European Sustainable Phosphorus Platform

February 2017 n° 124

SCOPE NEWSLETTER

Policy

EIP-Agri Focus Group Recycled Nutrients

Proposals for themes for Operational Groups and areas where R&D is need.

Regulatory status of struvite

Authorisation of recovered struvite as a fertiliser

Meetings

CIWEM UK P pollution conference

How to optimise reductions of phosphorus pollution and incite phosphorus stewardship

Global Organic Resources Congress (GORC) Dublin

Innovations in the bioeconomy and organics in the circular economy

Lombardy – South Holland working together on manure recycling

Companies, regulators and scientists from the two regions met in Milan to showcase nutrient recycling success stories and develop joint projects

P-recovery technologies

World's biggest P-recovery installation

Ostara units will recover nearly 10 000 t/y of struvite fertiliser from Chicago's sewage

Mussels for Baltic nutrient recycling

LCAs of nutrient recycling scenarios including harvesting mussels to reduce eutrophication and recycle nutrients

P recovery onto biochars

Nutrient recovery (P, N) by adsorption to hydrochars, biochars and chemically modified biochars

Osmosis P recovery

Calcium phosphate precipitation by seawater-driven forward osmosis without chemical addition.

Amorphous calcium silicate hydrates A-CSH

A mobile batch unit was used to test P-recovery by sorption onto CSH and fertiliser effectiveness was tested.

P-recovery from biowastes

P extraction from dairy cattle slurry with low acid dose and precipitation of calcium phosphate not struvite.

Agricultural Waste Products

Technology review of use of modified or unmodified of Agricultural Waste Products for P-removal and P-recovery

Hydrated poultry litter ash as PK-fertiliser

LCA benefits of chicken manure bio-energy and crop effectiveness of the ash as P and K fertiliser

Phosphorus management

Phosphorus in surface waters

Assessing eutrophication and restoring water quality

Improving crop phosphorus use

Understanding of plant and cellular mechanisms for P uptake and methods to improve crop P use

Agenda:

http://www.crugroup.com/events/phosphates/

8-10 May 2017, Ben Guérir, Morocco, SYMPHOS Innovation and Technology in the Phosphate Industry
http://www.symphos.com/index.php

Full events listing on back page and online at
http://www.phosphorusplatform.eu/events/upcoming-events

The partners of the European Sustainable Phosphorus Platform

Clariant; HIE Highlands and Islands Enterprise (Iomairt na Gàidhealtachd 's nan Eilean); Outotec; n|w Fachhochschule Nordwestschweiz; Science Campus Phosphorus Research Rostock; fertilizers europe; Deutsche Phosphor Plattform; Biomasa Peninsular; incopa; BSAG Baltic Sea Action Group; suez environnement; Queen's University Belfast; Fraunhofer IGB; ecophos; SEDE Veolia; NuReSys; Italpollina; Kemira; Timac Agro International; Lippe EGLV.de Verband; ICL Fertilizers; Nutrient Platform NL; Hitz Hitachi Zosen; Thames Water; Ostara Creating Value from Waste; Dequest; Italmatch Chemicals; Kanton Zürich Baudirektion Amt für Abfall, Wasser, Energie und Luft; Government of the Netherlands; Severn Trent Water

Policy

EIP-Agri Focus Group on Recycled Nutrients

Proposals for themes for Operational Groups and areas where research is need.

The **EU EIP-AGRI Focus Group 19 on Recycled Nutrients** brought together some 20 selected researchers and stakeholders from science, agriculture and nutrient recycling. After two meetings, and elaboration of 10 "mini-papers", proposals emerged for Operational Groups and for areas where further research is needed.

This Focus Group was initially proposed in 2015 by ESPP, **supported by nearly 60 different organisations** (see SCOPE Newsletter *n°114*).

The **mini-papers** produced by the group participants will shortly be published on the EIP-AGRI *website* and will cover the following themes: advantages of recycling organic matter to soil and classification of organic products, regulatory context of nutrient recycling, environmental impacts and LCA, nutrient recycling technologies, logistics and cooperation, nutrient use efficiency (NUE), on-farm tools for accurate fertilisation with organic materials, on-farm use of recycled nutrients, end-user requirements.

Key points which emerged from the group's work include:

- importance of **recycled product quality**, relevant to many of the mini-paper themes above
- importance of **demonstrating the agronomic and environmental advantages** of nutrient recycling (including organic carbon)
- importance of **trust along the value chain**: farmers, food industry, supermarkets, consumers. The absence of the fertiliser industry, food industry and consumers from the Focus Group was regretted.
- need to **involve farmers as users**
- **no need to (re)invent new business models, standards**, but rather to adapt and demonstrate those which already exist

Proposals for Operational Groups

After two meetings, the Focus Group proposes the following tentative themes for ***Operational Groups*****.** These are **local innovation and demonstration actions, linking R&D to farmer implementation**, which can be funded through EU Rural Development Funding RDF (see *document*). Themes proposed by the Focus Group can lead to Operational Groups **if Member State/Region RDF (Rural Development Funding) programmes include relevant themes**, and if local stakeholders groups submit action proposals.

The **five themes proposed for Operational Groups** by the EIP-Agri Focus Group on Nutrient Recycling could include:

- **Demonstration of nutrient recycling technologies and use of recycled nutrients in practice**, comparing local results to wider experience. This should involve the whole value chain: technology providers, farmers, food industry
- Integration of nutrient recycling into **certification schemes**, **in particular food industry certification systems** (supermarket purchasing criteria, Global GAP …) and relating to existing quality schemes for e.g. composts, sewage biosolids, digestates. Local projects involving farmers, consumers, industry …
- Demonstration (including long term field demonstration) of **agronomic performance of recycled nutrients and organic fertilisers**, including impacts on soil carbon. Development and testing of monitoring and decision support systems for use of these products.
- Demonstration **of low ammonia emission techniques for manure management** (stable, storage, land application), including assessment of emission reductions achieved and of agronomic impacts
- Local testing of **business and cooperation models** for nutrient recycling, looking at value chain organisation and marketing.

Research needs

The Focus Group's two meetings identified the following seven areas as possible **priorities where knowledge is currently lacking and research is needed**. This can provide input for consideration by the European Commission for future Horizon2020 programmes.

- **Life Cycle Analysis** methodologies, **risk assessments**
- **Environmental impacts**: e.g. on nutrient leaching, soil carbon
- **Organic contaminants**: data, impacts, effects of processing
- **Acceptance** of organic fertilisers, by farmers, food industry, public consumers
- **Precision farming** application of recycled nutrient materials: remote sensing, translation to yield and crop N content, combination with other monitoring tools

- On-farm tools for **nutrient content determination** and **soil carbon balance assessment**
- **Technologies to produce bespoke recycled nutrient products**, tailored to specific local farmer / crop needs

EIP-Agri Focus Group on Nutrient Recycling https://ec.europa.eu/eip/agriculture/en/content/nutrient-recycling
*Information on Operational Groups*https://ec.europa.eu/eip/agriculture/en/my-eip-agri/operational-groups

Authorisation status of recovered struvite as a fertiliser

Struvite recovered from wastewater is authorised for use as a fertiliser for some producers in some EU Member States, but not in others, which is an obstacle to roll-out of this P-recycling technology. Initiatives are underway to address this.

The situation today is summarised as follows:

- **Certain recovered phosphates (struvite, magnesium phosphate, dicalcium phosphate) are authorised as fertilisers by national regulation in the Netherlands** of 29/3/16*
  However, this regulation **does not ensure End-of-Waste status**. Waste status does not prevent application as fertiliser but is a procedural obstacle to cross border trade and to use as a raw material for fertiliser production. Clarification on the conditions for End-of-Waste status is still ongoing. Also, this regulation states that these phosphates **must be treated by a "suitable process" to eliminate "the majority of pathogens"** and definition of such processes is also ongoing.
- **Struvite is nationally authorised as a fertiliser in Denmark,** where it is produced by Aarhus sewage works*, Herning water (Suez Phosphogreen process) and Helsingør (Véolia Struvia process).
- **Case-by-case authorisations have been accorded for recovered struvite by national/regional authorities. These are applicable only to the specific product from a specific waste stream / site / process**: Agristo and Clarebout, both from potato processing (both NuReSys process) in Flanders*, Slough sewage works (Ostara process) in the UK**, Berlin Wasser sewage works in Brandenburg, Germany**, as well as in a number of other states worldwide (e.g. Canada** - Ostara, 42 US states – Ostara, Japan* – Swing and others …).
  These case-by-case authorisations depend on the specific quality of the authorised product and so do not constitute a 'blanket' authorisation for struvite in the relevant country. However, these case-by-case authorisations can provide a precedent for future authorisation for other production sites, subject to their also proving product quality and safety.
  In some cases, they are supported by a clause in national legislation, e.g. "*recovered precipitated phosphates*" in **German fertiliser legislation**, or acceptance as an "*ordinary fertiliser*" under **Japanese national legislation**.

Obstacle to implementation

This current **lack of clarity and disparities between Member States poses a significant obstacle to roll-out of struvite recovery** as a P-recycling solution, because a technology successfully installed in one country cannot necessarily be sold in another, because the resulting product cannot be sold as a fertiliser.

- **Struvite may be considered as authorised under the existing EU Fertiliser Regulation (2003/2003)**. Brandenburg Land Germany has stated** that struvite is covered by Annex I – B2 ("NP fertilisers" ***) of this regulation. The phosphorus solubility of struvite is conform to B2-1 (<2% of P soluble 'only' in mineral acids, meaning 98% is soluble in water or ammonium citrate or citric acid). Also, B2 specifies the following definition "Product obtained chemically or by blending without addition of organic nutrients of animal or vegetable origin": most recovered struvite conforms to this definition because it is obtained by a chemical reaction and organics are not added (but this could possibly be questioned for struvite containing significant levels of organic impurities).
- **Where a recovered struvite is authorised as a fertiliser, End-of-Waste status also needs to be resolved.** In some countries, this is achieved because it is considered a "by-product" not waste, in others it is resolved by company self-declaration of End-of-Waste status validated by the regulatory authorities, in others it is not resolved to date.
- **REACH** (European Chemical Regulation). The European Commission has provided a written opinion* to ESPP 7/12/2015 that Art. 2(d) of REACH applies to recovered struvite. That means that once the substance has been REACH registered by one producer (done by Berliner Wasserbetriebe), **other producers do not need to REACH register**

and do not need to pay registration fees to ECHA. They must however document that their "sameness" of their product (appropriate analysis, spectral data …). There are however questions concerning the quality of the current registration dossier and the need to update it.

Developments

Initiatives are underway to address these issues:

- **EU Fertilisers Regulation revision** and **STRUBIAS**. The new EU Fertilisers Regulation (see SCOPE Newsletters n°s *122* and *120*), currently in discussion in European Parliament and Council, will enable recycled nutrient products (conform to the new Regulation criteria and categories) to be sold in any Member State, when the new Regulation comes into force (probably not for at least two years). **Recognised products will also be granted de-facto End-of-Waste status**, so resolving also this issue. Composts and digestates are already included in the proposed Regulation text, but struvite is not. The EU's Joint Research Centre (JRC) has been mandated to make an impact assessment and (if this concludes positively) to propose criteria to add struvite, biochars and ash-based recycled nutrient products to the new Regulation annexes (STRUBIAS, see ESPP *eNews n°5*). ESPP is a member of the STRUBIAS working group. These criteria could be added simultaneously to the new Regulation entry into force.
- A bi-lateral initiative is also underway between France and the Netherlands to authorise struvite as a fertiliser, and resolve End-of-Waste questions, in these two countries, with participation of ESPP and stakeholders including Suez and Véolia, through the **North Sea Resources Roundabout** initiative (see SCOPE Newsletter n°*120*).

It should also be noted that the EU's "Expert Group for Technical Advice on Organic Production" (EGTOP) has emitted an opinion (2/2/2016) that recovered struvite and calcined phosphates (from ash) should be authorised for use in organic farming (under EU Organic Farming Regulation 889/2008), subject to their authorisation under the new EU Fertiliser Regulation. See ESPP *eNews n°4*.

** documents available and published at* www.phosphorusplatform.eu/regulatory
*** documents confidential*
**** struvite cannot be considered as a "Phosphatic fertiliser" (A2) under EU 2003/2003 because this category specifies a limited list of 7 specific chemicals/materials.*

Meetings

CIWEM UK P pollution conference

"Taking the P out of pollution" organised by *CIWEM* (Chartered Institute of Water and Environment Management), at the Royal Society of Chemistry, London, brought together a number of UK regulators, water companies, environmental NGOs, catchment managers and stakeholders.

New approaches to phosphorus management were presented, including eutrophication restoration, catchment approaches, flexible discharge permitting, P-recycling and new technologies for removing phosphorus down to low levels. The meeting was chaired by **Paul Hickey, Environment Agency**.

Cynthia Carliell-Marquet, Birmingham University (now at Severn Trent Water) presented flows of phosphorus in the UK (see SCOPE Newsletter *n°113*). She noted that the year for which this analysis was carried out (2009) was non-typical, as it was immediately after the 2008 phosphorus price peak, resulting in farmers cutting phosphorus fertiliser application (**P fertiliser application in the UK has risen >50% from 2009 to 2015**). However, even in 2009, the UK was dependent on imported phosphorus (imports 138 KtP/y, of which over 50% fertiliser, versus only 24 ktP/y in exports).

Of phosphorus applied to agricultural land in 2009, 62% was in animal manures, 27% in fertilisers and only 8% in sewage biosolids. However, the potential for land use of sewage sludge phosphorus is increasing as tighter regulatory constraints lead to removal of an increasing part of sewage input P into biosolids.

Costs of eutrophication

Simon Leaf, Environment Agency, explained that the value of to the UK economy of freshwaters is estimated at **nearly 40 billion UK£** by the office of National Statistics – and eutrophication degrades the main contributory ecosystem services associated with the estimate – public water supply, recreational visits and fisheries (*SCOPE editor's note: this includes neither biodiversity nor property value – whereas the latter was considered possibly one of the highest economic costs of eutrophication by Dodds et al. 2009, SCOPE Newsletter* n°72).

Phosphorus concentrations in English rivers rose from the 1950s to the 1980/90s with increased us of P-based detergents, population growth and use of artificial fertilisers in agriculture. Since the mid 1990s, some **1.3 billion UK£ capital has been spent by water companies in England and Wales and 650 sewage works to date have phosphorus remova**l. A further 0.6 billion UK£ is committed 2015 – 2020. Agricultural measures such as Catchment Sensitive Farming since 2006 have also helped. This has brought positive results, for example average P concentrations in East Anglian rivers had fallen from 1 mgP/l in 1981 to <0.2 mgP/l by 2011.

Nonetheless, **around 55% of UK rivers and 74% of lakes still exceed Water Framework Directive phosphorus standards for good ecological status**.

The UK government in 2013 stated that it was sensible from multiple perspectives to improve efficiency of phosphorus use across relevant sectors and to increase the amounts recycled and re-used (response to EU Communication on Sustainable Use of Phosphorus, see SCOPE Newsletter *n°99*). It is questionable however whether land spreading of sewage biosolids where iron salts have been used for chemical P-removal – the main UK method of P reduction - should be considered as recycling, given the questions about plant availability of the resulting iron phosphates. **The challenge in improving P stewardship** is to find methods of removing more P from sewage, to meet river quality standards and reduce eutrophication, but keeping the P in a form that can be recovered and/or effectively recycled. And to do this at reasonable cost and with reliable performance.

Matthew Hampshire, DEFRA, presented the *process* of elaboration of the **25 year plans for Environment and for Food and Farming**, based on grassroots consultation. He considers that Brexit presents new opportunities, enabling us to decide how we can improve our water environment whilst supporting a sustainable and competitive farming industry.

We should build on the good progress set out in our **River Basin Management Plans** and use the full range of tools from voluntary actions and advice to targeted incentives and regulation to deliver a stretching ambition for the water environment.

Participants underlined that **diet and farming policy** are key to phosphorus demand, use and management, and that these two plans should be integrated.

P in soil and P losses

Phil Haygarth, Lancaster University, underlined that catchments react slowly to reductions in phosphorus inputs, so that **recovery from eutrophication** is delayed. He underlined the important impacts of **storms and flood events**. Storm Desmond in the Lake District in 2015, with 31 mm of rainfall in a single day, led in a studied catchment to >10% of annual total phosphorus loss, 20% of sediment loss and >10% of nitrogen loss in a few days. Climate change is accentuating this: winter rainfall in this region has increased +30% since 1960, whereas summer rainfall has fallen -16%.

Paul Withers, Bangor University outlined an **integrated approach to the phosphorus cycle**. Higher Olsen-P levels in soil (higher Soil P Index) will inevitably lead to higher runoff SRP (soluble reactive phosphorus) in run off. The objective should be to "Feed the crop not the soil" rather than the current 'insurance based' farming strategy (which maintains high or excess P reserves in soils). Potential options can include precision placement of fertiliser, seed dressings and foliar-applied P, new types of fertiliser which are not readily soluble but are plant available when needed by the plant (e.g. struvite) or development of crops with more efficient P-uptake via their root systems. In the future, crops could be redesigned to have a lower P requirement requiring less P inputs and with lower environmental risk.

Recently published pot trials (Talboys 2016, see SCOPE Newsletter *n°121)* showed that **struvite gave a greater crop yield (wheat) than traditional mineral fertilisers**, but without the risk of direct P loss in run-off which can be a problem with highly-soluble fertilisers.

Catchment management

James Grischeff, Natural England, presented the work of **CSFO Catchment Sensitive Farm Officers**, who coordinate local actions and stakeholder information to for catchment management. Principal measures to reduce pollution should be at source (in particular by precision fertiliser application based on soil testing and husbandry, developing soil organic matter and improving nutrient management), interrupting flow pathways (to allow sedimentation and associated phosphorus retention) and buffers (such as constructed wetlands).

Key to CSFO effectiveness is **listening** to researchers and scientists telling what works and where; listening to policy makers to refine objectives; listening to industry and stakeholders to formulate a relevant catchment campaign; and most importantly listening to farmers who can tell us a lot about how measures can be deployed practically and sensibly.

To be effective, measures have varied to **adapt to specific farm situations**, must be targeted to the farms and fields where a cost-effective difference will be made, should have high uptake (not on only some farms) and must be understandable, clearly explained and fit clearly within the farm system (farmers must also believe that they will work).

Arlin Rickard, The Rivers Trust, presented the **Catchment Based Approach (CaBA)** to improve water quality. He noted that changes in agricultural practices over recent decades have increased risks of **phosphorus losses as a consequence of intensification and damage to soil structure**: e.g.

- appearance of maize as a crop
- increased silage production for livestock feed (which allows several grass cuts per year, requiring fertiliser input)
- winter rather than spring wheat
- increasing animal density with more slurry waste
- "soil poaching" : that is, compacting of soil and destruction of vegetation by livestock in areas where they congregate, such as around feeding or drinking zones or stables

Coordinated catchment action including **Paid Ecosystem Services and Cap & Trade** is necessary to address phosphorus reduction together with maintaining other ecosystem services. This offers synergies with improving water resource management, soil health, and biodiversity (e.g. through wetlands creation).

Catchment permitting and stretch targets

Ruth Barden, Wessex Water, presented a real-scale test of **"catchment permitting"** engaged with the regulator (Environment Agency) in the Bristol Avon catchment (66 sewage works STWs of varying sizes). The principle is that, instead of reducing each STW discharge permit (in isolation) to a low fixed level which must be respected, **catchment permitting is defined to achieve a reduced total load discharged from all of the catchment's STWs**.

Each STW must respect at all times a 'backstop' limit of 1 or 2 mgP/l (the existing Urban Waste Water Treatment Directive limit), but also has a **'stretch' target** which are together calculated achieve the total catchment load discharge reduction. This recognises that some STWs will achieve lower emissions than their 'stretch' targets, whilst others may, occasionally, not achieve theirs. The STW limits have been defined not only to achieve the total catchment discharge, but also to ensure improved water quality in identified stretches of river (P discharge reductions upstream and not only in large population centres downstream).

The objective is to **optimise costs for water quality improvement**, taking into account all costs related to P removal, for example increased sludge storage requirements resulting from use of iron for chemical P removal.

Eutrophication restoration

Linda May, CEH Edinburgh, presented experience of 30 years of action to address eutrophication in **Loch Leven**. A short algal bloom incident in 1992 ("*scum Saturday*") resulted in over 1 million UK£ of short-term economic losses to fisheries and leisure uses, and much longer term economic impacts because of damage to the lake's reputation (perceived as a polluted site).

An important challenge was the very **long delay between action to reduce phosphorus inputs and visible lake recovery**. In Loch Leven, despite reducing phosphorus inputs from 20 to 8 tP/y, lake water total phosphorus P (annual average) scarcely changed between the 1990s and 2006 and only started to drop significantly from 2007 onwards. However, seasonal changes in lake water P were detectable much earlier and could, perhaps, have been used to demonstrate that actions were already being effective.

New approaches to P-removal and P-recovery

Joff Edevane, Anglia Water, noted that **adding iron dosing chemical P removal to existing sewage works** implies a range of costs: chemical storage and dosing equipment, monitoring, increase in sewage sludge requiring larger storage tanks, additional thickening equipment, improved access to sites, power upgrades. Mr Edevane presented a range of other technologies being tested in the **UKWIR project looking for economic solutions to achieve low P discharge consents from sewage works (below 1 mgP/l). These** include:

- Alternative chemicals for P-removal, e.g. lanthanum chloride
- Nitrogen – phosphorus biological phosphorus reactor
- Enhanced biological phosphorus removal
- High rate algal ponds
- Adsorption onto different materials
- Advanced filtration processes

Pete Vale, Severn Trent Water presented both full scale experience of phosphorus recovery as struvite and R&D into possible new P-recovery processes.

The **PAQUES struvite recovery** installation operating at Severn Trent's Stoke Bardolph sewage works (biological P removal with anaerobic sludge digestion) is designed to recover approximately 550kg of phosphorus (as P) per day, this is **sold to OMEX, a fertiliser blender**.

This results in **operating savings of c. 165 000 UK£/year** by avoidance of nuisance deposits in pipes and pumps.

Also, the struvite recovery reduces soluble phosphorus levels which is necessary for operation of the Anammox process.

Processes being tested / demonstrated for possible phosphorus recovery at the Packington sewage works include **nano iron particle phosphorus adsorption** (ion exchange). The particles are regenerated using caustic soda (pH 13) then calcium phosphate is precipitated using lime. The driver for P-recovery is the saving in caustic resulting from lime regeneration.

Severn Trent Water are also sponsoring research by Cranfield University investigating **mainstream bio-struvite precipitation, by bacteria**.

He indicated that an obstacle to P-recovery implementation and to investment in sewage works P-removal upgrading is that sewage works infrastructure is accounted with a 60-year asset value.

Other sources of phosphorus

Daren Gooddy, British Geological Survey, indicated that **leakages of drinking water from pipes** results in an estimated 1 200 ktP/year phosphorus losses to the environment, because phosphate is dosed to drinking water. See SCOPE Newsletter *n°119*). Around 70% of these phosphorus losses go to surface waters and 30% to ground waters. In the Thames Water region, these drinking water phosphorus losses represent around 15% of sewage works P discharges. Drinking water phosphorus losses from pipes cost the UK an estimated 6 million UK£/year.

Ralph Early, Harper Adams University, reviewed the wide range of **functional properties that phosphate additives contribute to food systems** as applied in the manufacture of e.g. baked goods, processed meats, processed cheeses and carbonated beverages, etc.

He noted that **some 50 food additives containing phosphorus are used by the food industry**, providing or assisting in functions such as emulsification, water holding, acidity regulation and buffering, chelating of metal ions, colour control, etc. and that in many instances phosphate additives are difficult or impossible to substitute without changing the characteristics of food products.

Phosphorus Platforms move forward together

Chris Thornton presented ESPP (European Sustainable Phosphorus Platform), a "coalition for action" to improve the regulatory context for phosphorus recycling in Europe. Following the inclusion of phosphate rock in the EU Critical Raw Materials List in 2014, nutrients were identified as a **key area for action in the EU Circular Economy Package 2015**. This is being taken forward both by EU initiatives, such as the *revision* of the EU Fertilisers Regulation to cover the sale of recycled nutrient products such as composts, digestates, animal by products, processed plant materials or food wastes, and by national initiatives such as nutrient or phosphorus recycling obligations or objectives in Switzerland or Sweden, or the North Sea Resources Roundabout (SCOPE Newsletter *n°120*) between the UK, France, Netherlands and Flanders.

ESPP also showed a number of **success stories**, where companies or organisations are already recycling phosphorus, including certification schemes for agricultural use of treated sewage biosolids (*REVAQ*), production of 400 000 tonnes/year of organic manure fertiliser from manure (*COOPERL*), on-farm phosphorus recycling from drainage ditches (*Polonite* filter beds), and industrial recycling to *phosphate*, *fertilisers* or *P4*.

Malcolm Bailey, Link2Energy, presented the **project for a UK Nutrient Platform**. Three meetings were organised to define and launch this Platform in 2014-2015. This showed a wide interest from industry, stakeholders and academics, with a range of expectations. These meetings were funded by the EU (BioRefine project). However, in the absence of new project support of this type, a sustainable funding model for a UK Platform has not been established.

Conclusions

Key conference take-homes were:

- **important economic impact**s both of phosphorus loss (eutrophication) and loss mitigation (P-removal in sewage works, agricultural and land practices)
- good **progress** has been made on reducing phosphorus levels in the UK water environment, but still more must be done, and we also need to find ways to better recover phosphorus and make use of it as a resource
- **complexity** of sustainable phosphorus objectives, which involve questions such as food and diet, industry, agriculture, spatial planning, as well as needing research and data on questions such as plant nutrient use and soil behaviour, nutrient flows, phosphorus removal and recycling technologies
- importance of **dialogue** between regulators, farmers and stakeholders for phosphorus management
- effectiveness of collaborative actions at the **catchment level**
- need for communication and for mediators, such as agricultural **outreach services** and catchment managers, to facilitate dialogue and enable joint actions

CIWEM www.ciwem.org *"New Developments in Sustainable Phosphorus Management: Taking the P out of Pollution", London, Royal Society of Chemistry, 27th September 2016. Speaker slides online soon* http://www.ciwem.org/events/new-developments-in-sustainable-phosphorus-management-taking-the-p-out-of-pollution/

Global Organic Resources Congress (GORC) Dublin

The Global Organic Resources Congress, 3-4th of May 2016, Dublin, Ireland, organised by Cré, the Composting & Anaerobic Digestion Association of Ireland, in partnership with ECN, the European Compost Network, brought together over 150 delegates, speakers and exhibitors.

Summary prepared by Katrina Macintosh, Queen's University Belfast, with support from Lee-Jane Eastwood, Cré.

The focus of this year's Congress was on looking toward the future, at **innovations in the bioeconomy**, and setting a trajectory to be ambitious within the sector moving forward.

Martin Eves, Chairman of Cré, noted in his foreword the exciting prospects the recent EU Circular Economy package will bring to this sector in terms of producing high quality end products, as well as **creating new job opportunities from waste collection, processing and the sale of end products**.

The EU Circular Economy package has set new targets for recycling and landfilling waste, which include:

- A common EU target for **municipal waste recycling** of 65% by 2030;
- A common EU target for **packaging waste recycling** of 75% by 2030;
- **Material-specific targets** for different packaging materials; and
- A **binding landfill reduction target** of 10% by 2030

Bio-waste management in Europe now requires all Member States to collect this waste stream separately for both composting and anaerobic digestion, where technically, environmentally and economically practicable and appropriate. Thus recycling even more organic carbon and nutrients back into Europe's soils. Further to this, the revised EU Fertilisers Regulation (see SCOPE Newsletter *120*) aims to establish a regulatory framework to facilitate the production of fertilisers from recycled organic materials in order to place compost and digestate, on the European market, as soil improvers and organic fertilisers. Thereby truly adopting a circular economy by diverting bio-waste away from landfill and incineration.

Further to this, the use of anaerobic digestion provides the added benefit of **renewable energy and biofuel production**, thus reducing greenhouse gas emissions and reliance on traditional fossil based fuels. Organic resources offer exciting potential in terms of boosting Europe's 'Green Economy', through comprehensive waste collection, processing and the production of recycled products from bio-waste.

Vision 2050

Henrik Lystad, Chair of the European Compost Network presented on future predictions for anaerobic digestion and composting plants in the year 2050. Henrik discussed a holistic view of moving beyond compost and biogas to the production of methane and hydrogen as alternatives to fossil fuels; the production of organic fertilisers/soil improvers and the contribution of plants to the bio-economy through the production of bio-based products, such as biochemicals, bioplastics and fibres. Henrik also estimated that ***'100 million tons of bio-waste could create 20,000-50,000 new sustainable jobs in the EU'*** and called for '*setting an obligation for the separate collection of bio-waste as a guiding principle*'.

David Newman of the Bio-based and Biodegradable Industries Association, UK, then discussed the concept of the bioeconomy and its role in the development of a circular economy in Europe. The Bio-based and Biodegradable Industries Association was founded in 2015 and represents companies producing bio-based and biodegradable polymers. He emphasised the importance of the bioeconomy in terms of **recovering organics to maintain soil health, closing the '*soil to soil loop*' and promoting carbon sequestration.** Further to this, the added potential of biomass and waste to generate '*biorefineries*' for the production of fuel, biochemicals and biomaterials, and feedstock and food ingredients.

Sugar, as the '*new molecule of the future*' was highlighted for the production of fuel, chemicals, plastics and energy.

Mairead McGuinness MEP, Vice-President of the European Parliament, concluded the session on '*Vision 2050*' by giving an overview of the opportunities the **EU Circular Economy package** will create in terms of moving away from the current, wasteful, linear economy system towards a circular economy, whereby '*closing the loop*' will help reduce wastage and further change mind-sets in terms of recycling. Mairead detailed the package in terms of production and how products can be recycled; consumption in relation to raising consumer awareness through eco-labelling; revised waste management targets and creating a market for secondary raw materials.

Healthy soils – Health planet

Jane Gilbert, from the International Solid Waste Association, who focused specifically on the carbon and plant nutrient content of organic wastes and how they can be recycled to create high value products, which contribute towards feeding a rapidly increasing global population, as well as conserving resources and improving soils. She noted that 80% of the world's agricultural land suffers moderate to severe **soil erosion** and that 10 million hectares of agricultural land are lost each year through soil erosion, which further strengthens the need to return organic matter contained within organic waste to the soil.

Padraig Brennan from Bord Bia, the Irish Food Board, Ireland, detailed an Irish perspective on sustainable food production and how Bord Bia's Origin Green Sustainability programmes work with farmers and food companies to demonstrate and improve the sustainability credentials of products from the Irish food and drink sector. The scheme was launched in 2012 and Origin Green is the world's first independently verified national sustainability programme with 85% of Ireland's food and drink exports coming from member farms and companies. As part of Origin Green companies sign up to a **sustainability charter** and farmers participate in quality and sustainability schemes.

Eric Liégeois, DG GROW, from the European Commission, updated delegates on current proposals for a revised EU fertilising products regulation. The objectives of the revision are to make fertilisers more sustainable, promote the recycling of nutrients and boost the market for secondary raw materials.

Challenges relating to nutrient recycling were identified as: technological limitations, end-of-waste criteria and acceptability for all national legislators. The regulation proposes extending to fertilising products, notably organic/organo-mineral fertilisers, organic soil improvers, growing media, plant biostimulants (compost and digestate) and introducing a CE mark for fertilising products to ensure safety, quality, standardisation and conformity.

A CE-marked complaint fertilising product will cease being a waste. Further to this **a target of 30% of P_2O_5 from recovered sources by 2050** was discussed. It is also expected that the CE mark will extend to struvite, ash and biochar by early 2018.

Promising Innovation

Cristina Pintucci, Centre for Microbial Ecology and Technology, Ghent University, Belgium, who presented the **ManureEcoMine project** on nutrient recovery (nitrogen, phosphorus and potassium) from manure digestate using ammonia stripping and struvite precipitation.

René Rozendal, Paques, Netherlands, discussed '**Next generation anaerobic digestion – moving beyond biogas'**. His presentation detailed how the anaerobic digestion of organic wastes can be operated in such a way to generate volatile fatty acids instead of biogas. Volatile fatty acids can then be converted into products, more valuable than biogas, such as bioplastics and biopolymers. Since 2012 a pilot has been operational at industrial sites processing chocolate wastewater, paper wastewater and organic waste.

Stefano Facco, Novamont, Italy, reported on '**Locally integrated biorefining: the case study of Novamont'**, which produces value-added biochemicals by converting old industrial sites and co-operating with local farmers. This case study was an example of dry, pluriennal crops being turned into biomass and vegetable oils for the production of bioplastics, biolubricants, household and personal care products, plant protection products, food fragrances, and non-toxic additive for rubber and plastics.

Harm Grobrügge, European Biogas Association presented on '***Anaerobic digestion helping the food production sector reduce its greenhouse gas emissions'***.

Allan Yee, Composting Council of Canada, detailed '**Greenhouse gas reductions through composting'**: an overview of cap and trade, emission allowances and how such programs can support the recycling of organics.

Hans-Peter Schmidt, Ithaka Institute for Carbon Strategies, Valais, Switzerland, presented '**Biochar progress and its innovative uses'**: an overview of biochar progress and the potential markets for biochar in animal feed, animal bedding, slurry and use in soil improvers.

Feedstock Quality Management

Alberto Confalonieri and Massimo Centemero, of the Italian Composting and Biogas Association presented '**20 years' experience of a successful organic waste policy in Italy'** giving an overview, from the Italian perspective, of the legislation for source separation of food waste, the plastic bag ban, quality assurance for compost, subsidy for the use of compost on agricultural land and methods to control contamination. The Italian Composting and Biogas Association and associated companies manage around 80% of treated biowaste.

Percy Foster, Cré (the Composting and Anaerobic Digestion Association of Ireland), presented '**Successful results of a pilot on educating householders in Sligo to source separate food waste'**. Results from the pilot study (brownbin.ie) showed that by providing householders with a kitchen caddy (small collection container), compostable bags and educational information on food waste recycling not only did the quantity of collected food waste increase, but the level of contamination was reduced from 45% to 1%.

Operation experiences of anaerobic digestion and composting plant manager

Wilbert Smeet, S.E.S.A. S.p.A. (Società Estense Servizi Ambientali), Italy, presented '**The S.E.S.A. biomethane and compost production facility'**. The S.E.S.A. S.p.A. mega-plant is the largest biogas and compost facility in Italy, treating 365,000 tonnes of high quality municipal biowaste per year, producing biomethane, organic fertiliser, electricity and district heating. In 2014, the plant input 380,000 tonnes of biowaste and 75,000 tonnes of greenwaste, producing 43,000 MWh of electricity, 32,000 MWh of thermal energy and 50,000 tonnes of compost.

Gert-Jan Klaasse Bos, Plant Manager, Meerlanden Holding N.V. Netherlands detailed the '**De Meerlanden compost and biogas facility'**. The plant processes 55,000 tonnes of organic waste feedstock per year and all by products are utilised: biomethane is injected into the grid, heat exchangers in the compost plant, and heat and CO_2 are used in greenhouses. Finally Gerald Dunst, Managing Director of Sonnenerde, Austria, updated via Skype, on the '*Integration of biochar production into a composting plant*'. Biochar acts as a soil conditioner, however, the production of biochar by pyrolysis is costly due to the high temperatures involved.

Compost Site Visit to Bord na Mona

The **Bord na Mona site, Kilbery Co. Kildare**, is a composting and automated bagging facility for peat based products. The facility opened in 2005 and is licenced by the Environmental Protection Agency to accept 100,000 tonnes per annum. The site is located on 4.2 hectares and cost €4.5 million.In response to a growing demand for peat-free and peat-reduced growing media, **Bord na Mona now accepts and compost a range of materials, including green waste, garden waste, wood waste and by-products of the food/beverage industry** (namely brewery grains). Compost produced onsite is subject to licenced parameter and quality control checks in relation to:

- Temperature;
- CO_2;
- pH, EC, major plant nutrients;
- Respiration tests;
- Germination capability;
- Plant growth analysis; and
- Microbial and heavy metal analysis

Compost is produced as a substitute to peat in a range of peat based products which are mixed and packaged in the automated bagging facility located onsite. The site is also completely bunded and has a leachate collection and re-circulation system.

Sponsors included Novamont; Italian Composting and Biogas Association; S.E.S.A., Enviroguide Consulting; Fáilte Ireland and EPA Research.

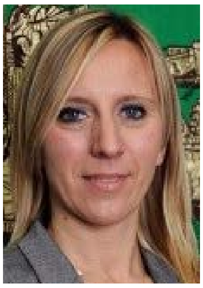
Exhibitors included Dorset Green Machine; Vogelsang; Novamont; Weltec Biopower; Nova Q; Environmental Technology Resources; Menart; Enviroguide; Air Liquide and MacMachinery.

Global Organic Resources Congress, $3-4^{th}$ of May 2016, Dublin, Ireland http://www.gore.ie/

Site visit to Bord na Mona, a composting and automated bagging facility for peat based products, located in Kilbery Co. Kildare.

Lombardy – South Holland working together on manure recycling

Technology suppliers, decision makers and experts from R&D centres, from South Holland and Lombardy regions met in Milan on 14th October to exchange experience of systems for manure processing and sewage nutrient treatment, and to develop joint project to demonstrate innovative nutrient recycling technologies.



The meeting was chaired by the **Lombardy Regional Minister for Environment, Energy and Sustainable Development, Claudia Maria Terzi**, and the **South Holland Regional Minister for the Environment, Water and Water Transport and Cultural Heritage, Rik Janssen**.

They indicated that the objective was to develop partnerships between actors in the two regions in order to implement actions for nutrient management and develop new business in nutrient recycling.

Sewage works visits

The Netherlands delegation visited three installations treating manure and municipal wastewater near Milan.

The **Nosedo municipal waste water treatment plant** treats around half of Milan's sewage (1.25 million p.e.). The key challenge faced is that **the sewage is very diluted on arrival** at the sewage works with below 2% phosphorus concentrations (total P). This is the result of high household water use in the Milan area, and of freshwater leakage into the sewerage network.

Because of this dilute wastewater, the works does not have primary settling, in order to bring a maximum organic load to the secondary treatment. The plant ensures a high level of wastewater purification with biological nitrification/oxidation/denitrification, iron or aluminium chemical phosphorus removal, and a sand filter to achieve low organic discharge levels. The sewage sludge contains only 1-2% P (dry matter) and **most of the sewage sludge is used on farmland**, with part having to go to incineration in cement works because of competition with manure for farmland.

The Nosedo works is the largest example of **reuse of sewage works discharge water for agricultural irrigation** in Europe, with over 430 000 m^3/day discharge water going to around 3 700 hectares of farmland (c. 90 farms). Disinfection is ensured by dosing of peracetic acid. This continues a historic tradition: the monks of Chiaravalle Abbey used to use Milan's sewage, via Roman sewage pipes, for agricultural irrigation, so recycling water and nutrients. The Nosedo works also recovers thermal energy from the treated wastewater using heat exchangers, for heating and air conditioning of buildings.

Participants also visited **Uni Aque**, one of the 8 companies of the **Lombardy Water Alliance**. The company explained that **major investments** were underway to improve sewage collection networks and treatment (including both organics and phosphorus removal) for many villages and towns, because of insufficient investment by municipalities in previous years. Tighter discharge consents are being introduced because of European Commission sanction procedures.

Solid fraction of digestate is used in agriculture

Upstream filter prevents membrane fouling

Advanced manure treatment

The delegation also visited the **Caraverde Energia in Caravaggio (BG) manure treatment centre,** operated by 9 livestock farming companies. The centre treats **manure from nine farms** (5 dairy cattle and 4 pig farms) located around the province of Bergamo and Cremona, with a total of 25 000 pigs and 1 800 milk cattle.

The manure is piped from the farms to the centre, and treated manure liquor is returned to the farms for field spreading also by pipes. This double piping network is a total of 22 km.

The centre treats 90 000 m^3 of manure per year, and also a small amount of food industry by-products (c. 10% of input). The treatment includes :

- **Anaerobic digestion**, producing biogas (8 000 000 kWh)
- **Nitrogen stripping from biogas, with recovery of nitrogen** as 30% ammonium sulphate (taken by the sulphuric acid supplier for industry recycling)
- The **digestate** goes to: screw press, flocculation (including aluminium dosing to precipitate phosphorus), centrifuge, decantation, filter, ultra-filtration (ceramic membrane) and 2-step reverse osmosis

This results in a **solid fraction of digestate which is used on farmland**, a **mineral concentrate** (2-3% nitrogen) which is returned to farms by the pipe network **and purified water** which is discharged to the river. The aluminium dosing ensures that 99% of inflow phosphorus is transferred to the solid fraction.

The plant has been operating for nearly 2 years. **The recent addition of the filter upstream of the membrane (ultra-filtration) to date appears to have resolved issues with membrane fouling**.

South Holland and Lombardy partnership for action

The workshop on 14th October at the Lombardy Region brought together 80 companies, research institutes and decision makers from Lombardy to meet the South Holland delegation of technology suppliers and experts. The meeting included explanations of circular economy policies for nutrients from The Netherlands, Lombardy and Europe, and then presentations of innovative nutrient technologies from the two regions.

Mario Nova and **Gian Luca Gurrieri, DG Environment of Lombardy Region**, and **Luca Zucchelli, DG Agriculture**, underlined that **the nutrient circular economy strategy requires integrated actions in environment and in agriculture** and challenges facing the Lombardy region.

Lombardy's 600 sewage works, serving over 12 million person equivalent and discharging into the Po Delta eutrophication "Sensitive Area" which then flows into the eutrophication hot-spot of the Adriatic coast. Today, a total of around 70% of phosphorus and 60% of nitrogen are removed from Lombardy's sewage.

SCOPE editor's note: the requirements of the Urban Waste Water Treatment Directive 1991/271 for sewage works > 10 000 p.e. in Sensitive Areas are 80% P removal and 70-80% N removal, or discharge concentration limits can instead be applied.

The Po Valley is also one of the world's 28 "hot spots" for atmospheric ammonia emissions, 98% of which come from agriculture. Ammonia and NO_x (which is around 50% from road traffic) are major precursors of atmospheric particulates ($PM_{2.5}$). The Lombardy Region considers that a 50% reduction in ammonia emissions is needed to bring atmospheric particulate levels in line with requirements of EU Air Quality Directive 2008/50/EC.

Lombardy has around **400 anaerobic digestion plants producing biogas**, producing some 300 $MW_{electric}$, and treating around a quarter of the region's pig manure. Total nitrogen content of manure in Lombardy corresponds approximately to crop needs, but around one third is lost as ammonia emissions, so that farmers have to purchase mineral fertilisers. Injection into soil of manure and digestate (instead of surface spreading) needs to be implemented to reduce ammonia emissions.

Nitrates Directive

The Lombardy Region also considers that **mineral concentrates recovered from digestates or manure** (after ultra-filtration or reverse osmosis) need to be recognised by the EU as outside the Nitrates Directive manure spreading limits.

David Röttgen, Italy national member of the IPPC, explained that Italy proposed legislation, notified to the European Commission in 2014, to enable mineral concentrates (so called "digestato equiparabile") to be considered as by-products and as comparable to mineral fertilisers. This legislation was in part rejected by the European Commission.

Art. 2(g) of the Nitrates Directive specifies that *"'livestock manure': means waste products excreted by livestock or a mixture of litter and waste products excreted by livestock, even in processed form*". Mr. Röttgen argues that the definition of livestock manure only applies to "waste" whereas digestate is not a waste, but a by-product, and that mineral concentrates should be treated as a "chemical fertiliser" (Art. 2(f) *"'chemical fertilizer': means any fertilizer which is manufactured by an industrial process*".

He suggests that classifying mineral concentrates as livestock manure is contrary to the spirit of the Nitrates Directive which aims to reduce pollution of waters by nitrates from agricultural sources, given that in mineral concentrates nitrogen is in the form of mineral salts, accessible to crops. He concludes that it appears incoherent that a waste can cease to be a waste (end-of-waste) whereas "livestock manure" always stays a waste under the Nitrates Directive.

Wouter De Buck, Netherlands Nutrient Platform, explained that The Netherlands' nutrient policy is partly driven by the European environmental obligations, in particular the **Nitrates Directive,** the **Water Framework Directive** and ammonia emissions under the National Emissions Ceilings Directive 2001/81/EC. Policy actions include the 2015 regulation authorising recovered phosphates as fertilisers (see SCOPE n°*110*) and the North Sea Resources Roundabout Green Deal (covering composts, struvite, see SCOPE n°*120*).

Circular economy policies

The Netherlands Parliament has now adopted a revised Circular Economy strategy, including the objectives to replace 50% of imported raw materials by recycling by 2030 and 200% by 2050. This covers not only phosphorus but also potassium and micro-nutrients (e.g. manganese recovery from end-of-life batteries).

However, to take these objectives forward pro-active polices are needed, such as innovation funding, financial incentives for recycling, green labelling, certification and standards for recycled fertiliser products.

European Sustainable Phosphorus Platform

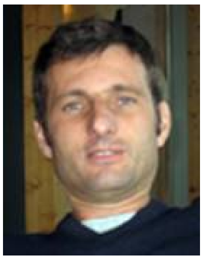
Chris Thornton, European Sustainable Phosphorus Platform, presented policy developments underway at the European level which support nutrient recycling and sustainable phosphorus management. In particular, the **revision of the EU Fertilisers Regulation** (currently in the European Parliament – Member States Council decision process, see SCOPE n°s *120* and *121*) will open the market for recycled nutrient products and for nutrient recycling technologies.

Other important developments underway include the **Switzerland obligation to recover phosphorus** from sewage sludge (SCOPE n°*118*), the new Germany P-recycling obligation for larger sewage works (September 2016), food waste reduction policies, standards development for secondary raw materials (CEN), standards specifying nutrient management in farm and food production chains …

ESPP also presented a range of **nutrient recycling business success stories** from different European countries, including processing manure to pelletised, crop-specific, organic fertilisers; struvite recovery from sewage and from food industry and use as a high-precision maize starter fertiliser; household bio-waste collection for biogas production; polonite filter beds for P-removal and recovery from agricultural drainage ditches, sewage biosolids quality certification, processing to fertiliser of chicken manure combustion ash and Meat and Bone Meal ash, feeding algae growth with digestate to produce biofuels and recover nutrients …

Stefan Jansen, Deltares, The Netherlands, presented the organisation's work developing joint project tools to facilitate nutrient management, in order to address **EU Water Framework Directive** objectives. Deltares aims to understand and improve the nutrient cycle in the soil and water system by monitoring, modelling, and developing and testing measures. Nutrient reduction impact modelling tools, decision support tools, gaming and participatory monitoring facilitate the implementation of shared incentive schemes. Tools include the *Deltares Nitrates App*. Iron coated sand from drinking water treatment is being recycled into floating or bed filters for P-removal from agricultural drains. Over 90% P-removal is achieved, but the phosphorus in the resulting product may not be a useful fertiliser.

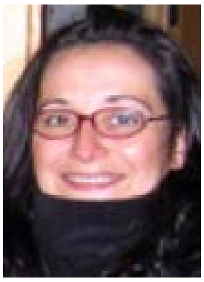
Innovations in manure treatment



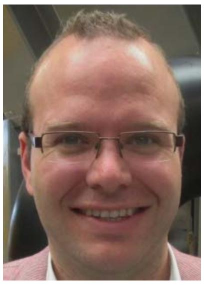
Fabrizio Adani, Ricicla Labs / DiSAA University of Milan, indicated that **anaerobic digestion** offers multiple advantages for manure processing: renewable energy (biogas), conversion of the organic carbon and nutrients into forms with improved agronomic properties (solid fraction). The liquid fraction of digestate is as effective for crops as mineral nitrogen fertilisers and enables lower atmospheric ammonia emissions, but only if injected into soil not surface spread.

Ammonia recovery from digester and manure processing offgases can generate ammonium sulphate or ammonium phosphate, at up to 8% N content (see Ledda et al., Riva et al. refs. below).

He also presented the **LIFE project "DOP"** (Demonstrative mOdel of circular economy Process in a high quality dairy industry *http://www.lifedop.eu/*) for integrated nutrient management from fodder production to manure treatment by anaerobic digestion, using digestate as substitute of fertilizers and reducing environmental impacts.



Fulvia Tambone, Ricicla Labs / DiSAA University of Milan, presented the *POWER* project, funded by the **Cariplo Foundation**, which is looking at different routes for nutrient recycling from digestates. Projects include production of fertiliser pellets from digestate and wood ash, struvite precipitation from manure digestate. Assessments of fertiliser value of digestates have been carried out on a range of crops including lettuce, beetroot and maize (data under publication).



Wouter van Betuw, Nijhuis Industries (*www.nijhuisindustries.com*), The Netherlands, presented the company's technologies for nutrient recovery in manure and wastewater treatment. **Nijhuis GENIAAL** is an integrated solution for the processing of manure, converting raw manure or digestate to approx. 70% clean water and approx. 30% bio-based fertilizers on demand (phosphate, nitrogen and potassium fertilizer). GENIAAL is adapted for large-scale manure processing companies treating approx. 50 000 tons raw manure per year. After anaerobic digestion (biogas), the digestate goes to a decanter centrifuge, separating a solid fraction which is hygienised and processed to solid organic phosphate fertilizer, and a liquid fraction. This liquid fraction goes to a Dissolved Air Flotation unit, then to ammonia stripping producing nitrogen fertilizer and finally to membrane filtration, resulting in clean water and a mineral concentrate which is evaporated into potassium fertiliser

Elena Bonadei, OB Impianti, Lombardy, presented a **semi-mobile reverse osmosis** (organic membranes, after solid-liquid separation) water purification plant. The plant fits in two transport containers, which can be installed one on top of the other to minimise footprint, and can treat 100 m^3/day.

70-80% of inflow is converted to clean water conform for reuse, 20-30% of inflow comes out as a mineral concentrate. A full scale pilot is already operational.

Maria Briglia, Mbriglia-NuReCo, Wageningen, The Netherlands, presented the company's **manure treatment** system, already operational at MV Sterksel, Someren and Esbeek in the Netherlands. Initial solid-liquid separation is carried out using a belt press with specific polymer flocculant dosing (no iron or aluminium), generating a shovelable solid of up to 35% dry matter, rich in available phosphorus. The liquid fraction goes to biological treatment where ammonia is converted to nitrate, then ultrafiltration and reverse osmosis, resulting in a concentrate of mineral nutrients (carbon, nitrogen-nitrate, potassium, magnesium and micronutrients) and purified water. The process is registered at BBIE as "Sustainable method for the treatment of swine slurry", BBIE-iDepot Nr. 076205, 4th March 2016.

Piero Manzoni, Neorurale, presented the **Aqua e Sole nutrient recovery centre project** (Cassinazza, Lombardy, see SCOPE n°*118*) where 120 000 t/year (wet weight) of separatively collected food wastes, manures and other biomass, will be anaerobically digested to produce biogas (2MW electricity production), digestate used for precision conservation agriculture to replace chemical fertilisers, and ammonia recovered as ammonium sulphate (15% concentration) for use as fertiliser in local tomato production.

Resources recovery from sewage

Erwin de Valk, Vallei and Veluwe water board, The Netherlands, explained that the authority has developed a number of **resource recovery** routes. These include sanitisation and drying of sewage sludge. Cellulose recovery in sewage plants is being developed, because this increases plant capacity (by removing recalcitrant organics) and the cellulose is re-used within the plants as a dewatering polymer.

A new digester at the **Harderwijk sewage works** will take manure and other materials from the Netherlands "positive list Annex Aa" Biogas production will be injected into the natural gas grid, which is more energy efficient than use for electricity generation. Carbon dioxide will be captured and used in a nearby building material production factory. The digester will use the sewage works' existing infrastructure, heat, electricity.

The resulting digestate will be exported as a fertiliser. This is possible because **digestate is on a positive regulatory list in the Netherlands and so is not considered waste**. The board also already operates two struvite plants for phosphorus recycling, with Ostara and NuReSys technologies.

Pieter de Jong, WETSUS, The Netherlands, presented the EU FP7 project **ValueFromUrine**, *www.valuefromurine.eu* demonstration of a bio-electrochemical system (fuel cell) for recovery of nutrients from urine (ammonia), preceded by struvite precipitation. Urine separation can be of interest for existing sewerage systems, because up to half the energy consumption for aeration in sewage works can be related to urine nitrogen. The first installations in The Netherlands have already been achieved. Most likely this technology will be initially applied in public buildings, airports and sports stadiums. Many of these already have urinals with urine separation.

In addition De Jong hinted at the shared challenges between The Netherlands and Lombardy region, with high population density, heavy industry and a large amount of livestock pressures on the environment are intense. To achieve WFD standards more breakthrough water technologies need to be developed and applied. Wetsus looks forward to team up with CAPHolding and other water companies in Lombardy region, as well as industries and agriculture to develop the highly needed solutions.

This meeting was organised by the Lombardy Region, the Netherlands Consulate in Milan and the Netherlands Nutrient Platform.

Refs. Cited: Ledda, C., Schievano, A., Salati, S., Adani, F., 2013. Nitrogen and water recovery from animal slurries by a new integrated ultrafiltration, reverse osmosis and cold stripping process: A case study. Water Research 47, 6157-6166; Riva, C., http://dx.doi.org/10.1016/j.watres.2013.07.037 *Orzi, V., Carozzi, M., (...), D'Imporzano, G., Adani, F. (2016). Short-term experiments in using digestate products as substitutes for mineral (N) fertilizer: Agronomic performance, odours, and ammonia emission impacts. Science of the Total Environment, 547, 206-214)* http://dx.doi.org/10.1016/j.scitotenv.2015.12.156

Phosphorus recovery technologies

World's biggest P-recovery installation opens

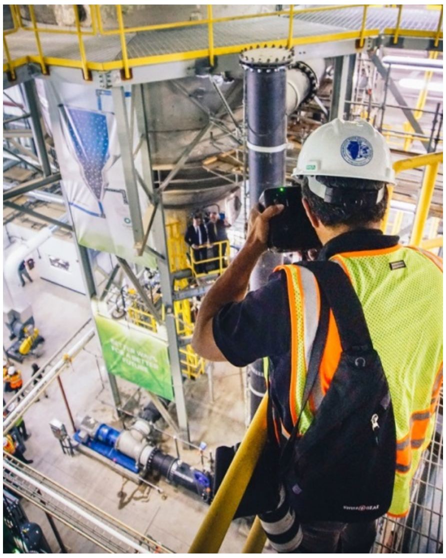
The Metropolitan Water Reclamation District of Greater Chicago (MWRD) opened the world's largest nutrient recovery facility in partnership with Ostara in 2016, at their Stickney Water Reclamation Plant in Cicero, Illinois, Chicago's largest sewage treatment works. The facility features three Pearl® 10K reactors treating the totality of the works sludge digestate, to produce 8 200 – 9 100 tonnes/year of struvite fertiliser.

The **Stickney Water Reclamation Plant** operates biological phosphorus removal and anaerobic sludge digestion, to produce biogas. The plant treats around 5.5 billion litres of sewage per day and serves **over 4.5 million residents**.

Discharge is to the Mississippi river basin, **which flows into the eutrophied Gulf of Mexico**, so reducing phosphorus output is a priority. The plant's P discharge consent is 1 mgP/l.

Three Ostara Pearl units together treat the full digestate liquor stream, downstream of dewatering centrifuges, recovering around 85% of the phosphorus from this stream (that is, around one quarter of the total sewage works phosphorus inflow, with most of the rest going to the sludge digestate), as well as some nitrogen, as struvite (magnesium ammonium phosphate), which is sold as **CrystalGreen fertiliser**.

Crystal Green struvite is sold as a premium fertiliser, and is virtually water insoluble with 99.6% purity. Its **continuous release properties ensure that nutrients (phosphorus, magnesium and nitrogen) are released only when the plant needs them** (by growing roots releasing citric acids), so the fertiliser significantly reduces the risk of run-off or losses of phosphorus to surface or groundwater. Also, the product does not "burn" roots or seeds. Ostara is selling Crystal Green fertiliser to the agriculture, turf and horticulture markets in North America, Europe and Asia.



WASSTRIP™ – recovery of up to 50% of sewage inflow phosphorus

Chicago is planning to further install an Ostara **WASSTRIP (Waste Activated Sludge Stripping to Remove Internal Phosphorus)** installation at Stickney Water Reclamation Plant. This unit is installed upstream of the anaerobic digester. Phosphorus is released from the biological sludge (by controlled agitation in anaerobic conditions), then a thickener separates a liquor stream rich in soluble phosphorus and magnesium, which is sent directly to the Pearl struvite reactors (in addition to the digestate centrifuge dewatering liquor). The thickened sludge stream goes to the anaerobic digesters. **This configuration is expected to recover as struvite around 50% of the total sewage works P inflow.**

Benefits for the Stickney plant from Ostara's Pearl system include revenue from Crystal Green fertiliser sales which contributes to the municipalities' circular economy objectives; **avoidance of chemical purchase** costs for P-removal; improving the reliability of achieving the **plant's P discharge consent**; and, improving operations such as **sludge dewatering** and **reduced plant energy consumption**.

Ostara currently have Pearl struvite recovery installations in operation at 14 wastewater treatment facilities worldwide (in the USA, Canada, the UK, Spain and the Netherlands) with a total production capacity of nearly 20 000 tonnes/year of struvite.

Ostara /MWRD press release, case study and fact sheet: http://ostara.com/mwrd/

List of Ostara installed and planned nutrient recovery installations to date: http://ostara.com/wp-content/uploads/2016/09/WEFTEC_Ostara_Overview_e.pdf *and* http://ostara.com/nutrient-management-solutions/

*Historical note: Ostara was a pagan German Goddess, or possibly she was in fact invented by the Venerable Bede. Her name is sometimes spelt Eostre, with the same origins as aurora (dawn) or East. She is associated with the Spring (or Vernal) Equinox, now renamed Easter by some, and so with fertility, and also with balancing eggs (*link*). The name Ostara was chosen because of the association with birth, which aligns with the technology creating a new product from a sustainable resource.*

Mussels for Baltic nutrient recycling

A thesis compares LCAs of various nutrient recycling scenarios including harvesting of mussels to reduce eutrophication and then recycling as fertiliser, wastewater urine and blackwater separation, food waste and slaughterhouse waste.

Mussels (*Mytilus edulis*) are grown for food in Sweden in the Skagerrak sea. **Mussels in the Baltic proper however are smaller, because of lower salinity, and cannot be used as food**.

Cultivation of mussels in the Baltic to remove nutrients and recycle as fertilisers was assessed. Field tests show that around 150 tonnes of mussels per hectare can be harvested after 28 – 30 months, cultivated on nets.

The mussels need to be processed, because fertiliser demand does not necessarily correspond to mussel production dates. **Composting of mussels mixed with straw** has been shown to be effective. Another process modelled but not tested would be crushing and storage as a pulp in water in anaerobic conditions to slow down decomposition: this would avoid the considerable nitrogen losses of composting, providing a fertiliser product adapted to the N:P requirements of crops.

Life Cycle Analysis

The LCA concludes that mussel harvesting for fertiliser use can be effective in removing nutrients from the Baltic and supplying renewable fertiliser nutrients. Cadmium levels in mussels can be significant, but are lower than in the mineral fertilisers and liming agents which were replaced by the composted mussels.

In the other scenarios considered in the thesis, choice of wastewater treatment system had a considerable impact on LCA conclusions. Urine separation reduced the environmental impact for the largest number of categories. Use of **meat meal (slaughterhouse waste), blackwater**, **urine** and **mussels** as fertilisers reduced greenhouse gas emissions and/or energy use compared to mineral fertilisers.

Slaughterhouse waste

LCAs of two different routes for valorisation of slaughterhouse waste (Animal By Products category 2) were compared:

- **Production of a meat meal fertiliser (Biofer, produced at Ortved, Denmark)** for use as a fertiliser and use of fats for energy. This system was a net consumer of energy, because of energy used in processing the meat meal.
- **Combustion for energy** of all the slaughterhouse waste together. This system was a net energy producer.

Biofer contains N and P (10:3 ratio) and comparable meat meal fertilisers contain c. 30% organic carbon. This can lead to excess phosphorus application to land because the N:P ratio is lower than crop needs. It contains c. 1.3 mgCd/kgP_2O_5 (compared to proposed EU Fertiliser Regulation limits of 20 – 60 mg).

Taking into account mineral fertiliser production, the LCA concludes that the production and use of meat meal as fertiliser can reduce greenhouse gas emissions, but that the environmental benefit depends on the available infrastructure.

Food waste

In a third study, different routes for **treatment of food wastes** were considered: anaerobic digestion and use of digestate as fertiliser, incineration and use of mineral fertilisers. The use of digestate scenario showed higher energy consumption, greenhouse emissions and other impacts, but the authors consider that this could be modified by improvements to the anaerobic digestion process.

"Bringing nutrients from sea to land e mussels as fertiliser from a life cycle perspective", Journal of Cleaner Production 51 (2013) 234-244 http://dx.doi.org/10.1016/j.jclepro.2013.01.011 *J. Spångberg, H. Jönsson, P. Tidåker*

"Environmental impact of meat meal fertilizer vs. chemical fertilizer", Resources, Conservation and Recycling 55 (2011) 1078-1086 http://dx.doi.org/10.1016/j.resconrec.2011.06.002 *J. Spångberg, P.-A. Hansson, P. Tidåker, H. Jönsson*

"Environmental impact of recycling digested food waste as a fertilizer in agriculture—A case study", Resources, Conservation and Recycling 95 (2015) 1–14, http://dx.doi.org/10.1016/j.resconrec.2014.11.015 *Y. Chiew, J. Spångberg, A. Baky, P-A. Hansson, H. Jönsson.*

Authors' address: Swedish University of Agricultural Sciences, Box 7032, 750 07 Uppsala, Sweden. johannaspangberg@gmail.com

"Recycling Plant Nutrients from Waste and By-Products. A Life Cycle Perspective", thesis, Uppsala 2014, J. Spångberg http://pub.epsilon.slu.se/11015/

P recovery onto biochars

Adsorption of P on biochars and hydrochars is mainly related to the presence of Ca or Mg. Chemical modification of the chars can increase the adsorption capacity. The adsorbed P is not however easily desorbed, so possibly limiting usefulness of the products as fertilisers.

Biochars and hydrochars are materials produced by the thermochemical or hydrothermal treatment of organic matter. **They can be obtained from a variety of waste biomass and have shown potential for recovering nutrients from various waste streams**. Hence they are increasingly gaining attention as economical and environmentally sustainable products that can be applied in waste management.

Takaya et al studied at lab scale (0.1g of char used in experiments) **sorption of phosphate (PO_4^{3-}) and ammonium (NH_4^+) onto biochar and hydrochars** obtained from a variety of waste raw materials (oak wood, greenhouse waste, anaerobically digested waste, treated municipal waste). The study aimed to i) investigate the recovery potential for the nutrients (phosphate and ammonium) and ii) to understand the physicochemical properties (like elemental composition, mineral content, and surface functionality) that enhance the nutrient uptake on the biochars and hydrochars.

No significant adsorption differences between biochars

Cation exchange capacity (CEC) was measured as an important parameter that could be related to the surface functionality and surface area. A higher CEC would usually imply an increase in surface functionality, which could mean an improvement in nutrient uptake. In the current study, no direct correlation between CEC and surface area was found.

The variation of CEC as a function of pyrolysis temperature and treatment with solvent (toluene) was checked. It was observed that **higher pyrolysis temperature (600 to 650 °C) generally resulted in higher CEC** on the biochars than the lower temperature (400 to 450 °C). Solvent treatment generally resulted in higher CEC for hydrochar whereas for biochars the CEC remained unaffected or was lowered.

The **phosphate and ammonium adsorption capacities for the materials ranged between 0 to 10 mg P/g and 80 to 115 mg N/g,** respectively. The phosphate adsorption capacities for the biochars increased with pyrolysis temperatures, and the authors found positive correlation with Ca and Mg contents.

The authors therefore attribute the phosphate sorption capacities to **metal ion reactions**, which include precipitation and surface deposition. For ammonium, there was a positive correlation between the functional groups and CEC. The ammonium adsorption was mostly attributed to chemical adsorption with oxygen containing functional groups. However, the authors conclude that despite differences in physicochemical properties and processing conditions, there were **no significant differences between the ammonium and phosphate adsorption capacities between the various chars tested**.

Chemically modified biochars

In another study, Takaya et al. studied the **recovery of phosphate using chemically modified biochars**. The treatments included chemical activation with **iron** and **magnesium** salts, surface activations with **potassium** hydroxide (KOH) or **hydrogen peroxide** (H_2O_2).Biochars treated with magnesium salts gained a significant enhancement on phosphate uptake while modification with other chemicals resulted in marginal improvements on phosphate uptake. The **biochars modified with magnesium salts exhibited a phosphate adsorption capacity** of c. 50 mg P/g, which was much higher than other chars.

Poor desorption

In both the studies, desorption experiments were carried out with 0.01 M potassium chloride (KCl) solutions. **The phosphate desorbed from the chars was low in most cases** so that recovery of the phosphate would be difficult. The concentrations of phosphate used in both studies (usually greater than 125 mg P/L) were unrealistic for adsorption from effluent of a municipal wastewater plant. But the authors reason that such high concentrations can be found in other sources, such as in anaerobic digestion plants and in agricultural and industrial wastewaters.

Obstacles to use of biochars for nutrient recycling

It is not very surprising that the authors are not able to significantly desorb phosphate from the char, because adsorption of phosphate is usually strong enough that weak electrolyte solutions (like 0.01 M KCl) will not be enough to reverse the reaction and release phosphate. Especially, if phosphate adsorption occurs via chemisorption or even precipitation, strong conditions like high concentration of sodium hydroxide (pH >12) will be required to desorb the phosphate. Although chemically modified biochars are able to remove nutrient like phosphate form wastewater streams, to justify the term recovery, the adsorbed nutrients also **need to be plant available**. The results of this study show that the adsorbed P is not easily desorbed, but in soils other processes may play a role. This aspect was not part of the scope of this study.

Takaya, C. A., et al. "Phosphate and ammonium sorption capacity of biochar and hydrochar from different wastes." Chemosphere 145 (2016): 518-527
http://dx.doi.org/10.1016/j.chemosphere.2015.11.052

Takaya, C. A., et al. "Recovery of phosphate with chemically modified biochars." Journal of Environmental Chemical Engineering 4.1 (2016): 1156-1165
http://dx.doi.org/10.1016/j.jece.2016.01.011

C. Takaya, L. Fletcher, S. Singh, U. Okwuosa, A. Ross, K. Anyikude, University of Leeds, LS2 9JT, United Kingdom
A.B.Ross@leeds.ac.uk

Osmosis P recovery

A phosphorus (P) recovery technology based on forward osmosis (FO), driven by seawater, without any chemical addition, is tested at laboratory scale on sewage sludge digestate dewatering liquor.

The proposed method targets (and is thus limited by) **dissolved P in sludge centrates** from anaerobic digestion of sewage sludge. Thus, it targets mainly sewage treatment plants applying enhanced biological phosphate removal in combination with sludge digestion. Typically only these plants have sufficiently high soluble P levels in the sludge to allow economical recovery.

In contrast to current struvite recovery processes, the proposed FO method **would not require any chemical addition** (i.e. no magnesium addition) and leads to calcium phosphate precipitate.

The **use of seawater as a draw solution** has the advantage that regeneration of the draw solution is not required.

According to the authors **forward osmosis has several advantages** compared to other membrane technologies:

- (I) up to 97 % of initial P can be retained in the concentrated centrate
- (II) fouling can easily made reversible by washing the membranes with pure water
- (III) bidirectional flow leads to pH increase in the feed solution allowing calcium phosphate precipitation
- (IV) seawater can be used as a draw solution and thus as a source for Ca.

A **lab scale cross flow FO system** was used with a membrane surface are of 123 cm^2 and two flow channels (CTA cellulose triacetate membranes). A sample of filtered sewage sludge dewatering liquor (3 liter, filtered at 0,5 µm, 29 mg P/l) was collected from a sewage treatment plant in New South Wales, Australia (configuration of the plant was not reported). This feed solution is separated by a membrane from the draw solution which is in this case was real seawater (5 liter, < 0.1 mg phosphate /L). These solutions were circulated at a rate of 1 l/min in the cross flow FO membrane system.

Due to osmosis, **water flows from the feed to the draw solution leaving a more alkaline solution**

behind, which is concentrated in Ca, Mg, K and P. Transfer of Ca or Mg from the draw solution to the feed solution was minimal, whereas K and Na showed transfer to the feed solution.

In this laboratory scale system it took around 3 days until 80 % of water volume moved from the feed solution to the draw solution but this can be expected to be considerably reduced in a full-scale system. The results indeed showed that P, Ca, Mg and K could be retained in the feed solution, most likely due to negative repulsion and/or size exclusion. At the same time the pH increased from 8.0 to 8.7. **About 92 % of the initial P in the feed solution precipitated**, about 4 % ended in the draw solution and about 4 % remained as dissolved P in the feed solution. Ca and P precipitated in significant quantities but also Mg, C, O and organic matter were found in the precipitates.

Mixed precipitate

The **P content in the precipitate was only 3 %** suggesting that next to calcium phosphate also calcium carbonate was formed. P-recovery was optimal at 65% water recovery and further concentration did not improve the recovery, probably due to a lack of remaining Ca and P in the solution. Over time the osmotic pressure decreased, thus reducing the membrane flux. When the sludge centrate was three times concentrated the water flux went down to 30 % of the initial value. Draw solutions with higher ionic concentrations than seawater could improve P recovery further (e.g. desalination brine).

Fouling of the membrane contributed only slightly to the decline in the water flux. In this experiment the fouling was fully reversible after washing the membrane with deionized water, this also shows that mineral formation took mainly place in the bulk solution. The authors suggest that **the technology is interesting but that it requires economic evaluation** (e.g. possible use of higher concentrated draw solution) and that the P content of the precipitate has to be increased.

"Phosphorus recovery from digested sludge centrate using seawater-driven forward osmosis." Separation and Purification Technology 163 (2016): 1-7
http://dx.doi.org/10.1016/j.seppur.2016.02.031

A. Ansari, F. Hai, L. Nghiem, Strategic Water Infrastructure Laboratory, School of Civil, Mining and Environmental Engineering, University of Wollongong, Wollongong, NSW 2522, Australia. W. Price, Strategic Water Infrastructure Laboratory, School of Chemistry, University of Wollongong, Wollongong, NSW 2522, Australia longn@uow.edu.au

Amorphous calcium silicate hydrates A-CSH

A mobile batch unit was used to test P-recovery by sorption onto CSH and fertiliser effectiveness was tested.

Amorphous calcium silicate hydrates (A-CSH) were synthesised as slurry from sand and calcium hydroxide (lime). The A-CSH were tested in **five batch runs in a 1000 litre mobile pilot reactor** to recover phosphorus by sorption from sewage sludge digester dewatering liquor. The recovered P-A-CSH product was tested as fertiliser in pot trials on Komatsuna.

The production of A-CSH from sand and lime and laboratory P-recovery experiments are presented in SCOPE Newsletter *n°93*. The **A-CSH is a low-cost, easily produced material which takes up phosphate by adsorption**, so that the P-enriched A-CSH (after P-recovery) can potentially be used directly as a fertiliser.

In this paper, a 1000 litre mobile pilot reactor (1.3 m high, 1.2 m diameter) installed on a small van was tested for five batch runs at a sewage works near Osaka, Japan. The sewage works uses biological phosphorus removal and the A-CSH reactor was fed with **dewatering liquor from the anaerobic sludge digestate centrifuges**. Because of flocs in the centrifuge liquor, it was necessary to pass this through a cotton filter before entry into the A-CSH reactor.

The reactor was stirred (2 blade agitator) and operated in batches: 1000 litres of liquor introduced and 590 – 720 g dry weight A-CSH was added, mixed for 20 – 60 minutes then settled for 30 – 60 minutes. 830 litres of supernatant was then withdrawn from the upper part of the reactor, and 170 litres of liquor/A-CSH mixture from the conical reactor base. The latter was filtered for 90 minutes in cloth bags to **separate the A-CSH – recovered phosphate, as a cake** with 83 – 87% water content.

The digestate dewatering liquor soluble phosphorus concentration was c. 175 mgP-PO_4/l and 72-85% was removed by the A-CSH reactor. The recovered P-A-CSH product contained around 10% P dry weight.

Fertiliser tests

The recovered P-A-CSH product showed low heavy metal levels. It was tested (after drying at 105°C for 24 hours) for **fertiliser effectiveness in 22 day pot trials** using Komatsuna (*Brassica rapa*), soil pH 5.0, and gave better results than both calcium superphosphate and Gifu-no-daichi commercial fertilisers for leaf length (at 7, 14 and 22 days) and for live weight (22 days). Also, the P-A-CSH showed to not inhibit seed germination.

The authors conclude that amorphous calcium silicate hydrates show **potential as a cheap and accessible sorbent material for P-recovery** from sewage liquors, and that the recovered P-enriched A-CSH can be directly used as an effective fertiliser. The 1000 litre mobile plant provides a useful tool for testing and process development.

Concrete sludge

In a further paper, the authors tested **acid-treated concrete sludge for phosphorus recovery** from pure chemical solutions and real anaerobic sludge digester liquor, in beaker – 3 litre laboratory experiments. The concrete sludge is a waste from construction sites where more cement is generated than required. Sludge was collected from a ready-mix concrete plant, washed, dried, filtered to produce a cake, ground, then soaked in 1.3 M hydrochloric acid for 60 minutes. 70 – 96% phosphorus removal was achieved from synthetic and real wastewater after 5 – 60 minutes. Heavy metals in the P-enriched concrete sludge product were low and P content was 8.2% (dry weight), with the phosphorus content < 0.01% water soluble. The fertiliser value of the recovered product and its agronomic impacts remain to be demonstrated.

"Amorphous calcium silicate hydrates and their possible mechanism for recovering phosphate from wastewater", K. Okano et al., Separation and Purification Technology, vol. 144, 2015, pages 63–69 http://dx.doi.org/10.1016/j.seppur.2015.01.043

"A mobile pilot-scale plant for in situ demonstration of phosphorus recovery from wastewater using amorphous calcium silicate hydrates", Separation and Purification Technology, vol. 170, 2016, pages 116–121
http://dx.doi.org/10.1016/j.seppur.2016.06.040

"A simple technology for phosphorus recovery using acid-treated concrete sludge", Separation and Purification Technology 165 (2016) 173–178 http://dx.doi.org/10.1016/j.seppur.2016.03.054

K. Okano, S. Miyamaru, Y. Yamamoto, K. Honda, H. Ohtake, Dept. Biotechnology, Graduate School of Engineering, Osaka University, 2-1 Yamada-oka, Suita, Osaka 565-0871, Japan. M. Kunisada, Mikuni Pharmaceutical Industrial Co., Ltd., 2-35 Kamisu-cho, Toyonaka, Osaka 561-0823, Japan. H. Takano, Research & Development Center, Taiheiyo Cement Co., 2-4-2 Osaku, Sakura, Chiba 285-8655, Japan. M. Toda, Research & Development Laboratory, Onoda Chemical Industry Co., Ltd., 39-13 Miyamoto-cho, Itabashi-ku, Tokyo 174-0054, Japan. okano@bio.eng.osaka-u.ac.jp

P-recovery from biowastes

P-recovery from waste streams by acid/alkaline extraction and sub-sequent chemical precipitation is a widely researched and practiced method. This Portuguese study does not attempt to differ from the path, but investigates P extraction and precipitation from organic fraction of municipal solid wastes (MSW) after anaerobic digestion and from dairy cattle slurry.

This paper presents (duplicated) **laboratory extraction (phosphorus dissolution) experiments performed on 40 gDM biowaste samples** using nitric acid (HNO_3) or sodium hydroxide (NaOH) at a liquid to solid ratio of 25 for 48 h. 100 ml, 1 hour, stirred beaker precipitation tests were then carried out, adjusted to conditions expected to result in struvite precipitation: pH 8.0 (using NaOH) and molar ratio Mg:N:P of 1:1:1 (using NH_4Cl as nitrogen source and $MgCl_2$ as magnesium source). The precipitate was analysed with X-ray Diffraction (XRD) and Scanning Electron Microscopy coupled with Energy Dispersion Spectroscopy (SEM-EDS).

MSW (municipal solid waste) digestates were collected from an anaerobic digester fed with mechanically separated organic fraction of MSW (Portugal). The sample was collected after the centrifugation process.

The **dairy cattle slurry** sample was collected from a local farm (Coimbra, Portugal). The sample, comprising scraped cattle excreta and wash down, was collected from the ditch connecting the animal housing to the slurry storage pit. The samples were refrigerated and subsequently analysed for water content, ash content, organic matter, pH, electric conductivity, total P, Ca, Mg, K and heavy metals (Cu, Zn, Cd and Pb).

P-recovery potential

The concentration of P in MSW digestate is 0.8% (dry weight) and in the dairy cattle slurry 0.4% (dry weight). Although the P levels are lower than, for example, in sewage sludge or the ashes thereof, the P recovered from **MSW represents a significant contribution of 36 tonnes P / year from a city with 100,000 inhabitants,** or over 1000 tonnes P from a city with 3.4 million inhabitants (e.g. Madrid, Berlin).

Calcium is the most abundant macro-element in both MSW digestate and dairy cattle slurry. MSW digestate contains higher amounts of heavy metals compared to dairy cattle slurry, in particular Pb, but both waste streams are well within the heavy metal limiting values for sludge application in agricultural soil in Portugal.

For both wastes **P extractions were higher using HNO_3 (acid) than using NaOH (alkali).** The P extraction from dairy cattle slurry reached 90-100% (depending on pH), and sufficient extraction was reached already at a relatively high pH of 4.5, reducing the need for acid reagent. Reagent consumptions were not reported in the article. The P extraction from MSW digestate reached about 90%, and contrary to dairy cattle slurry, pH below 2 was required to reach sufficient extraction. The difference is due to the different form P is present in these wastes. **In MSW digestate P is contained in the cellular structure of the microorganisms, making extraction more difficult**, whereas in dairy cattle slurry 60-90% of P is in inorganic form and is more readily available. The P extraction with NaOH did not exceed 22% for dairy cattle slurry and 9% for MSW digestate. Similar to P extraction, the extraction of heavy metals was also higher in dairy cattle slurry compared to MSW digestate, Cd extraction being the highest compared to other heavy metals. In the precipitation experiments the reduction of P in solution was around 94-98% (depending on extraction solution) for dairy cattle slurry and 96-99% for MSW digestate.

Calcium phosphate not struvite

According to the XRD and SEM-EDS results, the extracted P reacted with Ca **forming non-crystalline calcium phosphates instead of struvite**. Similar to several other studies on dairy manure, the high Ca:Mg ratio of 12:1 in this study could have inhibited the formation of struvite. The authors suggest that the calcium phosphate can be used as a fertilizer or as a raw material to fertilizer industry, provided that the presence of heavy metals does not exceed acceptable levels. **The study does not give an economic outlook** for the proposed process.

SCOPE editor's note: whereas the fertiliser effectiveness of struvite is well documented (see SCOPE Newsletter n° 121) this is not the case for recovered calcium phosphates.

"Valorisation of Phosphorus Extracted from Dairy Cattle Slurry and Municipal Solid Wastes Digestates as a Fertilizer" Waste and Biomass Valorization: 1-9.2015 http://dx.doi.org/10.1007/s12649-015-9466-0

V. Oliveira (1), L. Ottosen (2), J. Labrincha (3), C. Dias-Ferreira (3). 1 = Research Centre for Natural Resources, Environment and Society (CERNAS), College of Agriculture, Polytechnic Institute of Coimbra, Bencanta, 3045-601 Coimbra, Portugal. 2 = Dept. Civil Engineering, Building 118, Technical University of Denmark, 2800 Lyngby, Denmark. 3 = Materials and Ceramic Engineering Department, CICECO, University of Aveiro, Campus Universitario de Santiago, 3810-193 Aveiro, Portugal. celia@esac.pt

P-removal by Agricultural Waste Products

Literature overview and critical assessment of adsorption onto (modified) AWPs as a P-recycling route

In two papers (2012, 2014), the authors assess **available literature data and studies on P-removal by adsorption onto Agricultural Waste Products (AWPs),** in particular using modified AWPs (application of bases, different ions, carboxylates to the AWPs).

The P-loaded AWPs can, if appropriate, be **used as a fertiliser or soil amendment**, so recycling the phosphorus and the organic content into agriculture.

In the 2012 paper, the authors provide (table 2) an overview of 13 different technologies for P-removal, summarising effluent P concentrations, advantages and limitations. They conclude that different technologies offer different characteristics and so are advantageous in different circumstances. This list does not include using wastewater to feed algal or plant growth.

The use of (modified) Agricultural Waste Products (AWPs) as P-biosorbents offers the following advantages:

- Some modified AWPs offer **high P-adsorption capacity**
- **Abundant availability, low cost**
- No negative **environmental impacts**
- Economic and ecological **disposal route for AWPs**
- If appropriate, P-loaded AWPs **can be used as a fertiliser / soil amendment**

In the first paper (2012), the authors provide lists of 14 different AWPs (table 3) **tested for P-adsorption** in literature, summarising data available on adsorption capacity, P removal efficiency, tested operating parameters. The AWPs tested include sawdusts and wood particles, orange waste, ashes, date stones, barks/stems of different plants, coconut shell and coir pith (coconut husk fibre). This list is further completed in the 2014 paper, with thermally treated oyster shells and eggshells, metal modified wheat straw, reeds, banana stems, cotton stalks, ..

The 2012 paper also provides a table of **modifying agents applied to AWPs** (table 4) and this is explored in more detail in the 2014 paper, which specifically looks at ABP modification.

Chemical modifications indicated in the first paper include urea, ammonium quaternary salts, copper, iron, zirconium, ash, H_2SO_4 and several organic chemicals (e.g. diethylenetriamine). The second paper covers a wider range of modifications (Fig. 1): thermal activation, chemical activation, steam activation, metal loading cationization, quaternization (quaternary ammonium salts), sulphate coating (sulphuric acid).

Different **metal loading methods** are described: grafting carboxyl groups (esterification, etherification), base treatment (saponification), deposition (reaction with cationic binding sites on AWPs). Tables of phosphate absorption capacity and other performance aspects of phosphate biosorbents are given, based on collated literature data.

Modification of AWPs

The authors note that **most studies have used modified AWPs (agricultural waste products), not natural AWPs, and that the modification can considerably improve P-removal performance**. In particular, the use of bases or grafting of carboxylate groups improves iron capture, and so phosphorus sequestration.

Poor desorption

The 2012 paper notes that several studies have attempted to **desorb the phosphorus from P-loaded AWPs**, using e.g. HCl or NaCl. However, these processes were not very successful with only low P-recovery rates. It therefore seems that the P-loaded AWPs should best be used as fertilisers / soil amendments.

The 2014 paper concludes that modified AWPs show **phosphate adsorption capacity comparable to, or even better than, commercial adsorbents**. However, many modified AWPs cannot be used as fertiliser because of the nature of the modifying chemical, so limiting recycling.

Further research is needed **to find modifying chemicals or methods which both enable high phosphate adsorption and also are compatible with reuse of the P-charged AWP material as a fertiliser - soil improver**.

"Modification of agricultural waste/by-products for enhanced phosphate removal and recovery: Potential and obstacles", Bioresource Technology, in print 2014
http://www.sciencedirect.com/science/article/pii/S0960852414010347

H. Nguyen (a), H. Ngo (a), W. Guo (a,b), J. Zhang (b), S. Liang (b), D. Lee (c), P. Nguyen (d), X. Bui (d,e).

"Phosphorous Removal from Aqueous Solutions by Agricultural By-products: A Critical Review", J. Water Sustainability, 2(3), Sept. 2012, 193–207
http://www.jwsponline.com/uploadpic/Magazine/pp%20193-207%20JWS-A-12-020.pdf

H. Nguyen (a), H. Ngo (a), W. Guo (a), V. Nguyen (a).

a = *School of Civil and Environmental Engineering, University of Technology, Sydney (UTS), P.O. Box 123, Broadway, NSW 2007, Australia. b = Shandong Key Laboratory of Water Pollution Control and Resource Reuse, School of Environmental Science & Engineering, Shandong University, Jinan 250100, PR China. c = c Dept. Chemical Engineering, National Taiwan University, Taipei 10617, Taiwan. d = Faculty of Environment and Natural Resources, Ho Chi Minh City University of Technology, District 10, Ho Chi Minh City, Viet Nam. e = Division of Environmental Engineering and Management, Ton Duc Thang University, District 7, Ho Chi Minh City, Viet Nam. ngohuuhao121@gmail.com* ; HuuHao.Ngo@uts.edu.au ; h.ngo@uts.edu.au

Hydrated poultry litter ash as PK-fertiliser

Study shows LCA benefits of chicken manure bio-energy and tests show crop effectiveness of the ash as phosphorus and as potassium fertiliser and as a liming material

A Life Cycle Analysis of the BMC-Moerdijk chicken litter combustion plant, the Netherlands, shows less emissions of greenhouse gasses compared to field application of the chicken litter. The poultry litter is processed to a hydrated poultry litter ash which is an odourless, sterile PK fertiliser. Five reports assess the phosphorus and potassium fertiliser effectiveness of the hydrated poultry litter ash, on green beans and rye grass, and its liming effectiveness.

The BMC-Moerdijk plant, The Netherlands, *http://www.bmcmoerdijk.nl/en/home.htm* **treats over 0.4 million tonnes of chicken litter per year, from 700 chicken farms in the Netherlands**. The litter is a mixture of manure, bedding (straw, sawdust) and feathers. A technical challenge noted is the tendency of the combustion ash to aggregate, but BMC-Moerdijk has overcome this challenge. The ash is transported to regions with nutrient demand. The average content of the hydrated poultry litter ash is 11% P_2O_5, 12% K_2O and it has an acid neutralising value of 34%

Positive Life Cycle Analysis comparison

The published Life Cycle Analysis study shows **LCA benefits from combustion of the chicken litter to produce electricity, compared to field spreading**. The LCA shows benefits even in a 'worst case' scenario comparing to natural gas use for electricity production and taking into account energy needed to produce mineral nitrogen fertilisers equivalent to the nitrogen content of the chicken litter which is lost during combustion (and assuming no N loss during field application of chicken manure, which is not the case).

The litter combustion to produce bio-electricity shows **lower environmental impact** for climate change, terrestrial acidification, particulate matter formation, marine eutrophication and photo-chemical oxidant formation.

Fertiliser effectiveness of hydrated poultry litter ash

In a second **set of five reports**, the fertiliser/soil improver value (P, K and liming) of the BMC-Moerdijk hydrated poultry litter ash was compared to commercial mineral phosphorus fertilisers (Di Calcium Phosphate DCP and Triple Super Phosphate TSP) and to mineral potassium fertiliser (potassium sulphate) in **pot trials** with rye grass (*Lolium perenne L.*) and with green beans (*Phaseolus vulgaris L.*).

The pot trials used 5 kg pots, with acidic soil pH- 5. The bean plants were harvested 47 days (K) and 64 days (P) after sowing, looking at leaf and bean matter yield. The rye grass was harvested with six cuts. Each cut was taken after approximately 28 days of growth, total duration was 167 days (K) and 152 (P).

The phosphorus effectiveness of the chicken litter ash, in this mild acidic soil, showed to be comparable to DCP but lower than TSP for beans, but comparable to both DCP and TSP for rye grass.

The authors suggest that this may be because the **duration of the trials** was longer for rye grass (resulting in a higher update of P and K. The hydrated poultry litter ash showed potassium effectiveness comparable to potassium sulphate for both green bean and rye grass.

The fifth report assesses the **liming potential of the hydrated poultry litter ash**, in a 16-week soil incubation study, comparing effect to calcium carbonate (chalk) and calcium hydroxide (hydrated burnt lime). The liming effect of the ash was around 50% of these two reference materials after 16 weeks, showing that it is effective for adjusting pH of acid soils, and at that time was continuing to increase so might prove higher after a longer duration.

"Electricity from poultry manure: a cleaner alternative to direct land application", P. Billen, University of Leuven, et al., J. Cleaner Production 96 (2015) 467e475
http://dx.doi.org/10.1016/j.jclepro.2014.04.016

"Efficacy of phosphorus of hydrated poultry litter ash" (1) "Phosphorus use efficiency of green bean" and (2) "Phosphorus use efficiency of rye grass" - "Efficacy of potassium of hydrated poultry litter ash" (1) "Potassium use efficiency of green bean" and (2) "Potassium use efficiency of rye grass" – "Efficacy of hydrated poultry litter ash as liming material" - all five with ISSN 1566-7197, P. Ehlert & J. Nelemans, Alterra, Wageningen, The Netherlands. Four reports, 2015. For more information, please send an email to info@bmcmoerdijk.nl

Phosphorus management

Phosphorus in surface waters

Hydrobiologia and J. Applied Ecology special issues: metrics and targets for water quality and defining phosphorus targets to avoid toxic algae.

A special issue of Hydrobiologia presents conclusions from the EU-funded **WISER** *project*, developing and reconciling metrics based on biological parameters for **assessing Water Framework Directive quality status of surface waters**, and for recovery of deteriorated waters. A further paper in the Journal of Applied Ecology examines whether target phosphorus levels can be defined for lakes to avoid the development of toxic algae.

There is general agreement that **bio-indicators are a valid and pertinent method for assessing the ecological status of surface waters**, that is whether lakes, rivers and estuaries are negatively affected by human impacts (pollution, modification of water system morphology and functioning, water extraction), or whether they are in a state similar to their natural quality. Bio-indicators are metrics of ecological quality status based on assessment of different BQEs (Biological Quality Elements), for example phytoplankton populations, macrophytes, macro-invertebrates and fish.

Intercalibrating bio-indicator systems

The WISER project reviewed 297 different biotic assessment metrics for rivers, lakes and estuaries, based on information provided by water authorities in 28 European countries.

The authors (A) note that the high number of metrics suggests that the **methods used are adapted to regional situations**, for example predominant stressors (environmental issues), local species and local scientific understanding and historic data sets. However, the consequence is that results are not directly comparable.

The **intercalibration of methods developed through the EU Water Framework Directive implementation**, has shown that the aggregated assessment results, that is when different BQE indicators are combined to define overall "Ecological Status", are generally comparable across Europe.

Restoring Europe's water quality

The EU Water Framework Directive requires that water bodies identified as not achieving "Good Ecological Status" should be restored, so that their water chemical quality and ecosystem biodiversity and functioning are comparable to (only a sight deviation from) "reference" conditions (pre-disturbed state). The conclusions of the first **River Basin Management Plans** in member states show that non-achievement of "Good Ecological Status" is the situation for many waters in Europe, particularly in densely populated regions where almost all rivers and lakes fail "Good" status. Restoration of water bodies will therefore be a challenging task across Europe for the coming decades.

The key questions concerning **water restoration** identified by the authors are: what is the (spatial) extent of restoration measures needed and how long will it take after implementation of these measures before "Good Quality Status" is restored?

The authors note that after significant or intense deterioration of water quality status, affecting diversity of biological populations, **15 – 25 years may be needed for most water systems to re-attain a biotic diversity and ecosystem functioning** comparable to the pre-disturbed state (Good Ecological Status).

They also emphasise that there may be a need to **reconsider the reference conditions, and consequently restoration targets**, because climate change could accentuate eutrophication effects.

Assessing specific metric systems

In a further paper in Hydrobiologia (B), the authors **compare 11 biological quality metrics developed from over 2000 European lakes**.

The strongest and **most sensitive indicator for assessing eutrophication pressure was phytoplankton chlorophyll-a** (which is the traditional metric, and effectively measures total aquatic algae), as well as more complex indicators based on algal species composition and relative growth, a macrophyte species index and the Nordic fish index.

The authors use total phosphorus as the only indicator of eutrophication pressure in this paper, and the **correlation between total P and phytoplankton chlrolophyll-a** (primary producers) has been known for a long time. This study shows again that phytoplankton biomass is the first and most direct indicator of eutrophication pressure. Benthic (lake floor) invertebrates and fish are more indirect indicators, responding through secondary effects such as availability of phytoplankton or phytoplankton-derived organic matter as food or changes in light, oxygen availability or habitat. Macrophytes are more slowly impacted, because they rely on nutrients in sediments and are affected by nitrate availability, as well as being impacted by changes in light (water transparency).

The authors note that **other indicators such as cyanobacteria blooms or the European lake fish index** are less strongly correlated to total phosphorus at the European level, but remain valid indicators of eutrophication, and may be better metrics for individual lakes. In particular, they measure effects which are of relevance to sustainable water use. Specific metrics may give a better measurement of particular pressures or water use impacts, for example macrophytes or littoral benthic algae. In general, a combination of several metrics will give the best picture of overall lake quality status.

In (C), the authors **compare 6 different phytoplankton based metrics for assessing eutrophication impacts in lakes**. Annex V of the EU Water Framework Directive specifies that three different features of the phytoplankton BQE should be considered in assessing lake quality status: phytoplankton biomass (often proxied by chlorophyll-a) – because this directly affects water transparency and other conditions, phytoplankton composition (variety of species or taxons) and plankton bloom frequency and intensity.

As indicated above, existing methods for **assessing phytoplankton abundance using chlorophyll-a** have been demonstrated to be a relatively robust first indicator of eutrophication pressure, subject to appropriate calibration of measurement and sampling programmes.

Coherent methods for **assessing algal taxon/species variation** have been developed over recent years, based on trait-based functional classifications (grouping different types of phytoplankton according to their ecological role). These different methods today need to be benchmarked and intercalibrated.

Regarding **measurement of algal blooms**, the authors note that today there is still not an agreed definition, although a metric based on the actual abundance of cyanobacteria (blue-gree algae) was shown to be significantly robust and indicates water usage issues because of their potential toxicity.

Preventing eutrophication problems in lakes

In (D) the authors consider **how to set water total phosphorus concentration targets for lakes** at levels necessary to avoid toxic algal blooms, based on assessment of data from over 800 European Lakes. The threshold of algal blooms was defined using the World Health Organisation (WHO) criteria of "low health alert", which corresponds to a biovolume of 2 mm^3/litre of blue-green algae.

The likelihood of exceeding this WHO safety level is only around 5% at 16 µg total phosphorus per litre (summer concentration), but increases to 40% at 54 µg TP/l, showing a threshold effect for toxic algal bloom risk.

However, around **50% of studied lakes stay below the WHO alert level for blue-green algae, even with high summer total phosphorus concentrations**, showing the importance of other factors affecting algal development, including water flushing rate.

The authors note that blue-greens tend to be absent in low-alkalinity lakes (soft water), so that only 5% of lakes in Northern Europe show summer blue-green blooms, compared to 37% in Central Europe where most lakes are high-alkalinity (hard water).

The authors conclude that the target TP (total phosphorus) concentration in lake water will **depend on local conditions and on water usage objectives**. If a low probability of blue-green blooms is an objective, then a summer total phosphorus concentration of <20 µg TP/l should be targeted.

(A) "Assessment and recovery of European water bodies: key messages from the WISER project", Hydrobiologia (2013) 704:1–9
http://link.springer.com/article/10.1007%2Fs10750-012-1438-9#

D. Hering, C. Feld, Dept. Aquatic Ecology, University of Duisburg-Essen, Universitätsstr. 2, 45141 Essen, Germany A. Borja, Marine Research Division, AZTI-Tecnalia, Herrera Kaia Portualdea s/n, 20110 Pasaia, Spain. L. Carvalho, Centre for Ecology & Hydrology, Bush Estate, Penicuik, Midlothian EH26 0QB, UK. C. *daniel.hering@uni-due.de*

(B) "Ecological status assessment of European lakes: a comparison of metrics for phytoplankton, macrophytes, benthic invertebrates and fish", Hydrobiologia (2013) 704:57–74
http://link.springer.com/article/10.1007%2Fs10750-012-1436-y

A. Lyche-Solheim, C. Feld, S. Birk, G. Phillips, L. Carvalho, G. Morabito, U. Mischke, N. Willby, M. Søndergaard, S. Hellsten, A. Kolada, M. Mjelde, J. Böhmer, O. Miler, M. Pusch, C. Argillier, E. Jeppesen, T. Lauridsen, S. Poikane. als@niva.no

(C) "Strength and uncertainty of phytoplankton metrics for assessing eutrophication impacts in lakes", (2013) 704:127–140
http://link.springer.com/article/10.1007/s10750-012-1344-1

L. Carvalho, S. Poikane, A. Lyche Solheim, G. Phillips, G. Borics, J. Catalan, C. De Hoyos, S. Drakare, B. J. Dudley, M. Järvinen, C. Laplace-Treyture, K. Maileht, C. McDonald, U. Mischke, J. Moe, G. Morabito, P. Noges, T. Noges, I. Ott, A. Pasztaleniec, B. Skjelbred, S. Thackeray laca@ceh.ac.uk

(D) "Sustaining recreational quality of European lakes: minimizing the health risks from algal blooms through phosphorus control", Journal of Applied Ecology 2013, 50, 315–323
http://onlinelibrary.wiley.com/doi/10.1111/1365-2664.12059/abstract

L. Carvalho (1,2), C. McDonald (2), C. de Hoyos (3), U. Mischke (4), G. Phillips (5), G. Borics (6), Sandra Poikane (1), B. Skjelbred (7), A. Lyche Solheim (7), J. Van Wichelen, A-C. Cardoso (1).
laca@ceh.ac.uk

Improving crop phosphorus use

This review paper provides details of current understanding of plant cell phosphorus regulation, uptake and transport and proposes approaches to improve crop phosphorus use in practice.

Phosphorus in soils is generally rapidly transformed to non plant-available forms. In acid soils $H_2PO_4^-$ reacts with insoluble iron, aluminium and manganese oxides. In alkaline soils $H_2PO_4^-$ reacts with calcium to form insoluble calcium phosphates (tri calcium phosphate). Often only around half the phosphorus fertiliser applied to fields is taken up by crops in the growing season, whereas the remainder is "lost" to such poorly plant available forms, or in run-off or infiltration to surface or ground waters. The authors conclude that it is therefore **important to better understand the biological mechanisms of plant phosphorus uptake**, in order to improve crop P use.

Within the plant, most P is stored in the cell vacuole.

Plants have two phosphorus uptake and transport systems: the first is high-affinity, regulated by cellular energy supply, cell P consumption and proton electrochemical gradient; the second is low-affinity, transporting solutes according to the concentration gradient.

Effects of phosphorus starvation

Different families of **phosphate transporter molecules** identified in various plants to date are discussed. These interact with **genes induced by phosphate deficiency** and mainly expressed in roots and shoots. Certain **transcription factors of such genes** have also been identified in some plants and have been shown to influence root architecture. Low P conditions have been demonstrated to modify root development and structure, mediated by specific micro-RNAs and non-coding RNAs and by hormones such as ethylene, auxin, giberellins and indole 3 acetic acid (IAA).

Phosphorus deprivation has also been shown to modify cellular metabolism, including synthesis of purple acid phosphatase enzymes (AtPAP) and reduced phytate production.

During P starvation, some **roots can release organic acids**, produced by phosphenolpyruvate carboxylase (PEPC), malate dehydrogenase (MDH) and citrate synthase (CS) to solubilise metal-bound phosphorus in soils (see above).

Improving crop P use efficiency

The authors outline the following **three strategies to improve crop P use**:

- **Arbuscular mycorrhizal fungi (AMF):** these fungi enter the plant root cortex then develop branched hyphae. Arbuscules provide an efficient signalling and nutrient transfer with root cells. AMF colonisation into crops can improve P use efficiency, but it is important to select strains adapted to the crop species in order to optimise carbon consumption and P transfer.
- **Intercropping**: crop alternations such as maize – flava bean can improve P use efficiency, through mechanisms such as acid phosphatase, carboxylase, citric acid or malic acid release in the root zone by the intermediate crop
- **Homologous gene overexpression**: molecular-marker assisted plant selection and breeding has made only limited progress in developing low-P tolerant crop varieties. Homologous gene overexpression, by gene transformation techniques, offers better potential to enhance P uptake by accentuating cellular P regulators and transcription factors (see above). Tissue-specific gene overexpression could be a promising strategy to take this forward whilst allaying public concerns about GMOs.

Research needs

The authors conclude that **further work** is needed on:

- P **transport mechanisms** in different crops
- **Large scale metablome** (different metabolites) profiling for P metabolism
- **Fine QTL** (quantative trait loci) mapping of genetic pathways
- Information on **hormone** and **micro-RNA** regulation
- Study of mechanisms of how **intercropping** improves P use efficiency
- Development of **appropriate symbiotic AMF** (arbuscular mycorrhizal fungi) strains

"Mini Review. Regulation of phosphorus uptake and utilization: transitioning from current knowledge to practical strategies", Cellular & Molecular Biology Letters (2016) 21:7
http://dx.doi.org/10.1186/s11658-016-0008-y

Md. Mahmudul Hasan, X. Li, Key Laboratory of Plant-Soil Interactions, MOE, Center for Resources, Environment and Food Security, Dept. Plant Nutrition, China Agricultural University, Beijing 100193, China. Md. Mainul Hasan, Fac. Agriculture, Patuakhali Science and Technology University, Dumki, Patuakhali, Bangladesh. J. Teixeira da Silva, P. O. Box 7, Miki cho post office, Ikenobe 3011-2, Kagawa-Ken, 761-0799, Japan. steve@cau.edu.cn

Nutrient Platforms

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

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

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

North America Phosphorus Sustainability Alliance SPA ***https://sustainablep.asu.edu***

Stay informed through ESPP:

Website: ***www.phosphorusplatform.eu***
News - events - regulatory - R&D projects list

Twitter:
@phosphorusfacts
Information only - short updates on your mobile – links to reports and documents

Slideshare:
now on our website ***www.phosphorusplatform.eu***

Agenda

- 13-15 March 2017, Tampa, Florida, **Phosphates 2017** *http://www.crugroup.com/events/phosphates/*

- Save the date 11 or 12 April, Paris, **COMIFER / ESPP P recycling in agriculture** (in French) s.droisier@comifer.fr
- 8-10 May 2017, Ben Guérir, Morocco, **SYMPHOS -** Innovation and Technology in the Phosphate Industry *http://www.symphos.com/index.php*
- 19 May 2017, Washington DC, North America **Sustainable Phosphorus Alliance (SPA)** stakeholder meeting *https://sustainablep.asu.edu/about*
- 12 - 14 June 2017, Fort Lauderdale, Florida, **WEF Nutrient Symposium** *http://www.wef.org/Nutrients/*
- 21-23 June 2017, Belfast, **Ireland sustainable P meeting** *https://phosphorusie.wordpress.com/*
- 3-5 July 2017, Paris, **PBSi 2017** P, B & Si *http://premc.org/conferences/pbsi-phosphorus-boron-silicon/*
- 4-5 July, Manchester, UK, **BIG Phosphorus conference** *http://www.aquaenviro.co.uk/events/conferences/*
- 5-9 August, New York, **IWA Resource Recovery** conference *www.irrc2017.org*