBPR).

The authors conclude that both chemical and biological phosphorus removal have been demonstrated as **reliable and able to achieve effluent of 0.5 mg TP/l.** In both cases, this can be further reduced by incorporating tertiary filtration before discharge. Chemical P-removal has lower initial investment costs, but higher long-term operating costs. Biological nutrient removal (BNR) requires larger installations (tanks), operator experience and waste water rich in **volatile fatty acid organics** (VFA - rbCOD, readily bioavailable carbon, to "feed" the biological phosphorus removal micro-organisms). VFAs can be generated onsite by fermentation of sludges, so enabling improvement of EBPR performance. This can be enhanced by phosphorus stripping, to prevent micro-organisms consuming the VFAs as they are produced.

For discharge consents below 0.5 mg TP/l, BNR with chemical precipitation "finishing" is often the optimal solution.

Very demanding nutrient discharge levels, in ecologically sensitive areas, can be achieved by "polishing" processes, such as sand filters combined with chemical P-removal, ballasted precipitation, methanol dosing to support bacteria growth for post-denitrification and best-available solids abatement (e.g. **membrane ultrafiltration, reverse osmosis**). Thus 0.01 mg TP/l and < 3 mg TN (total nitrogen)/l and < 1 mg TAN/l (total ammonia nitrogen) can be achieved.

The full report includes detailed discussion of phosphorus removal design and operation, covering biological and chemical phosphorus removal configurations, combinations of these, and tertiary phosphorus removal.

Emerging technologies

Many sewage treatment plants face space limitations (footprint), posing challenges to installation of nutrient removal or capacity increases. Technologies addressing this include **vacuum degasification of mixed liquor (Biodegradex), membrane bioreactors (MBR), integrated film activated sludge (IFAS), moving bed biofilm reactors and batch aerobic granular sludge.**

Membrane systems remain expensive, despite improvements, because of high energy requirements for operation and because membranes must be changed every 8 years.

Another challenge is reduction of energy consumption. New technologies addressing this are **Anammox** (see SCOPE Newsletter n°89) and the **aerobic granular sludge (AGS) process**. Anammox is today state-of-the art, used in c. 100 sewage works worldwide, but typically on warm sludge dewatering liquor. Adapting the process to treat cool, mainstream sewage works flows, with lower ammonia concentrations, is an R&D priority. Another possible option in warmer zones would involve **biofuels production** e.g. by micro-algae growth on final effluent.

These emerging technologies are presented in detail in the full report.

Nutrient removal costs

The authors estimate that moving from sewage treatment without nutrient removal to discharge consents of 0.3 mg TP/l and 5 mg TN/l **multiplies sewage works operating costs by nearly 3x.** Reducing discharge consents to 0.01 mg TP/l and 2 mg TN/l **multiplies costs by a further 2x**.

Experience of USA watershed partnerships shows that the costs of reducing one kg of P or N discharge from sewage works are typically **ten times higher than costs of reducing agricultural nutrient losses**.

Nutrient recovery

The authors estimate at c. 43 000 tonnes/year the phosphorus in Canada's municipal sewage. Struvite recovery, already operational at e.g. Saskatoon WWTP (120 000 m^3/day), using the **Ostara Pearl process**, is considered an economically attractive option in plants operating BNR with low discharge consents. Experience from **11 plants already operating struvite recovery in North America indicate a 7-14 year return on investment.**

The recovered struvite has developed a niche market in Canada, and the **market is considered to be able to take any amount of struvite generated** at Canadian sewage treatment plants.

Nitrogen recovery, on the other hand, is currently much more expensive than nitrogen removal, by e.g. Anammox, except perhaps in particular cases where the recovered ammonia has a value onsite.

The full report presents a range of possible nutrient recovery routes and technologies, including P-recovery from sludge, ash, mainstream and ammonia recovery.

Application of treated sewage biosolids in agriculture remains the most widely implemented route for nutrient recycling in Canada. Scientific information is however inadequate on the potential impact of emerging substances of concern (pharmaceuticals, consumer chemicals) and there is also a research gap regarding the availability to crop plants of P and N in biosolids, especially where chemical P-removal is being used.

Policy and action recommendations

The full report includes a detailed assessment of the **regulatory and policy framework** (including discharge limits) in Canada, USA, Europe (EU, France, Poland, Austria, Denmark, Netherlands, Germany), Australia and China, an assessment of feasibility and cost of nutrient recovery in Canadian municipal wastewater treatment plants and an outline of research gaps regarding nutrient removal and recovery (including proposals for pilot and demonstration plants for certain technologies).

Recommendations to policymakers include, in addition to a range of technical proposals:

- **Watershed approach** to water quality
- **Develop regulations which encourage nutrient recovery**, as well as energy efficiency / greenhouse emission reduction
- Regulations should allow **sporadic excursions above discharge limits**, based on receiving water impacts, to avoid over-design of facilities
- Develop, in partnership with agriculture, **knowledge on nutrient release rates from recovered nutrient products**
- **Determine phosphorus release rates, in different conditions, from biosolids** containing iron and aluminium precipitates from chemical P removal

"Options for Improved Nutrient Removal and Recovery from Municipal Wastewater in the Canadian Context", J. Oleszkiewicz oleszkie@cc.umanitoba.ca, *D. Kruk, T. Devlin, M. Lashkarizadeh, Q. Yuan, S. Lobanov, D. Mavinic, G. Nakhla, B. MacBride, Canadian Water Network, Canadian Municipal Water Consortium, 200 University Ave. W., Waterloo, ON, N2L 3G1 Canada, Summary (5 pages, Sept. 2015) and full report (560 pages, March 2015)* http://www.cwn-rce.ca/project-library/project/options-for-improved-nutrient-removal-and-recovery-from-municipal-wastewater-in-the-canadian-context

Reports and workshops

Struvite P-recovery experience and challenges

The EU LIFE+ PHORWater workshop, held at LAGEP Lyon, brought together struvite technology providers, water companies, the fertiliser industry and regulators. Different struvite processes today in operation were presented and participants discussed obstacles today preventing placing of the recycled nutrient product on the market as fertiliser.

The workshop was opened by **Hamid Elaissari**, who presented **LAGEP (Process Control and Chemical Engineering Laboratory, Lyon University).**

Chris Thornton, ESPP (European Sustainable Phosphorus Platform), summarised the regulatory context of struvite recovery in Europe. **Producers of recovered struvite do not need to Register under REACH (European Chemical Regulation), by application of Article 2(7)d "recovered substances"*,** but producers do have certain obligations under REACH.

The **EU Fertiliser Regulation revision process** should introduce European criteria for placing struvite on the market as a CE-mark fertiliser (criteria definition underway at JRC, to be added to the revised EU Fertiliser Regulation annexes as soon as this revised Regulation is adopted) … but this will not be until at earliest 2017-2018. Once implemented, the revised EU Fertiliser Regulation will also ensure End-of-Waste status for all struvite conforming to the criteria.

REACH Art 2(7)d: once one company has Registered a substance (this has been done for struvite) then further producers of the recovered substance do not need to Register.

Regulatory obstacles in France, Spain

Until then, struvite producers in some countries (e.g. France, Spain) **cannot place their product on the market because it is not validated under national fertiliser regulations**. Participants underlined the need to address this rapidly to unblock industrial development of struvite recovery.

Philippe Eveillard, UNIFA (French fertiliser industry association) emphasised that nutrient recycling is already widely practiced in agriculture: **over half of phosphorus applied to French farmland is from farm animal excreta, during grazing or collected in manures, applied directly or after processing**.

France already imports manure nutrients in composts from the Netherlands and Flanders. **Phosphorus management in French agriculture is today efficient, with a very low P-balance, indeed often zero or negative in grain growing regions**. This balance does not take into account losses, so that French farmers are now progressively consuming soil phosphorus reserves.

Improving sewage P recycling

UNIFA considers that **recycling of phosphorus from sewage could be increased** both by extracting more P in soluble forms (such as struvite) and by increasing the share of sewage biosolids being used in agriculture after appropriate treatment (currently around 60% in France). **Challenges are concerns about contaminants** in sewage biosolids or in struvite, and **homogeneity / reliable characteristics of organic recovered nutrient products**: farmers need to know that products offer reliable properties, the same over time and between different suppliers (physical characteristics, dry matter content, nutrient availability).

Jean-François Gaillaud, French Ministry for Economy, presented the **North Sea Resources Roundabout Green Deal** (see SCOPE Newsletter 120). This agreement between France, the Netherlands, Flanders and the UK aims to create cross-border markets for secondary raw materials by removing obstacles to transport and use. Compost is one of the first products covered.

Addressing obstacles to struvite fertiliser use

A struvite case is currently under preparation for the North Sea Resources Roundabout process, led by **Waternet** and **Restoffenunie** in the Netherlands, with **Suez**, **Angibaud Derome** and **Veolia**, with in particular the objective of exporting Netherlands produced struvite for sale as a fertiliser in France. Current obstacles for recovered struvite include absence of EU End-of-Waste status, transport issues and absence of fertiliser authorisation in France. These will be addressed by the Netherlands and France cooperating on safety requirements and enforcement for recovered struvite.

Nico Stuijt, Timac Agro (Roullier) Netherlands, explained that phosphorus recovery responds to Netherlands farmers' **need to address manure excesses**. This situation is becoming more pressing with the end of milk quotas. Dairy farmers pay around 15€/m^3 to get rid of slurry, but need mineral fertiliser as starter phosphorus for maize.

Struvite: performance placement fertiliser

Maize needs phosphorus fertiliser and ammonium in the first 4-6 weeks to support root development. **Struvite is a non-burning fertiliser, enabling "ultra-localisation", that is placement of these two nutrients right by the seed**.

Full-scale field tests have demonstrated the agronomic effectiveness. To enable production of this specific struvite fertiliser product, the recovered struvite must be dry (to enable micro-granulation). **Timac Agro** further adds ammonium to ensure the correct nutrient balance. Also, the company needs a continuous supply and consistent quality in order to operate industrial processing.

Philippe Eveillard notes that nearly all agricultural fertilisers sold in France are as 2-4 mm granules, for which **farmers' spreading equipment** is adapted. There is however a niche market for smaller particle forms. Struvite also needs blending with other nutrients, to provide a balanced NPK product.

He pointed out, that, when new fertilisers are placed on the market, **proof of fertilising efficiency** for the specific crops and soil types need to be provided to ensure farmer confidence.

Christian Kabbe, KWB Berlin, proposed, since there have already been made many pot and field tests with struvite and other recycled nutrient products, to compile the results of these studies in one inventory to prevent unintended replication and to identify the gaps or demand for specific test assemblies still lacking.

He noted that P-**REX project tests showed that the most reliable indicator fertiliser effectiveness of P in recovered products is citric acid or NAC (neutral ammonium citrate).** Struvite has the advantage of releasing nutrients as a function of plant root activity, so that crops take up the nutrients on demand as they grow, so optimising fertiliser efficiency and reducing nutrient loss risks.

He underlined that to facilitate phosphorus recovery installation and implementation of biological phosphorus removal in sewage works, **flexible discharge consents are needed** (P limits averaged over time, not rigid ceilings).

Recovery and recycling of sewage nutrients

He presented the **different routes for recovery and recycling of nutrients in sewage**.

Today, **around 40% of Europe's sewage biosolids are spread on land, but the real rate of recycling depends on the plant availability of the nutrients** (may be low if iron or aluminium salts are used for P-removal), appropriate spreading rates and use on farmland not as in-fill for land reclamation.

Struvite recovery from liquor flows in sewage works can recover up to a maximum of 30-40% of works total inflow phosphorus, when sludge disintegration is enhanced and combined with downstream struvite precipitation. **The driver for installation is not phosphorus recovery but resolution of clogging and deposit problems and reduction of sewage sludge drying or disposal costs**, in sewage works operating biological phosphorus removal and anaerobic sludge digestion.

In order to take recycling objectives further the Amersfoort sewage works, the Netherlands, has installed a combination of **WASSTRIP** (to maximise P available for recovery) and Ostara struvite recovery. **Vallei en Veluwe, the Netherlands**, is looking to add ammonia stripping (recovery of ammonia water or salts, which could be sold as a nitrogen fertiliser raw material). These "nutrient recovery cascades" reflect the second generation nutrient recovery.

Laura Pastor Alcaniz, DAM (Depuracion de Aguas de Mediterraneo), Alberto Bouzas Blanco (Valencia University), Stéphane Labouret and **Denis Mangin (LAGEP Lyon),** presented the EU **LIFE+ PHORWater project** and results, at the **El Cidacos municipal wastewater treatment works (Calahorra, Rioja, Spain).** This 23 000 m^3/day A2O plant operates EPBR (Enhanced Biological Phosphorus Removal), anaerobic sludge digestion of mixed primary and secondary sludge and a sludge centrifuge for digestate dewatering.

Optimising sewage works flows for struvite recovery

The project has carried out a targeted phosphorus balance and speciation in different flows within the wastewater and sludge treatment lines of the treatment worksto identify the optimal point for installation of struvite recovery and optimal sludge inputs, using **DESASS© simulation software** to optimise configuration. This uses a mixing chamber (primary and WAS Waste Activated Sludge) with return flow back to the primary sludge gravity thickener. Before intervention, only 9% of works inflow phosphorus was available for struvite recovery and most P loss was in the digester. **After re-configuration: biological P-removal increased from 80% to 90%, P-loss in the digester was reduced by nearly 50% and inflow P available for struvite recovery increased to 17%.**

The struvite is precipitated in a stirred reactor. The lab-scale reactor (21 litres volume) initially **developed by LAGEP with CEEP funding in 2001** (see SCOPE Newsletter 73 and 81) was tested onsite in order to establish operating conditions with the real effluent.

This reactor was then scaled up to a demonstration reactor (5 m^3 reactor volume, treating **20 m^3/day,** producing c. 2 tonnes struvite/year), treating half of the sewage works sludge stream. Scale up factors of importance are mixing power, fluid velocities in inlet pipes and pipe positioning to avoid zones of too high saturation and so formation of fines. The reactor design was then based on fluid dynamics modelling (using COSMOL© Multiphysics) and particle population balance modelling was used to fix operating parameters.

Operational experience of struvite recovery

The full-scale reactor has now been operated for nearly a year at pH 8.7 with Mg/P ratios 1.6 and 1.3 (dosing of magnesium chloride) and residence times of 4 and 2 ½ hours in the reaction zone. No significant reactor fouling has occurred. Work is currently underway to assess the influence of calcium on product (struvite / calcium phosphate) and to improve the washing of the recovered struvite. The recovered struvite has been used for field tests of fertiliser potential on potatoes and wheat (underway, harvest June 2016).

Mathieu Delahaye, Suez, presented the company's approaches to phosphorus recycling, including **Phosphogreen** struvite recovery processes. Different P-recovery technologies are adapted to different situations. Suez offers, for example, apatite adsorption beds for small sewage works.

Suez's **Phosphogreen** struvite technology is adapted to sewage works of c. 40 000 pe or more operating biological phosphorus removal with anaerobic sludge digestion, and with soluble phosphate concentrations of >70 mgP-PO_4/l in digestate after dewatering. It uses an airlift fluidised bed reactor (FBR) with recirculation and a conical insert to reduce losses of fines. Struvite granules of 1-3 mm are produced. **Two full scale installations are already operational**: **Aby WWTP in Aarhus, Denmark**, 84 000 pe plant capacity, operating since 2013, treating a combination of bio-P release (sludge thickening) liquor and digestate and producing c. 75 tonnes struvite/year; **Herning, Denmark**, operating since 2015 (not all plant installations completed to date), 150 000 pe sewage works, operating upstream of anaerobic digesters on bio-P-release liquor producing around 100 tonnes struvite/year.

The **advantages of installation struvite recovery** are:

- **Sale of struvite**: 75-300 €/tonne, if sale in countries where authorised by national fertiliser regulation
- **Reduction in chemical costs for chemical P-removal**
- **Avoidance of clogging** and nuisance deposits
- **Reduction of sewage sludge volumes**
- **Reduction of energy consumption** for biological nitrogen removal (N in struvite)

This results in an overall **return on investment of 5-10 years**

Marisa Cunha, Veolia, presented the company's **STRUVIA** struvite recovery technology, using a patented stirred reactor with lamellae to prevent fines loss. This compact design is effective with soluble phosphate inflow > 60 mgP-PO_4/l and functions with low liquor retention time (1/2 – 1 hour in the reaction zone) and simple operation (no recirculation). Operation is at Mg:P ratio of c. 1.3-1.4 and pH around 8. Digestate is often already at this pH so that often no alkali dosing is needed. The simple design results in low CAPEX and OPEX. Operation to date shows no reactor fouling.

A 500 litre mobile demonstration plant was tested at the **Aquiris municipal waste water treatment plant, Brussels** (P-REX project, on effluent from ATHOS Wet Air Oxidation installation and centrate from thickener, for 12 months), and also at **Lille Marquette (France), Braunschweig in Germany** and at a **dairy plant in Poland**. A full scale plant was started in **Helsingør, Denmark** in April 2016 (4.2 m^3 total reactor volume, 76 300 pe sewage works). Due to its compact footprint, STRUVIA met the constraints of the installation in a small area of a basement with a height of only 3.5 m.

Results show struvite with low organic carbon (TOC < 2%), very low heavy metal levels. If calcium:phosphorus ratio is > 0.5, then amorphous calcium phosphate can be formed instead of struvite.

Struvite particles of 200 – 500 µm are produced, which can be dried by simply standing, drying to >90% dry solids after 20 days gravity draining. This can be **mixed into organic fertilisers to improve their nutrient ratio and availability**. Veolia's affiliate **SEDE** and **Angibaud Derome & Spécialités** fertilisers France (Bavay, Ingrandes, Béziers) can take the struvite, granulate using only physical processes (no additives) and market as a fertiliser – subject to authorisation as a fertiliser under national regulation.

Fanny Marie, Naskeo, and **Mohammed Benrahim, Rittmo**, presented experience operating since October 2014 of full scale struvite recovery at Castres municipal sewage works, France (see SCOPE Newsletter n°120), treating 50% of the 130 000 pe works digestate dewatering flow (EBPR plant with anaerobic sludge digestion). The patented Naskeo reactor design is fluidised bed reactor (FBR) with recirculation. An industrial by-product (magnesium oxide) is used to dose magnesium, and because this is alkali no NaOH dosing is needed. The 90 m^3/day reactor produces around 30 tonnes struvite/year.

Installation of struvite recovery has resulted in a **reduction of sewage works P discharge from 2.5 to 1 mg/l,** enabling discharge consents to be achieved using biological P removal.

The recovered struvite shows product homogeneity over time, with < 5% organic carbon (TOC), > 60% dry solids content and low heavy metals. Pot trials have been carried out using rye grass and petunia, showing **struvite provides fertiliser performance comparable to triple super phosphate** (TSP).

Ecotoxicity tests

Six ecotoxicity tests of the struvite have also been carried out to ISO/ENO test protocols: daphnia, algae, earthworms, duckweed (lemna), mycorrhizal fungus Glomus, nitrifying activity.

Denis Mangin, LAGEP, closed the workshop by thanking participants and the PHORWater and LAGEP organisation team.

PHORWater LIFE+ Integral Management Model for Phosphorus recovery and reuse from Urban Wastewater. Speakers' slides will be put online at http://phorwater.eu/

RISE report on nutrient recovery and reuse

The RISE Foundation (Rural Investment Support for Europe) has published a 92 page report on issues, opportunities and actions for nutrient recovery and reuse (NRR) in European agriculture. The report makes 16 recommendations to enable nutrient recycling to contribute to better nutrient stewardship and, by diversification of nutrient sources, to nutrient supply security.

The report is written by Allan Buckwell and **Elisabet Nadeu** and was funded by **Acqua & Sole**, **Carlsen Langes Foundation** and **Fertilizers Europe**. It was launched at a **Forum for the Future of Agriculture** (FFA) assembly event, in Brussels, 21st March 2016 by **Janez Potocnik** and **Corrado Pirzio-Biroli, Chairman and CEO of the RISE Foundation**, at a launch with over 100 participants from the European Commission, companies and stakeholders.

Sustainable production and sustainable diet

At the launch, **Corrado Pirzio-Biroli**, chairing, emphasised that nutrients are today a problem, but through recovery and reuse are also part of the solution, offering **important business and innovation opportunities**, but requiring financial and policy interventions to address externalities.

Janez Potocnik underlined that nutrient efficiency and reducing nutrient leakages are essential to achieve the **United Nations Sustainable Development Goal n°12 (sustainable production and consumption).** A clear message from the RISE nutrient recycling report, as from the *Nitrogen on the Table* study published in January 2016, is that **changes in diet towards less meat consumption** are essential to achieve nutrient sustainability, but also a balanced and healthy diet.

Allan Buckwell, Emeritus Professor, outlined **objectives for progress identified by the report**: recover more nutrients (quantity), with a higher value (quality), in a safe, transportable and storable form (logistics). He noted that the scale of operations (production, logistics) for nutrient recycling will always be smaller than for mineral fertiliser, raising issues of cost competitivity, but may also create opportunities for developing rural jobs and incomes. To move forward, **collaboration between the private sector and regulators is essential**, and is already developing through platforms such as ESPP (European Sustainable Phosphorus Platform) and national nutrient platforms. However, proactive policy and economic tools are necessary, going beyond harmonisation and removal of obstacles, to address cost differentials (price integration of externalities of nutrient leakages), including support for R&D and data development, financial stimulants and economic penalties.

Ryan Dermot, Senior Advisor to the EU Commissioner for Agriculture, indicated that nutrient recovery and reuse fits coherently with EU policies including sustainable food production, food security, farm economic viability, reducing nutrient pollution and ensuring resource security. **Precision farming is a key tool** to improve nutrient use efficiency and reduce losses. EU actions launched such as the **Circular Economy Package**, **prevention of food waste** and the **revision of the Fertilisers Regulation** will strongly support nutrient stewardship.

Marco Contiero, Greenpeace, emphasised the need to develop data to better **price environmental impacts** such as nitrogen emissions and soil degradation. The RISE NRR report confirms the need to reinvent the current farming system, to change businesses and society lifestyles. However, **in Greenpeace's opinion, the report does not formulate recommendations that could bring about the necessary systemic changes, limiting itself to address solutions which can be defined as 'end of pipe'.** The report rightly focuses on livestock production and its detrimental impacts but fails to properly address mineral fertiliser use, which has an even greater impact on N and P nutrient cycles than livestock production. Action must be engaged to **reduce over-consumption of meat**: public policy should address this. Agricultural practices which enable lower mineral nutrient inputs should be promoted and supported, including use of leguminous plants to fix nitrogen, improved crop rotations, mixed livestock / crop systems. The 8-year long USDA Iowa State University field study on crop rotation shows that this feasible (Davis reference below)

Kees Langeveld, ICL, explained that his company is already active in phosphorus recycling, and is accelerating with a new process to **'upcycle' sewage sludge ash and other waste-sourced phosphorus to high-value P_4 (white phosphorus) and derivatives**, see SCOPE Newsletter 120. Manure offers opportunities for production of biogas and recovery of ammonium and phosphorus. He emphasised difficulties with national and EU **regulatory barriers** relating to waste status and the Animal By Product Regulation. For ICL, absolute priorities are ensuring quality (agronomic value, precise nutrient release curve) and safety (contaminants) of recycled nutrient products. Industry also is strongly aware of the need for new, flexible approaches, adapted to local resources and local energy.

Participants at the meeting underlined

- the **importance of soil structure and organic carbon** in improving nutrient use efficiency and in reducing nutrient losses,
- the importance of involving the **agri-food industry and supermarkets** to ensure that Sustainability Standards do not exclude recycled nutrients (waste-sourced, c.f. the Global GAP exclusion of use of organic-sourced fertiliser materials),
- the need for **local solutions** and integration with renewable energy production,
- the need for specific **regulatory and financial tools** to support nutrient recovery and reuse.

Key report messages

The RISE report concludes the following key messages for sustainable nutrient management:

- The key driver is **nutrient leakages**, causing serious environmental impacts, accentuated by growth in nutrient flows (N and P) through the global agriculture – food system
- The **livestock sector** is responsible for a large proportion of nutrient impacts, and is inherently biologically inefficient and leaky
- **Nutrient recovery and reuse** can improve diversification of EU nutrient supply sources, and so resilience to possible global supply disruption
- The most promising sources for recovery and reuse of nutrients in Europe are **animal manures, sewage sludge and food chain wastes (including slaughterhouse waste).** Together, these currently represent 2 – 5 million tonnes/year of nitrogen (N) and 0.6 million tonnes of phosphorus (P) which is currently not recovered, that is 18-46% of EU mineral nitrogen fertiliser use, and 43% for phosphorus
- Challenges are **complex**, involving many actors
- Recovery and reuse will not significantly develop without further **collective actions**

The report recognises that whilst nutrient recovery and reuse can make a significant contribution to addressing the environmental impact of the massive nutrient leakages, if real change is to occur it must be done alongside the **reduction of nutrient flows and leakages**. A concerted effort needs be made to promote dietary change to lower livestock consumption and to improve crop and animal production nutrient use efficiency, in particular through precision agriculture

Recommendations

The RISE report makes sixteen recommendations for actions (pages 12-13 of the report):

Improve data

1) Common **methodology and indicators** to monitor nutrient flows and organic carbon in waste streams (refers to DONUTSS *www.phosphorusplatform.eu/donutss*)

2) Implement this data collection at the EU and in Member States

Regulatory coherence

3) Conduct a full review of EU and national legislation to ensure coherence, remove barriers and identify changes necessary to stimulate NRR

Policy support for nutrient recovery and reuse

4) **Analyse the potential impact** of NRR on the environment, resource security, job creation, rural incomes

5) Analyse the feasibility and cost-benefits of specific support measures, including **subsidies and taxes**

6) Provide public funding for pilot development and roll-out of NRR technologies

7) Flag NRR projects for EU Rural Development and European Investment Bank funding

8) **Coordinate R&D** on NRR through clustering, including JRC

EU Circular Economy Package

9) Develop **standards, certifications and traceability protocols** for recycled nutrient products susceptible to contain organic contaminants, covering both contaminants and safety, but also product quality and application techniques

10) Establish an EU recognised **analytical framework** for nutrients and a check-list for potential actions to develop NRR in Europe

11) Establish and exchange information on **Best Available Technologies and Best Practices**, through existing information platforms

Consumer acceptance and land managers

12) **Awareness campaign** to inform consumers of nutrient use impacts and benefits of NRR

13) Provide R&D funding for analysis, understanding and risk-assessment of **organic contaminants** in NRR

14) Inform and educate food processors and retailers

15) Integrate NRR and soil carbon into EU policies on renewable energy and climate change

Levels of livestock production and consumption

16) High-level review of the place of **livestock** in the EU, including environmental impacts, health issues of meat consumption, spatial distribution of livestock production, contribution to landscape

Information and examples

These report conclusions and recommendations are supported by an **in-depth analysis**, including many tables and diagrams. 17 pages are devoted to "Scope, scale, technologies and the potential for nutrient recovery". This includes summaries of nutrient flows, leakages and recycling potential. The main routes for nutrient recovery and reuse are summarised, including anaerobic digestion, composting, and technical nutrient recovery processes from liquid and ash streams. Examples presented include the VEAS (Oslo) – Yara nitrogen recovery from sewage (via ammonia stripping in anaerobic digestion).

The chapter on policies identifies **30 EU regulatory and policy tools relevant to nutrient management, in addition to Member States policies**. A number of barriers to implementation of NRR are assessed, including market structure, attitudes and safety and business challenges (process and logistics economics, data needs for benchmarking, investment, demand). Policy tools considered are: obligations, voluntary targets, innovation grants, subsidies for production or products, fiscal reliefs, nutrient source, loss or surplus taxes, landfill or incineration gate fees.

A key question identified is the **economic viability of agriculture, where nutrient efficiency improvements could be to farmers' economic advantage**, if policy ensures that the economic context of implementation costs and economic returns functions correctly.

Davis AS, Hill JD, Chase CA, Johanns AM, Liebman M (2012) "Increasing Cropping System Diversity Balances Productivity, Profitability and Environmental Health", PLoS ONE 7(10): e47149. 2016
https://dx.doi.org/10.1371/journal.pone.0047149

RISE Foundation "Nutrient recovery and reuse (NRR) in European agriculture. A review of the issues, opportunities and actions", 92 page, 2016, A. Buckwell, E. Nadeu, with contributions from L. Six (Fertilizers Europe), K. Van Keer (Yara) and A. Williams
http://www.risefoundation.eu/projects/nrr *and full report*
http://www.risefoundation.eu/publications

Finland launches nutrient recycling programme

The Finland Minister of Agriculture and the Environment, Kimmo Tiilikainen, launched a 12 million Euros national Key Project programme 2016 - 2018 for innovation in nutrient recycling technologies and logistics at a two-day seminar in Helsinki 19-20 April "Recycle Nutrients for Clear Waters"

The Minister stated:
"*Nutrient recycling is one of the key elements of the circular economy and our national food security. The profitability of farms depends on new thinking, sustainable production, resource efficiency, promotion of local food and economies, and branding the products. There are new business opportunities, for example, in recycling the nutrients contained in animal manure and sewage sludge. At the same time we will considerably reduce loading to waters when nutrients that are about to run into waters are brought back to the cycle*".

The aims of the programme include the **promotion of processing technologies, nutrient recycling logistics and service solutions** as well as **developing high-quality products from biomasses**.

The funding is primarily targeted to companies developing and testing new technologies and project actors working in close collaboration with companies to promote nutrient recycling.

Wide interest

Over 350 people took part in the **Finland national nutrient recycling programme launch** at a national presentation on 19th April and at an international seminar in Helsinki, plus many participants by web transmission (*https://www.youtube.com/user/mmmviestinta*) on 20th April.

The first day saw a presentation of the programme objectives and funding possibilities, specifying links to the **Baltic Sea nutrient reduction objectives** and the objective to process 50% of farm manure and sewage sludge, to enable nutrient recycling.

The focused on national level and was targeted to Finnish stakeholders, especially entrepreneurs. It was coordinated by the **Finland Ministry for the Environnement** and supported by the **Ministry of Agriculture and Forestry** and by **Soilfood** (see below).

In the opening speech The **Finland Minister of Agriculture and the Environment Kimmo Tiilikainen** presented the new program objectives and funding possibilities, specifying links to the Baltic Sea nutrient reduction objectives and the **objective to process 50% of farm manure and sewage sludge, to enable nutrient recycling**.

Juha Helenius, University of Helsinki, pointed out that it is crucial to see the **food system as a whole entity**, and nutrient recycling has to be seen as part of it and summarised the background reasons of the need for nutrient recycling.

Hannu Uusihonko, Foodpark Oy, encouraged entrepreneurs to build new cooperation networks with other entrepreneurs and farmers. He emphasized that it is always the question about the persons behind the organisations, and continued by saying that it is possible to create reliable cooperation between several companies, as can be seen in **Kirkkokallio agroecological symbiosis**, where he is strongly evolved.

The energy shot of the day was given by a previous **Finnish rock star, Mato Valtonen**, who nowadays calls himself a commissioner of creativity and wanted to wake up the audience to take risks in life. He pointed out that **crazy people build the world, ordinary people only keep it running**. He really gave a lot to think to the audience. There's no way to reach development unless you are ready to take risks.

Success stories

The presented several examples of the success stories mainly from Finland. Four companies, a municipality and several research & education institutes presented their projects, solutions and innovations concerning nutrient recycling, especially in the field of manure and sewage sludge. This gave a challenging picture of the status of actions in nutrient recycling. Thanks to the **Finnish financing program for nutrient recycling** – coordinated by the ministry of environment, many stakeholders have had the opportunity to pilot their ideas since 2012. The program is the consequence of the commitment made by the Finnish Government in 2010 in the Baltic Sea Action Summit.

Outside the seminar room **experts presented the main financing instruments available in Finland to enhance nutrient recycling**. During the breaks, on the "clinic for financing" the participants were able to ask questions to the authorities about the financing possibilities. Next to this, the Forum for Solutions offered companies and projects the opportunity to present their innovative solutions to the participants. **Eija Hagelberg, BSAG**, chairperson of the theme group "Environment and Climate" of Rural Network Finland, summarised the day's conclusions: a practical problem to solve, good scientific background information, determined decision making, positively crazy and innovative entrepreneurs and functional cooperation among stakeholders can lead to more efficient nutrient recycling and generally to more sustainable use of natural resources, economically sound business solutions and better status of the environment, including the waters.

The discussion during the day was fruitful and constructive. The day was full of networking among the participants, who stayed faithfully in the seminar room right to the end and even to the cocktail event after the seminar.

Finland's international ambitions

The international seminar was organised by the **Finland Ministries for Agriculture and the Environment and for Employment**, with the support of **Natural Resources Institute Finland (Luke)** and the **European Sustainable Phosphorus Platform (ESPP),** enabled a **meeting between Finnish companies and stakeholders and innovative companies in nutrient recycling with success stories from other European regions**.

Tarja Halonen, former President of Finland, opening the international meeting, underlined that nutrient stewardship is key to the **United Nations Sustainable Development *Goals*** n°s 2 Zero Hunger, 14 Life Below Water and 12 Responsible Consumption and Production. At the 2010 Baltic Summit, Finland committed to become a model country in nutrient recycling (see also HELCOM Ministerial Declaration 2013 in SCOPE Newsletter n° 98). The current Finnish Government has targeted one of its "Key Projects" to meet this goal, aiming for increased nutrient recycling and energy self-sufficiency in agriculture. The target is to process 50 % of farm manure and community wastewater sludge in sensitive areas by 2025.

SITRA has estimated that the circular economy could bring 2.5 billion € per year to Finland's economy. Nutrient recycling offers new business opportunities. Information exchange and cooperation between stakeholders is needed to enable these.

Nutrient stewardship will also need changes in consumer habits. Today, Finland throws away 400 000 tonnes of food waste per year. **Tarja Halonen** concluded "***We need to act with our hearts as well as our minds***".

Bruce Oreck, Executive in Residence at Aalto University and former US Ambassador to Finland set the urgency for humanity of global environmental problems against the "incremental" actions. He pointed to four myths: clean energy which won't resolve exponential growth/demand, sustainable development whereas the West's level of consumption cannot be shared sustainably at a global level, time to act when climate change is already happening and technological solution which can't resolve the systemic instability of exponential development. **He called for "transformative innovation", with completely new approaches not just the same only more efficient**. He concluded that the magnitude of opportunities matches the magnitude of challenges and that Finland can be a frontrunner with strengths in education, engineering and in biomimicry, basing new approaches on nature's experience.

VIERASKYNÄ

Kiertotalous hyödyttää ympäristöä ja bisnestä

Ravinteiden kierrätys auttaa Itämeren rehevöitymisen ja ilmastonmuutoksen hillitsemisessä, parantaa ruokaturvaa ja luo uutta yritystoimintaa.

PÄÄKIRJOITUS 18.4.2016 2:00

Helsingin Sanomat

91

VÄESTÖNKASVU, ruokailutottumusten muuttuminen, luonnonvarojen ehtyminen ja ilmastonmuutos asettavat ruoantuotannolle uusia haasteita. EU-maat ovat lisäksi hyvin riippuvaisia maanviljelyssä välttämättömän fosforin tuonnista.

Euroopan unionin ainoat fosforivarannot sijaitsevat Suomessa. Maailman fosforivarantojen rajallisuus on saanut EU:n ottamaan raakafosfaatin kriittisten raaka-aineiden listalle. Listalla on EU:n taloudelle tärkeitä aineita, joiden saatavuus on uhattuna.

Arnoud Passenier, President of the European Sustainable Phosphorus Platform, showed how over the last few years **phosphorus has changed from being a "waste problem" to a prominent example of the circular economy**. P-recycling can both help address Baltic Sea eutrophication and stimulate rural jobs and farmers' incomes. He presented the European Sustainable Phosphorus Platform, with nearly 40 partners after three years and an emphasis on action: addressing regulatory barriers, promoting innovation and success stories, enabling networking between companies, technology suppliers, nutrient user industries, R&D and society stakeholders. As Finland's leading daily newspaper says: Finland can show the world its actions in nutrient recycling.

Recycled nutrient fertilisers: jobs and growth

Eric Liégeois, European Commission DG GROW (skype link), presented the objectives of the proposed revision of the EU Fertilisers Regulation (see SCOPE Newsletter n° 120), a leading initiative in the EU Circular Economy Package. **The new EU Fertilisers Regulation will cover recycled nutrient products and organic products (such as composts, digestates)**

instead of only mineral fertilisers as at present. This will create jobs and growth, make fertilisers more sustainable whilst ensuring product safety, improve resource efficiency and reduce dependency on imported phosphate rock.

The Commission's objectives are the replacement of 28% of mineral fertilisers by biomass-based fertilisers by 2025 (+22% compared to a scenario without the new regulation). This should create 120 000 jobs, reduce the carbon footprint of fertilisers, and reduce heavy metal inputs to European soils by 10%.

In the present proposal, raw manure (and e.g. dried, solid-liquid separated, granulated manure) and sewage sludge are excluded. They may be progressively introduced after adoption of the new regulation, if safety concerns can be resolved. Subsidiarity is ensured in that Member States will continue to be able to have national fertiliser authorisations for such products, but these will not be tradeable at the EC level. This will facilitate local innovations which if successful may then be implemented into the European regulation.

The European Commission is also working on measures to accompany implementation of new EC fertiliser products, e.g. **support for R&D and for upscaling of pilots to industrial scale**. The European Sustainable Phosphorus Platform is an important partner for the Commission in linking to stakeholders.

Regulation, research, communication

Anders Nättorp, FHNW (Fachhochschule Nordwestschweiz) summarised developments in Switzerland, the first country in the world to require phosphorus recovery from sewage sludge and meat and bone meal ash, see SCOPE Newsletter n° 118). The January 2016 Swiss decree gives a 10 year transition period to implement phosphorus recovery. The conditions of the P-recovery obligation remain to be defined, in particular the % phosphorus which must be recovered, plant availability if used as fertiliser, acceptable technologies (BAT). **In total, Swiss sewage sludge and slaughterhouse waste contain around 9 100 tonnes P/year.** The cost of this measure is estimated by FHNW at 1 – 45 million € per year (including 90 – 380 million € investment).

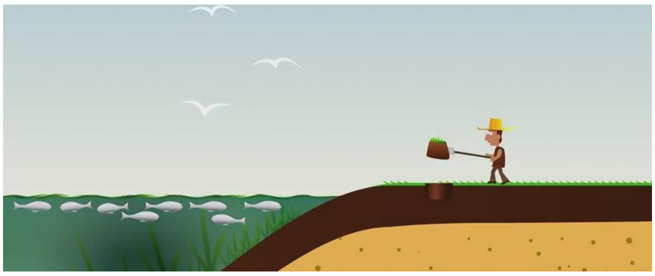
The **Zürich Canton is a frontrunner**, opened a centralised mono-incineration plant for sludge from all the canton's wastewater treatment works in 2015 (see below, Ludwig Hermann, Outotec) and has announced (see SCOPE Newsletter n° 119) construction of a pilot process to extract phosphoric acid from sludge incineration ash using sulphuric acid then purify using solvent extraction (*Editors note: this is essentially the "wet acid" phosphoric acid process and the purification route used for most phosphate fertiliser and industrial purified phosphoric acid production worldwide today*).

To accompany this obligation, the **introduction of a new category, inorganic recycled fertilizers, in the Swiss fertiliser regulation** (*OEng* = DüV, with specification of contaminant limits in *ORRChem* = ChemRRV) has been engaged. Heavy metal limits in the current regulation are suitable for organic recycling fertilizers such as compost and manure, but are considered too low for inorganic recovered fertiliser products. The new category is expected to propose higher heavy metal limits and a minimum phosphate content (publication expected early 2018).

For information: comparison of heavy metal limits for inorganic fertilisers Switzerland / EU

Mg/kg DM (unless otherwise stated)	*Current Swiss RVV recycled fertiliser regulation (mg*	*Proposed EU Fertiliser Regulation revision (as published 18th March 2016) for Solid inorganic macronutrient fertiliser (e.g. minimum 12% P_2O_5)*
Cadmium	20 $mgCd/kgP_2O_5$	60 $mgCd/kgP_2O_5$ (reduced to 20 $mgCd/kgP_2O_5$ after twelve years)
Lead	120	150
Nickel	30	120
Arsenic	na	60
Mercury	1	2
Chromium (CrVI)	na	2

Kaisa Riiko, BSAG (Baltic Sea Action Group) summarised the recently published **Jarki Lannoite project** *report* analysing legislation relevant to nutrient recycling across Europe, both EU and national regulations, including fertilisers regulations, sewage sludge Directive, organic farming, air quality (ammonia emissions), Industrial Emissions Directive/ BAT, animal byproducts, Nitrates Directive. She noted considerable national differences in implementation of the Nitrates Directive, in particular derogations from the 170 kg/ha spreading limit for "processed manure" in Nitrate Vulnerable Zones and the inclusion of phosphorus in Nitrates Directive Action Programmes in some countries. Manure treatment costs reported also vary, for example 5 – 20 €/m^2 in The Netherlands and up to 15 €/m^2 in Flanders. Further limitations on phosphorus application can be expected with progressive application of the Water Framework Directive water quality status objectives.



A new **Baltic Sea Action Group (BSAG) – SITRA (Finland Innovation Fund) video** *https://t.co/8nj4wFqIlv* (2 minutes) explains the importance of **soil organics** in optimising nutrient availability to crops and minimising nutrient losses to surface waters. It is stated that mineral fertilisers cost Finland 240 million €/year and could be 80% replaced by recycling of organics (manure, sewage sludge) and improved agricultural nutrient management practices.

Markku Jarvenpaa, LUKE (Natural Resources Institute Finland) indicated that Finland generates 27 million tonnes of organic by-products per year, mainly manure (72% of phosphorus), but also grass, straw. Livestock production and manure are geographically concentrated in several regions (South-West Finland and West coast of Finland) so that treatment is necessary to enable respect of environmental obligations. Solid-liquid separation can reduce the surface needed to spread 1 tonne of raw manure from nearly 1 500 to below 200 hectares for spreading of the liquid part.

He concluded that recycling technologies are today available, but that **smart business models are needed to ensure "productisation":** developing quality, cost-effectiveness safety and acceptance. Incentives are needed to support use/markets and investment.

International and Finland success stories

Sébastian Homo, COOPERL (farmers' cooperative, Brittany, France) presented the cooperatives innovative approaches for pig manure nutrient management, integrating the farm – abattoir – meat processing chain. This combines **innovative piggery housing systems (TRAC scraper system)**, on-farm or groups of farms anaerobic digestion (biogas production) and then solid-liquid separation, centralised processing of the solid fraction at abattoir/meat processing site, along with slaughterhouse wastes, to produce bespoke organic fertilisers for different crops (granulation, addition of other nutrients). **400 000 tonnes of organic fertilisers are produced annually and applied to crops in other regions of France** (see SCOPE Newsletters 111, 114, 118).

The **TRAC piggery housing system** enables at-source separation of the solid from the liquid fraction of pig manure (slatted floors, scraper system for collection of solids) and reduces by 50% ammonia emissions (urine does not stand in the building), so reducing atmospheric nitrogen emissions and improving animal and farmer welfare. The solid portion contains 90% of the phosphorus, 50% of nitrogen and 100% of carbon and enables c. 40% higher methane production, so economic benefit for the farmer. The **French bank Crédit Agricole** has agreed an interest rate bonus for farmers investing in TRAC housing. 6 installations have already been built and COOPERL's objective is 300 000 pigs/year produced in TRAC housing by 2018 (100 000 places in TRAC buildings).

Kari Koppelmaki, Palopuro Agro-Ecological Symbiosis *http://blogs.helsinki.fi/palopuronsymbioosi/english/* presented this developing local initiative, including a 400 ha organic grain farm and a bakery, from which threshing, grain milling and bread production wastes feed an organic chicken farm. Chicken manure, local horse manure, food and green wastes are used to produce biogas, digestate (recycled locally as organic fertiliser) and biochar. Objectives include reducing Baltic nutrient losses and increasing soil carbon, innovative crowdsourcing investment funding, local sufficiency and addressing the "metabolic rift" in agriculture by social reintegration of farmers.

Saara Kankaanrinta, Soilfood Ltd, presented this new company's service to farmers. Soil analysis (nutrients, microbial activity …), specific expertise in nutrient balance (**patented C-N ratio and balance**) and soil biology, and knowledge of different locally available organic materials (by-products, recycled organic materials) enables the farmer to adjust nutrient application, ensuring nutrient balance and organic carbon inputs which will support soil microbial activity. The company states that productivity is ensured, nutrient losses reduced and soil health is improved, and that results show an average 10-15% per hectare saving for farmers in inputs costs compared to standard application of mineral fertilisers. To date, contracts have been signed with **Gasum**, bioenergy company, for cooperation with sidestreams of energy production. The objective is to scale up to manure handling using the same concept. The company states that results show an average 10-15% per hectare saving for farmers in inputs.

Peter Balslev, Suez Environment Denmark, presented operating experience of the **PhosGreen™ process recovering phosphorus as struvite full-scale at Aarhus Åby (70 000 pe) and Herning (150 000 pe) municipal sewage works.** This has resolved major operating problems at these works, which use biological phosphorus removal EBPR (with additional iron dosing to ensure low phosphorus discharge consents of 0.3 mgP/l): at Aarhus, phosphorus return from sludge dewatering has been reduced from over 40% to 10% of inflow to EBPR, deposit blockage problems in pipes, pumps, valves and within the anaerobic sludge digester are avoided. The struvite is sold as a fertiliser as **PhosCare™**, to farmers at c. 300 €/tonne, with support of SEGES agricultural consultants, and in the **LUKSUS** brand to households. Struvite has been validated as an authorised fertiliser in Denmark in 2014. Return on investment (RoI) is around 6 years, with operating savings around twice the value of struvite sales: reduced iron chloride consumption, reduced polymer consumption in sludge dewatering, lower sludge disposal costs (lower P:N ratio), lower energy consumption in denitrification, increased biogas production.

Ludwig Hermann, Outotec, reminded that the key issue in nutrient recycling from organic by-products, in particular manure, is the challenge of transport from where they are produced to where they are needed. **Energy efficient drying** is therefore key. He presented **Outotec's Closed Loop Steam dryer technology (CLS),** which can reduce energy consumption from 800 to 1200 kW/kg water removed in a standard dryer to 300 – 400 kW/kg. The technology is now being demonstrated for sewage sludges and other organic wastes at the Skelleftea municipal sewage works, with the DeBugger industrial pilot CLS dryer (capacity c. 1 tonne/hour), see SCOPE Newsletter n° 116.

Efficient drying could be combined with **Outotec's TWIN gasification process**, to produce dried, granulated fertiliser products from organic by-products such as manures or sewage sludge. The operating temperatures of nearly 200°C ensure elimination of all pathogens. Gasification of sewage sludge upstream of energy recovery in cement production can potentially enable phosphorus recovery (ash production upstream of the cement kiln) whilst retaining existing sludge energy valorisation routes in the cement industry.

The **Outotec mono-incinerator inaugurated by Zurich Canton, at Werdhölzli sewage works in 2015**, treats the sludge from all the canton's municipal sewage works (100 000 tonnes/year), see above (Anders Nättorp and SCOPE Newsletter n° 119). This new, efficient, centralised incinerator has enabled a 40% operating cost saving for sludge incineration, showing how efficiency investment engaged to enable phosphorus recycling can reduce or maybe cancel possible costs of P-recovery to tax payers or water charges.

Calls for partners

Inka Orko, VTT Technical Research Centre of Finland explained that VTT is **inviting partners to collaborate on a new nutrient recovery initiative**, based on membrane technologies, organic coagulants, thermal sludge treatment, evaporation, and adsorptive and electro chemical technologies.

Marjukka Porvari, John Nurminen Foundation presented the **NutriTrade project for voluntary nutrient emissions trading in the Baltic Sea region**. The project has already identified a number of cost-effective actions for either reducing nutrient load to the sea or removing nutrients from the sea including:

- **fishing roach and other undervalued Baltic Sea fish species for human consumption** in the Archipelago Sea area, so taking nutrients out of the sea in the form of fish and producing human food. Roach products, as well as other products made out of less valued fish are currently making a commercial breakthrough in Finland, e.g. **JärkiSärki** *roach products* have been nominated as one of the candidates to become Food of the Year in 2016.
- production of **mussels** and processing to animal food and fertilisers in Sweden.
- improving **municipal sewage treatment** to reduce nutrient discharges from Belarus and Russia
- **gypsum** application to fields in the Archipelago Sea area: this can reduce c. 50% of field phosphorus losses to the sea immediately.
- **exchange of nutrients** e.g. between biogas plants and forest industry

John Nurminen Foundation is calling for further projects which can cost-effectively reduce nutrients to the Baltic Sea and for financers to fund the selected nutrient reduction projects *http://www.johnnurmisensaatio.fi/en/clean-baltic-sea-projects/nutritrade/*

Conclusions: Finland innovation and European networking

Tarja Haaranen, LUKE and Finland Agricultural and Environment Ministry, thanked the ministry staff and others who ensured the seminar organisation, in particular Noora Mantere, and concluded:

- **Many developments and considerable innovations in Europe** towards nutrient recycling, both in technologies and in value chain approaches
- Adaptation of **legislation** is important
- Importance of **systemic change**, beyond nutrient recycling, including questions of consumer behaviour and diet, and government initiative is important to facilitate this
- **Need for dialogue** between Finland (R&D, companies, farmers, regulators) and European networks, to share experience, support Finland's "Clear Waters" nutrient recycling programme, and involve Finland in European developments and opportunities

Launch of Finland Government Key Project national nutrient recycling programme and "Recycle Nutrients for Clear Waters" seminar 19-20 April 2016, Helsinki http://mmm.fi/en/recyclenutrients *and* https://www.youtube.com/user/mmmviestinta

'Nutrient recycling into practice', Finland Ministry of Agriculture and Forestry and Ministry of the Environment joint press release, 19th April 2016 http://www.ym.fi/en-US/Latest_news/Press_releases/EUR_124_million_for_the_experimentation_(38965)

Challenges

Flanders manure processing innovation competition

The 2nd Ivan Tolpe Flanders manure processing award offers 2000€ prize and promotion for innovation proposals in manure nutrient valorisation. **Deadline for application is 28th October 2016.**

As a homage to farmer Ivan Tolpe, pioneer in manure processing, the Flemish coordination centre for manure processing (*VCM*) organizes every two years an **innovation award for market-ready techniques contributing to a sustainable, cost-efficient manure processing for nutrient valorisation**.

The award is open to all organisations / companies / individuals / scientists / … The proposed technique should be ready for practical application and quickly implementable for processing of manure, and be applicable in the Flanders (Belgium) context. All aspects of manure processing can be addressed, with focus on better **energy efficiency** or a more optimal **valorisation of nutrients** from manure.

The Ivan Tolpe Award 2015 winner is developing a new type of **manure separation device**, based on sieve disks, applicable for both pig and cattle slurry with a high separation efficiency. The other laureates of 2015 were Wouter Saeys, who performed **PhD research on the potential of a mobile VIS/NIR-spectrophotometer** for online measurements of pig manure composition and the construction company *Detricon*, who **recycles the ammonium nitrogen in manure** using a stripping/scrubbing process, producing a mineral fertilizer.

The winning prize is a cash award of €2000, plus promotion on the VCM-website and in the VCM-newsletter, and the possibility of presenting the project on the International **Manuresource Conference** in 2017, including a free participation to the conference. Additional nominated projects also get the possibility to join the conference for free and are allowed to present a poster. **The application form is in English or Dutch, but the final oral presentation must be in Dutch**.

Application form, award criteria and rules are available in English and Dutch on the VCM website. Flanders http://www.vcm-mestverwerking.be/news/index_en.phtml?id=394

2015 Ivan Tolpe award winner (in Dutch only) http://www.vilt.be/marc-bollaert-wint-ivan-tolpe-prijs-met-mestscheider

George Barley Prize

Everglades teams with Ontario for 11.2 million US$ nutrient removal and recovery challenge. Opening of the challenge is expected before mid-July with first submission deadline end summer 2016, then several rolling submission deadlines.

The Everglades Foundation Grand Challenge for new approaches to remove recycle phosphorus from dilute waters (rivers, drainage ditches, lakes) has now partnered with the Ontario Ministry of Environment and Climate Change and Xylem, to offer a **total of 11.2 million US$ prizes**. For more information, see summary of Everglades Grand Challenge in SCOPE Newsletter n°111.

A new website has been launched and submission application documents will be online at the challenge opening, expected early before mid-July. **To be informed and pre-register, create your user profile:** ***www.barleyprize.com***

"Everglades Foundation Announces The George Barley Science Prize Competition at White House Event Today" http://www.evergladesfoundation.org/2015/10/07/everglades-foundation-announces-the-george-barley-science-prize-competition-at-white-house-event-today/

Nutrient Platforms

Europe: ***www.phosphorusplatform.eu***

Netherlands: ***www.nutrientplatform.org***

Flanders (Belgium): ***http://www.vlakwa.be/nutrientenplatform/***

Germany: ***www.deutsche-phosphor-plattform.de***

North America Partnership on Phosphorus Sustainability NAPPS ***https://sustainablep.asu.edu***

Agenda

- 17th June, Amersfoort, Netherlands. **ESPP technical meeting on struvite regulation**: REACH exemption, REACH dossier update, EU Fertiliser Regulation criteria, struvite fertiliser value *info@phosphorusplatform.eu*
- 23rd June Paris, **UNIFA conference** on fertilisation, circular economy and climate change (in French) *www.engrais-agriculture.fr*
- ESPP working meeting on **EU Fertiliser Regulation**, 29th June Brussels discussion of proposed Regulation text, application to recovered nutrient products, composts, digestates *info@phosphorusplatform.eu*
- 30th June, Logrono (La Rioja) Spain, Struvite recovery workshop and **PHORWater LIFE+ pilot plant visit** *http://phorwater.eu*
- 10-13 July, Denver, Colorado, **WEF/IWA Nutrient Removal and Recovery conference** opening plenary session on P-recovery success stories presented by ESPP at IWA-WEF Nutrient Removal and Recovery Conference 2016 (11-14 July) plus Workshop on Nutrient Recovery at WWTPs 10th July *http://www.wef.org/Nutrient-WEFIWA*
- 16-20 Aug, Kunming, Yunnan, China, 6th **Sustainable Phosphorus Summit** *http://sps.ythic.com/*
- 5-9 Sep, Lake District, UK, Germany, **International Organic Phosphorus Workshop** *http://www.soilpforum.com*
- 12-16 Sept, Rostock, Germany, **8th International Phosphorus Workshop (IPW8)** *http://www.wissenschaftscampus-rostock.de/*
- 27-28 October, Copenhagen, **Nordic Phosphorus Conference** *https://dakofa.com/conference/conference*
- 13-15 March, Tampa, Floria, **Phosphates 2017** http://www.crugroup.com/events/phosphates/

Updated events listing online at: http://www.phosphorusplatform.eu/events/upcoming-events

To add your event, please contact info@phosphorusplatform.eu