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Sustainable phosphorus policies

Sweden

Swedish EPA proposes national P-recycling targets

An EPA report to the Swedish Government proposes phosphorus and nitrogen recycling targets for 2018 from different waste streams. Recommended thresholds for contaminants in certain wastes have opened debate.

New book

Phosphorus, food and our future

Product of the 2011 Sustainable Phosphorus Summit, this new Oxford University Press book provides a complete reference to phosphorus sustainability questions

Sustainable Phosphorus Summit

A blueprint for global phosphorus security

A 12-page document has been published as a key output from the 3rd Sustainable Phosphorus Summit 2012 identifying actions, changes to practice and attitudes, unresolved issues and knowledge gaps and listing stakeholder roles and responsibilities.

Phosphorus flows

Phosphorus flows

Quantification of P surplus in the Netherlands

Phosphorus flows through agriculture, industry and households in The Netherlands are assessed and scenarios to reduce the national phosphorus surplus to reduce soil P accumulation are proposed.

Australia

Modelling implications of P-use efficient wheat

Use of modelling suggests that phosphorus use efficient wheat could reduce the need for P fertiliser application, particularly on P deficient or P sorbing soils, reducing farmers costs, and reducing eutrophication-causing agricultural P losses.

Phosphorus recycling as struvite

LIFE PHORWater

Waste water treatment works management for P-recovery as struvite

The EU-funded PHORWater project is looking at integrated management for economic and ecological P-removal and recycling from urban sewage.

Struvite bio-precipitation

Biological pathway for P-recovery demonstrated

Certain bacteria are shown to precipitate struvite crystals from wastewater, also achieving discharge-compatible nutrient removal.

Field trials

Three year test of struvite as crop fertiliser

Struvite recovered from corn fibre processing wastewater was tested in a three-year field trial on maize and soybean crops.

Pot and field trials

Fertiliser testing of phosphates recovered from sewage and ash

17 different recovered phosphate products were tested for plant uptake by maize, including from sewage sludge ash incineration, meat and bone ash, calcium phosphate CSH precipitates and struvites.

Beaker tests

Precipitation of struvite and other minerals

In pure solutions, at different Mg:Ca ratios and pH, seven different minerals were precipitated. Struvite is most attractive for P-recovery but prior low pH brushite precipitation may be beneficial.

EU consultation on phosphorus use

http://ec.europa.eu/environment/consultations/phosphorus_en.htm
(until 1st December 2013)

Agenda: dates 2013-2014

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European Sustainable Phosphorus Platform

Sweden

Swedish EPA proposes national P-recyling targets

Sweden's Environmental Protection Agency (EPA) has published a report and proposals on sustainable phosphorus recycling, commissioned by the Swedish Government in February 2012. The EPA report assesses the quantities of phosphorus in different waste streams in Sweden, the contaminants present and the issues around ensuring that P- recycling remains free of undesirable contaminants, and proposes targets for 2018 for phosphorus and nitrogen recycling from different waste streams.

A proposal for thresholds for metals and organic contaminants in wastes for recycling has drawn criticism because it would be an **obstacle to methanisation of food wastes** and other recycling routes.

2002 P-recycling objective

The Swedish EPA proposed in 2002 a phosphorus recycling objective of 60% P-recycling to farmland from sewage sludge (by 2015). This objective was translated as follows into Sweden's environmental objectives:

- ***By 2015 at least 60% of phosphorus compounds present in wastewater will be recovered for use on productive land. At least half of this amount should be returned to arable land.***

http://www.miljomal.se/Environmental-Objectives-Portal/Undre-meny/About-the-Environmental-Objectives/15-A-Good-Built-Environment/Interim-targets/Waste/

Government policy request

The 2013 EPA report was requested by Government to address the need to ensure that phosphorus recycling does not also recycle undesirable materials and so contradict Sweden's "generational" (ie. 2020) **objective of A Non-Toxic Environment**, to assess the potential for sustainable P-recycling, to propose intermediate targets ("milestone" = 2018) for P-recycling and to propose statutory requirements. This should then serve as a basis for Government decision making and for phosphorus recycling initiatives.

Swedish EPA starts by emphasizing that **data is insufficient**, unreliable or contradictory both on phosphorus content and on contaminants in many waste streams. Surveys of phosphorus and pollutant flows in sewage and various other wastes have improved knowledge but further monitoring and assessment is necessary.

Phosphorus surplus and P-recycling potential

Annual inputs of phosphorus to Sweden's agriculture and food system are mainly in mineral fertilisers (9.4 ktP/year, equivalent to c. 4 kgP/ha/year), animal feedstuffs (7.4 ktP/y) and human foods (6.6 ktP/y). The annual surplus of phosphorus in agriculture is 3 kgP/hectare/year.

Phosphorus quantities in different waste flows are estimated to be:

- 25 ktP/y in **agricultural livestock manures**, plus some 3 ktP/y in horse manures. The current fate of the horse manures is not clear.
- 4.9 ktP/y in **human discharges** (of which over 64% in urine, 36% in faces). Additionally, around 0.5 ktP/y from detergents goes to sewage, along with other sources, whereas some of the human discharges do not reach sewage sludge (lost to surface waters, not connected to sewerage), resulting in a total of around 5.8 ktP/y in sewage sludge
- 2.2 ktP/y in **non-recycled food wastes**
- 7.5 ktP/y in **bio-energy ashes, in particular from wood burning**. At present only around 1.5 ktP/y are in ash whose quality enables land spreading. P-recovery from the remaining ash would be difficult because the P concentrations are very low.
- 60 ktP/y in **iron ore wastes**

A further estimated 1 million tP is **stockpiled in mine wastes** (Kiruna, Malmberget), for which P-recovery is currently being studied by LKAB.

Large quantities of phosphorus are also accumulated diffusely in the **Baltic Sea sediments**, where dilution makes recovery, for example after dredging, probably not feasible in the short term.

Routes for P-recovery

At present, **only around 25% of Sweden's sewage sludge is spread on farmland**. Acceptance of increased P-recyling by this route will depend on societal acceptance, which will depend on ensuring that the sludge is free of undesirable contaminants.

The EPA also note that **the value of such recycling depends on how accessible the phosphorus is to**

plants (plant availability may be low if chemical precipitation is used for P-removal in sewage works).

P-recovery after combustion of biowastes is noted as having the advantage of eliminating organic contaminants (hormones, pharmaceuticals, organic chemical pollutants) but of not recycling soil-enriching organic carbon and nitrogen. For P-recovery from sewage sludge ash after incineration, **"mono-incineration" of sludge is necessary** (incineration in dedicated installations, not mixed with other wastes). At present there are no mono-combustion facilities in Sweden.

P-recovery as struvite is identified as making a finished product recovering both phosphorus and nitrogen for recycling as fertiliser. Struvite recovery is already being tested in Sweden (eg. pilot plant already operating at Öresundsverket in Helsingborg). However, this route is with present approaches, limited only to sewage works operating biological nutrient removal, of which there are only 20 today in Sweden.

Undesirable contaminants

The EPA report underlines the questions surrounding **contaminants in sewage and in manures and the risk of spreading these to cropland** if phosphates are recovered and recycled. Heavy metal levels are generally declining in sewage, but copper and zinc are not. Metals can also be found in manures, in particular pig manures, because they are present in diets.

Recycling also needs to ensure that organic contaminants are not spread to farmland, such as **hormones, pharmaceuticals, pathogens, organic chemicals, dioxins** generated in ash. Certain organic contaminants and pathogens can be reduced or removed by biological waste treatment or anaerobic digestion. Knowledge gaps remain concerning whether or not hormones and pharmaceuticals reaching soil pose a potential for uptake in crops or risks for health or the environment.

The EPA therefore proposes regulation to limit the application of undesirable contaminants to land, with thresholds for certain organic contaminants in the recovered materials, and limit concentrations for eight metals in soils where such materials can be applied and in the materials themselves. This proposal also includes treatment of biosolids (other than biofertiliser and compost) to remove pathogens and preventive measures to reduce concentrations of contaminants reaching wastes.

Table 16 in the EPA report : **"Recommended limits for certain metals and organic substances in materials going to recycling or agricultural use (organic substance limits apply only to waste materials)"** has drawn criticism including in an article signed by the Swedish Water Association, the Swedish Farmers association, the Swedish Waste Organization and for Swedish Energy Gas.

http://www.dagenssamhalle.se/debatt/naturvardsverkets-foerslag-foerstoer-miljoen-6141 *in Swedish*

The EPA table proposes limits for 8 metals (lead, cadmium, copper, chrome, mercury, nickel, silver, zinc) and 4 organic substances (PFOS, chloroparaffins, PCB and brominated BDE flame retardants). Proposed limits for cadmium are 1 mgCd/kg solid waste/material by 2015, reducing to 0.8 mgCd in 2030.

The different limits are criticized as being **more restrictive for materials recycled to agriculture than for food (cadmium)** and as being 2.5x more restrictive for residues of biomass digestion than for fertilisers.

Such limits could strongly restrict energy and nutrient recover from food waste, because the proposed limits are lower than levels in food wastes, and so contradict objectives of increased recycling, energy recovery and eutrophication mitigation. No contaminant limits are proposed for imported foods, although Sweden currently imports over 50% of its food. **Only a very small number of analyses of cadmium in foods are available today**, compared with thousands per year in sewage biosolids.

Milestone targets

EPA proposes to the Swedish Government the following intermediate (2018) targets requiring both **balanced fertilization in agriculture** (nutrient application limited to nutrients removed in crops) and **targets for N and P-recovery** from different waste streams:

"The eco-cycle of nutrient materials should be resource-efficient and free of undesirable materials to the extent possible. The application and removal of nutrient materials should be in balance in forests and agriculture. Waste management systems should be developed to facilitate sustainable recycling of nutrient materials.

"By 2018 at the latest:

- **• At least 40 percent of the phosphorous in waste will be utilised and recycled as nutrients for fields without entailing exposure to pollutants that pose the risk of injuring people or the environment.**

- **• At least 10 percent of the nitrogen in waste will be utilised and recycled as nutrients for fields without entailing exposure to pollutants that pose the risk of injuring people or the environment.**

- **• Stable manure will be utilised on farmland so that the application of nutrient materials is in balance with their removal.**

- **• At least 50 percent of food waste from households, institutional kitchens, shops and restaurants will be sorted and treated biologically so that nutrients are utilised, of which at least 40 percent is treated so that energy also can be utilised (already decreed by the Swedish government).”**

Swedish EPA press release 5th September 2013: http://www.swedishepa.se/News-and-press/A-step-towards-a-sustainable-phosphorus-recycling/

Sweden EPA report n° 6580, September 2013 (in Swedish, 8-page extended summary in English) “Sustainable phosphorus recycling: Swedish EPA report in response to a Government mandate” http://www.naturvardsverket.se/978-91-620-6580-5

New book

Phosphorus, food and our future

The 225-page book ‘Phosphorus, food and our future” provides a full reference to phosphorus sustainability issues. 10 chapters cover phosphorus in biology, in agriculture, phosphorus rock resources, recovery and recycling, transdisciplinary approaches, cultural values and future sustainable phosphorus management scenarios.

All 10 scientific chapters of the book situate the Phosphorus Challenge in the **overall objective of sustainable development approach**, addressing environmental, social and economic aspects, as well as a **transdisciplinary, complex systems approach**. Each chapter is illustrated with original artwork resulting from the collaborative outreach approach of the Sustainable Phosphorus Summit.

Consensus declaration

The book takes as its starting point the ‘consensus statement’ of the 2011 Sustainable Phosphorus Summit (3-6 February 2011, Arizona):

https://sols.asu.edu/sites/default/files/frontiers/2011/pdf/fils_consensus_2011.pdf .

This declaration stated that:

- Phosphorus is **essential and limited**
- The phosphorus cycle has become **unbalanced**, in order to achieve increased food production, but with negative impacts on water quality and biodiversity
- Phosphorus plays a key role in global **food security**
- **Phosphorus recycling** can reduce geopolitical tensions on phosphorus supply and enhance farmer prosperity
- **Demand can be reduced** by improving agricultural efficiency, addressing losses, reducing animal products in diets
- Phosphorus stewardship is interconnected to **other sustainability challenges** (water, chemicals)
- P-management offers **economic opportunities** for innovation, job creation and well-being for health and the environment

Sustainable development

The opening chapter **“P is for philosophy and process”** situates phosphorus management of sustainable development, showing how phosphorus sustainability is embedded within the three spheres of environment, society, economy (see diagram p age 9), concluding that this implies a transdisciplinarity approach to work towards a vision for a sustainable future.

The second chapter **“P is for phosphorus”** presents an overview of phosphorus biology: the role of P in different molecules essential to life, how phosphorus is essential for plants and crops and particularly for high agricultural productivity, soil P cycling and loss of phosphorus from agricultural soils to surface waters. Because phosphorus in soil can be rapidly immobilized by physical or chemical processes, continuous application is often necessary to maintain high yields, resulting in a low efficiency of crop uptake of fertilisers in the year of application, and considerable transfer to surface waters by leaching and soil erosion.

Costs of phosphorus losses

A summary of available data concerning the **economic costs of phosphorus losses to surface waters is provided**, based on literature published figures. Eutrophication of inland waters is estimated to cost nearly 3 billion US$/year in the USA (Dodds 2009) and around 200 – 300 million UK£/year in the England and Wales (Pretty 2002). Algal blooms alone are estimated to cost 30 million US$/year in fisheries losses and 100 million US$ overall. Eutrophication of marine coastal waters also has high economic costs (Anderson 2000, Hoagland 2002).

Resources and efficiency.

Chapter 3 **"P is for price"** addresses sources of mineral phosphate rock and how production is driven by demand. Phosphorus is widely present over the earth, but only a few large deposits are exploited for phosphate rock production.

Total **phosphorus present in topsoils** is probably of the same order of quantity as mineral resources, but soil phosphorus is not necessarily available to plants, or not rapidly enough to enable productive agriculture.

This chapter emphasizes that **phosphorus reserves are economically determined,** and so will change over time depending on price (whether or not it is economically viable to extract), whereas phosphorus resources are geologically determined and do not change (although estimates may evolve because of knowledge is insufficient).

Chapter 4 **"P is for productivity"** looks at phosphorus in agriculture, for the production of food and fuels. The high variation in different crops' phosphorus biology is emphasized. P content of different crop plants varies by a factor of 10, and the phosphorus use efficiency (PUE) of crops also varies considerably (with bananas and potatoes, for example, being 6x and 3x more efficient than maize and wheat.

Other issues of agricultural phosphorus management raised include that of DPG (**dry distillers grain**), a by-product of ethanol production which is used as animal feed. This results in significantly increased P content of livestock diets, and so higher P content of manures and so both phosphorus inefficiency and increased losses to surface waters.

Innovative solutions to improve agricultural phosphorus efficiency are outlined, including BMP (best management practices) and precision fertilizer application, polymer coating of fertilisers (+ve charged copolymer impedes the fixation of –ve phosphate ions to soil minerals), direct application of liquid fertilisers to crop foliage (avoids contact of phosphate with soil mineral ions), plant breeding to improve root systems and phosphorus uptake, use of phytase to improve phosphorus metabolism efficiency in monogastric livestock (eg pigs).

Case studies of local phosphorus flows

Chapter **5 "P is for preservation"** presents phosphorus flows, with a number of short case study summaries of flows at local, regional or farm levels, looking at agricultural systems, urban systems and receiving ecosystems. Examples presented are crop based agriculture (US and Canada soil P balances ; intensive soy production in Mato Grosso, Brazil), livestock based agriculture (North Carolina, USA, chicken and dairy production ; UK dairy production), urban systems (Phoenix, Arizona ; Norway) and ecosystems impacted by eutrophication (Lake Nahuel Huapi, Patagonia, Argentina ; Wapata Lake, Washington, USA.

Proposals for making phosphorus management more sustainable in different systems are summarized.

Recovery and reuse

Chapter **6 "P is for processing"** presents up-to-date knowledge regarding potential points for reducing phosphorus use or recycling, based on phosphorus flow analyses (with examples from Africa, China, The Netherlands and Japan) and presents possibilities for recovering phosphorus for recycling or for reducing P-losses from different waste streams.

An inventory summarises **13 technologies for P-recovery from sewage waste streams in existing sewage treatment infrastructures**. Proposed technologies for capturing phosphorus in the environment are outlined (constructed wetlands, adsorption to different materials, PhosphoReduc filter beds …), as are possibilities for ecological sanitation (EcoSan) incorporating nutrient and organic material reuse, capture of phosphorus from solid waste streams and recovery from livestock manures. The synergies of phosphorus recovery with energy recovery through anaerobic digestion are highlighted.

The authors identify as **future challenges** the balancing of costs and benefits, the move to reuse phosphorus rather than disposing as a waste, and the need to integrate P-management into regulatory tools.

Social, cultural and transdisciplinary aspects

Chapter 7 **"P is for people"** looks at how cultural beliefs and values impact phosphorus management. Several examples are assessed. The question of transgenetic engineering of crops to improve phosphorus efficiency is considered, which could reduce phosphorus consumption and eutrophication losses but meet opposition from society for a range of other scientific, economic, environmental and social reasons.

Meat consumption is considered in the context of religions. Increasing animal product in diet is a significant driver for increased phosphate consumption and environmental phosphorus losses. The Hindu religion limits or in many areas excludes meat consumption, Buddhism limits meat consumption, the Muslim and Jewish religions exclude consumption of certain types of meat, whereas Christianity has no meat exclusions, which may to some extent account for the comparatively high meat content of 'western' diets. Also, many religions define attitudes to management of human wastes, to which has been added societal attitudes, posing today considerable obstacles to recycling of nutrients from sewage and to the introduction of ecological sanitation (EcoSan) systems.

Chapter 8 **"P is for parity"** shows how transdisciplinarity contributes to sustainable phosphorus management, taking into account the need to deal with complex adaptive systems.

Transdiciplinarity is defined as a "*research approach that links scientific theories and results with real-world data from practitioners*". This is illustrated with the examples of phosphorus material flow analysis, the complexity of agroeconomic system, the need for international multi-partner initiatives to address phosphorus sustainability, and the importance of educational reform to introduce complex systems thinking.

Future scenarios and planning

Chapter 9 **"P is for preferred (P) futures"** poses questions about future management of the Phosphorus Challenge, including wider visions for society, iterative processes to adapt to uncertainties and the challenges of scale.

The importance of developing scenarios for **managing phosphorus to achieve global food security** is underlined and examples of possible actions are given: improving agricultural P efficiency, changing social behavior norms on diet and food consumption, reuse and recovery of phosphorus from organic wastes. Obstacles and possible policies to address these are outlined.

Chapter 10 presents overall **conclusions "P is for planning"**. Phosphorus is a case study for sustainability science and its application, covering environment, society and economy aspects. Dialogue is needed with actors involved in all areas of phosphorus management and use, and with society as a whole (phosphorus consumers).In particular, the **institutional gaps** relating to governance of phosphorus extraction, application and impact are emphasized.

Finally, the conclusion underlines the **multiple benefits of phosphorus management**, for example the health benefits (in the western diet) of reducing meat consumption or the environmental benefits of reducing eutrophication, and the need for a holistic approach, including both institutional and individual actions.

"Phosphorus, food and our future", Oxford University Press, 2013, ISBN 978-0-19-991683-2, 225 pages, approx. 75 Euros.

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https://sols.asu.edu/research/frontiers/2011/sustainable-p

2011 Sustainable Phosphorus Summit (3-6 February 2011, Arizona):
https://sols.asu.edu/sites/default/files/frontiers/2011/pdf/fils_consensus_2011.pdf

Sustainable Phosphorus Summit

A blueprint for global phosphorus security

The 3rd Sustainable Phosphorus Summit (February 2012, Sydney) brought together over 100 participants from worldwide, mainly from research institutes and industry (see detailed summary in SCOPE Newsletter n° 85). The 'Blueprint for global phosphorus security' is now published in the run-up to the 4th Sustainable Phosphorus Summit (Montpellier, France, 1st-3rd September 2014 *http://SPS2014.cirad.fr*).

The Blueprint formalizes Sydney Summit outputs in a 12-page document outlining **recommended priority actions**, changes to practice and attitudes, unresolved issues and knowledge gaps and identifying stakeholder roles and responsibilities.

The Blueprint aims to encourage research and policy action towards phosphorus sustainability and to bring attention to phosphorus management as a **global sustainability challenge**, with a target audience of governments, researchers and media.

Objectives of a sustainable phosphorus future are outlined as to secure the continued availability of phosphorus fertilizer to ensure global food security whilst taking into account negative impacts of inappropriate fertilizer use. This will imply **integrated phosphorus management** with fair distribution of costs, improved efficiency and reduced P losses, farming innovation and education, closing the phosphorus loop by recycling, improving knowledge transfer and integrating management of other nutrients including potassium, nitrogen and sulphur.

Priority actions

Actions identified in the Blueprint as necessary to achieve sustainable phosphorus management and global food security, include:

- increasing **awareness**
- interdisciplinary stakeholder **engagement**
- developing **recycling** and P-use **efficiency** throughout the food chain
- improving linkage between **research** and **policy**
- **introducing policies and incentives** to support sustainable phosphorus management and recycling, including research funding.

Necessary changes to practices and attitudes indicated include:

- **transparency** concerning phosphate rock reserve and resource data
- **regulation** of livestock production to avoid local nutrient overproduction
- changes in **diet**
- improving phosphorus **fertilizer** use, avoiding over-fertilisation
- accounting **externalities** into market systems
- **changing attitudes** to recycling and reuse of organic wastes and management of contaminants in these wastes (chemicals, pharmaceuticals, hormones …).

Knowledge gaps

A range of unresolved issues and knowledge gaps are identified by the Blueprint, including :

- global governance of **phosphorus resources** and access
- **tools, targets and regulations**: what tools are effective ? how to involve stakeholders ? how to respect varying local conditions ? how to integrate sustainable phosphorus into international aid systems ?
- **subsidies and pricing**: are subsidies warranted and if so under what conditions in areas such as reducing food waste, water treatment, fertilisers, food production ?
- animal products in the food chain: the issue of **meat in diet**, under different production systems
- **interpreting and communicating** phosphorus scarcity: what messages should be developed ? how to communicate ? how to ensure reliable data ?

The Blueprint also includes recommendations for breaking down **stakeholder roles and responsibilities** for these different areas of action between intergovernmental, national, regional, finance, industry, philanthropic, NGO, farming sector, research, media and individuals in society.

"Blueprint for global phosphorus security", outcome of the 3rd Sustainable Phosphorus Summit (Sydney 2012)
http://sustainablepsummit.net/

4th Sustainable Phosphorus Summit, 1 - 3 Sept. 2014, Montpellier, France http://SPS2014.cirad.fr

Phosphorus flows

Phosphorus flows

Quantification of phosphorus surplus in the Netherlands

A short conference paper summarises the 57 page report quantifying phosphorus flows (mass flow analysis, for 2005) in agriculture, households and industry in The Netherlands. The national P surplus is estimated at nearly 60 000 tonnes P/year (ktP) of which over 38 000 tonnes accumulates in farmland or is lost to surface waters. In a further 43 page report, agricultural scenarios to reduce this phosphorus surplus and avoid accumulation in soils are proposed.

The overall Netherlands phosphorus surplus estimate is similar to that published in another study in 2011 (van Enck et al., see SCOPE Newsletter n°79), but the estimates for **accumulation in farmland soils and for loss to surface water** in the present study are significantly smaller, possibly because of a better accounting of household and industry flows.

The present paper considered phosphorus flows (inflow and outflow) in agriculture (fertiliser, animal feeds, arable land, pasture grassland and silage, grazing animals, intensive livestock, manures), in households, food industry, , non-food industry, waste streams, and emissons to the environment (including landfills, gardens, nature and surface waters).

Data were derived from national statistics (CBS, which collects data from all sectors of the Netherlands and BINternet, which collects data from a number of representative farms). These data and also from other statistics sources and publications were extrapolated to the national land scale.

National phosphorus flows were estimated for a comprehensive range of products including meat, arable crops, ocean caught fish, pet foods, animal carcass byproducts, dishwasher detergents, horticultural products, wool etc …

The **national system P inputs** in 2005 are estimated as 21 ktP in fertilisers, 1.4 ktP in non-food industries, 57.6 ktP in animal feeds and 28 ktP per year in imported human foods.

National P exports are estimated at 1.3 ktP in non-food industries, 37.5 ktP human foods and 9.7 ktP in wastes and manures.

Phosphorus accumulation

This results in a total P import for The Netherlands of 110 ktP/year, whereas total export was only around half of this amount. **The authors estimate that 31.3 ktP/year accumulates in Netherlands arable and grassland soil (16.5 kgP/ha/year), and that 6.8 ktP/year is lost to surface waters** (the effluent of waste water treatment plants contributes for 50%, the other half can be attributed to leaching and runoff in agriculture).

Some 21.4 ktP/year is lost from wastestreams which end up in landfills or in waste or biosolids incineration ashes,then used in cement production or other uses such as road foundations.

At present, only around 10% of The Netherlands manure production is exported.

Only a relatively small proportion of the total phosphorus flow reaches households (20 ktP/year, of which 1.3 ktP = 7% in dishwasher detergents). Of the total inflow into households, some 50 – 70% is estimated to be consumed in foods. Of the total inflow into households, 2/3 leaves in sewage and the remainder in domestic refuse/solids to compost.

The authors conclude that **the development of phosphorus recycling is necessary to reduce national P accumulation and reduce losses to surface waters** provided that the recycled P is exported from the Netherlands, unless a radical reorganization of agriculture is undertaken. Returning more manures and biosolids to agricultural land is not a useful option in The Netherlands as farmland is already facing a phosphorus excess and accumulation.Dutch legislation will push to implement solutions because **from 2013 balanced fertilization of farmland (input = output) is imposed**.

In a further report, the authors show that The Netherlands national phosphorus surplus fell by 9 ktP from 2005 to 2008, mainly because of reduced mineral P fertiliser application, as well as increased manure export and decreased (net) animal feed import. Accumulation of P on farmland consequently fell significantly (from 31 to 19 ktP/year), whereas sequestering in wastes increased slightly and losses to surface waters fell very slightly (improving wastewater treatment).

Scenarios to reduce P surplus

Three general agriculture scenarios for reducing The Netherlands phosphorus surplus were proposed and assessed (including in combination):

- **Phosphorus Application Standards** requiring reductions in farmland phosphorus applications,
- **phosphorus "mining" from agricultural land** requiring application of P only balanced to or below the P removed in crops
- reducing animal feed phosphorus use by 10% whilst maintaining meat and milk production

The implementation of the Phosphorus Application Standards enable a reduction of the soil P accumulation by around 50% to around 10 ktP/year, whereas the more severe agricultural P "mining" scenarios reduce this further or even begin to reduce the existing accumulated soil P surplus. However, these scenarios also result in significant **increases in the manure P surplus** because they effectively limit agricultural manure spreading (manure export would need to increase from 13 ktP/year in 2008 to in the most severe case 33 ktP/year).

The implementation of the **reduced animal feed P scenarios**, if implemented in both dairy and intensive livestock, could reduce the national P surplus by up to 9 ktP/year.

Paper "A quantification of phosphorus flows in The Netherlands through agriculture, industry and households", Grassland - a European resource? Proceedings of the 24th General Meeting of the European Grassland Federation, Lublin, Poland, 3-7 June 2012 2012 pp. 789-791 http://edepot.wur.nl/247201

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Report "A quantification of phosphorus flows in The Netherlands through agriculture, industry and households", Plant Research International,Wageningen UR Report 364 (December 2010) http://edepot.wur.nl/247486

Report "Agricultural scenarios to reduce the national phosphorus surplus in the Netherlands", Praktijkonderzoek Pland & Omgeving Wageningen UR Report 466 (July 2012) http://edepot.wur.nl/161849

Australia

Modelling implications of phosphorus use efficient wheat

The release of organic anions by plant roots (eg. citrate) can improve phosphorus uptake but field evidence is lacking. Therefore an APSIM modelling approach was used to estimate expected wheat yields for hypothetical PUE (phosphate use efficient) wheat with different citrate release rates, fertiliser application and soil P sorption in Australia.

A **life cycle inventory of farm inputs and outputs** was modelled, assessing fertiliser application, costs for farmers, and environmental impacts including phosphorus losses causing eutrophication problems.

The agricultural production system model (APSIM) was configured to compare **citrate efflux enhanced wheat (releasing citrate from roots)** to similar standard wheat for three case study sites in Australia (in Western Australia, South Australia and New South Wales), using local climate and soil characteristics. The citrate efflux wheat was taken to release 100 nmol citrate/g fresh weight root/hour, corresponding to the upper range of values already reported in plant-bred commercial wheat strains, or 5x this amount corresponding to a possible objective through genetic manipulation.

The authors note that such PUE wheat would rapidly deplete phosphorus in P-deficient Australian soils if phosphorus fertiliser application was not continued, but enable a **more efficient use of phosphorus** because fertiliser applied one season is accessible to crops in following seasons.

Life Cycle Assessment

Factors examined in the APSIM model included land use, water, farm energy consumption, nitrous oxide, methane and CO_2 greenhouse emissions, phosphate resource depletion and eutrophication.

The model indicated that **PUE wheat would reduce long-term phosphate fertiliser consumption by up to 46% or 68%** (for the 100 and 500 citrate efflux hypotheses). The impact was higher in cases with P sorbing soil or where initial soil phosphorus was low. There are a variety of site factors which determine the efficacy of the PUE trait.

The PUE wheat also resulted in a **reduction of agricultural phosphorus losses to surface waters**, and so contribution to eutrophication, of 0.3 – 0.7 kgP/ha/year.

"Life cycle assessment of phosphorus use efficient wheat grown in Australia", Agricultural Systems, in press 2013
http://dx.doi.org/10.1016/j.agsy.2013.04.007

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Phosphorus recycling as struvite

LIFE PHORWater

Waste water treatment works management for P-recovery as struvite

Led by DAM (Depuración de Aguas del Mediterráneo), Valencia, Spain, the European Union LIFE programme funded project PHORWater aims to demonstrate biological phosphorus removal with struvite recovery in a stirred tank reactor in a municipal waste water treatment plant, including integral plant management to optimise P-recovery, design and construction of the struvite precipitation reactor, implementation and testing, validation of the struvite as fertiliser and economic assessment.

The project has a total budget of 1.3 million Euros and will run for 3 years from September 2013 to December 2016.

It also involves LAGEP (University Lyon 1 Claude Bernard), specialised in industrial precipitation and crystallization processes, and CALAGUA (University of Valencia), with knowledge in the design, operating and optimization of biological nutrient removal wastewater treatment plants.

Integrated management model

The project will assess the El Cidacos municipal waste water treatment plant (Calahorra, La Rioja, Spain, **see photo**), operating **enhanced biological phosphorus removal (EBPR) and anaerobic digestion of sludge**, including analyses in both the water treatment and sludge lines, in order to determine the flows of phosphorus through the plant and the type and extent of phosphorus fixation or precipitation at different points.

The main goal of this project is to demonstrate that EBPR combined with an **integral management of P in the WWTP including struvite recovery by crystallization** can be an economically viable technology. For that purpose it is necessary to consider the plant as a whole in order to achieve high efficiency in P recovery.

A plant model will be used to optimise P-removal and P-recovery as struvite, with the objective of improving on the current estimated 30% of plant inflow phosphorus recovered in struvite processes.

Stirred struvite reactor

A stirred struvite precipitation reactor will be designed, constructed and implemented in the plant (planned reactor capacity = 25% of plant sludge dewatering stream, that is approx. 20 m3/day).

This reactor will be based on **stirred reactors widely used for precipitation processes in industry**, generally easier to operate than fluidised bed or air stirred reactors, based on the experience of the pilot reactor constructed by LAGEP for CEEP (*www.ceep-phosphates.org*) and then further developed and tested in cooperation with Universitat de València (see SCOPE Newsletters n° 81 and 73).

This reactor is composed of a mixing zone in which precipitation takes place and a settling zone to retain the solid particles inside of the reactor. The reactor is operated with continuous liquid throughflow and periodic particle removal.

The stirred precipitator will be completed with a liquid/solid separation and drier to extract the struvite and an algorithm control system.

The project includes training of the treatment plant operators to ensure **optimal integration into the biological P-removal process, phosphorus recovery levels and struvite purity**. The morphological and agronomical aspects of the recovered struvite will be analysed and evaluated, with characterization and agriculture application assays.

An **economic study** will assess the overall economic impact of the P-recovery implementation, both on plant operation and through the value of the recovered fertiliser product. In particular, plant phosphorus discharges, sludge production volumes, energy consumption and other operating costs (including nuisance deposit problems) will be monitored. Results will be disseminated by communications, onsite visits and workshops.

PHORWater project summary, DAM website: http://www.dam-aguas.es/en/noticias.php?id=121

Struvite bio-precipitation

Biological pathway for P-recovery demonstrated

Biological (bio-mineral) struvite precipitation was tested in beaker-scale batch experiments using 4 different bacteria species in firstly pure nutrient solution (synthetic wastewater) and then in two different real sewage liquors: wastewater/liquor collected from the activated sludge tank, and centrifuge liquor from the dewatering of sludge after anaerobic digestion (both from a domestic sewage treatment plant operating without nutrient removal).

The **four bacteria species** used were selected on the basis of previous literature indicating potential for struvite bio-precipitation: Myxococcus xanthus, Bacillus pumilus, Halobacterium salinarum, and Brevibacterium antiquum.

These 4 bacteria species, after prior incubation of the purchased cultivar to develop bacterial population of the given species, showed **bio-precipitation of struvite crystals from the synthetic media**, consisting of yeast extract, magnesium sulfate and potassium phosphate (the latter at 2gK_2HPO_4/l). In some cases, the crystals initially formed (after 1-3 days) within the bacteria cells (in the cytoplasm), but after 5-7 days struvite crystals showed outside the cells, in the media.

SEM and SEM-EDX analysis of the crystals showed an orthorhombic structure and phosphorus content conform to struvite.

In this synthetic media, the different bacteria species produced from **63 to 2160 mg/l of struvite crystals (after 7 days)**, the most productive bacteria being Myxococcus xanthus.

Real wastewaters

In the real wastewaters, Myxococcus xanthus failed to grow or to produce crystals, and the growth rates of the other 3 bacteria were also lower. In this case, the best crystal production was **Brevibacterium antiquum, which produced large struvite crystals in the medium** (up to 250µm) which were easily separated out by centrifuge or filter, giving a crystal production of 226 mg/l after 10 days.

Phosphorus removal

The phosphorus concentrations in the activated sludge wastewater and sludge centrifugate were 7.5 and 30 mgP/l. These were reduced to 1.5 – 2.2 mgP/l in both liquors after 10 days with both Bacillus pumilus and Brevibacterium antiquum, that is **72 – 95% P-removal and a residual phosphorus concentration low enough for discharge potentially compliant** with EU Urban Waste Water Treatment Directive requirements.

Ammonia removal was greater than stoichiometric to struvite precipitation (1:1 to phosphorus), suggesting that other nitrogen metabolism reactions were in play, whereas magnesium removal was approximately stoichiometric.

The authors consider that this work opens ground for a radically **different route for P-removal and recovery from wastewater, potentially with a one-step biological process**.

However, the growth rates for the bacteria tested are very low, especially in real wastewater, and so **further work is needed** both to identify bacteria capable of growing and bio-precipitating struvite more rapidly, and also to better understand the biological and physic-chemical processes at work in order to maintain and develop populations and action of appropriate bacterial populations.

"Bio-Struvite: A New Route to Recover Phosphorus from Wastewater", Clean – Soil, Air, Water (Wiley), 2013, 41, in print www.clean-journal.com

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Field trials

Three year test of struvite as crop fertiliser

Struvite was recovered from the aqueous waste stream of a corn-fibre bio-energy processing plant. The crop availability of phosphorus in this struvite was evaluated in three year field trials at three sites in Iowa, comparing to triple super phosphate fertilizer with a maize – soybean – maize crop rotation over the three years, measuring plant above-ground dry weight, P-content, P-uptake at the plant growth stage, grain yield, P-accumulation and post-harvest soil phosphorus.

The field trials were carried out at three different sites in Iowa, each for three years but with only one initial fertilizer application. All three sites had **low or very low soil phosphorus**. Treatments were replicated 3 or 4 times and used 7 different phosphorus application rates, from 0 to 120 kg P/ha as struvite and as commercial triple super phosphate (TSP) fertilizer. The struvite and TSP were both granulated, with similar granule size.

Soil pH at the three sites was in the range pH 5.5 – pH 6.5, that is somewhat acidic soil, and texture was loam, silt loam, and silty clay.

Comparable to TSP

The fertilizers were applied by spreading one month before sowing of the first maize crop, and incorporation into the soil by the first maize seed planting.

Results confirmed that soil P at all three sites was largely below crop needs, with 20% - 30% increases in parameters such as plant dry weight or grain yield at the higher fertilizer application rates (compared to zero P fertiliser).

Results for struvite and TSP fertilizer were very similar. In some cases, struvite showed slightly higher early plant dry weight and P-uptake or higher grain yield than for TSP. Overall the authors conclude that, in these slightly acidic soils, struvite is as effective a phosphorus fertilizer, or slightly more effective, than triple super phosphate.

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

Pot and field trials

Fertiliser testing of phosphates recovered from sewage and ash

This paper presents the results from several separately reported pot trial experiments assessing the fertilizer value (plant availability) of different recovered phosphate products. These experiments generally used maize as the test plant, in sandy and loamy acidic soils (pH 3.3 – 6.8). This paper shows results, as a comparison to triple super phosphate and raw phosphate fertilizers.

The recovered phosphate products tested included:

- phosphates recovered from sewage sludge incineration ashes after chemical processing to remove heavy metals
- meat and bone ash, sinter product and Cupola furnace slag
- plant residue combustion ashes

Low P value of incineration ash products

The recovered phosphates from sewage sludge incineration ashes and meat and bone ash showed **low plant availability of phosphorus**, even over long periods and in the acid soils used for testing:

- **12 sewage sludge incineration ash recovered phosphate products**: all after heavy metal removal using chloride (and in one case sulfuric acid)
  From Sindlingen (Germany) and from Slibverwerking Noord Brabant, The Netherlands. These ashes had respectively low iron – high aluminium (2% Fe, 13% Al) and average iron and aluminium (11% Fe, 5% Al).
  Plant P availability: 0 –40 % (compared to SSP) over short term (10 weeks), 5 – 67% over 12 months.
  Source: Schick 2010

- **3 other thermally recovered phosphate products**: meat and bone meal ash (TM Asche), meat and bone meal sinter product (produced by sintering meat and bone meal at around 1000°C with soda ash and quarz, ULO-Phos, VTS Koop Schiefer, Thüringen KG, Unertloquitz), Cupola furnace slag, (from a small-scale thermal elemental phosphorus process) (VTI Thüringer Verfahrenstechnisches Institut, Saalfeld).
  These products showed very different plant P availabilities, tested over c. 10 weeks at three different locations/soils and two years, varying from 9-30% for the meat and bone meal ash, 65-87% for the ULO-Phos to 24% (Acid sandy soil) and 121% (neutral loamy soil) for the Cupola slag.
  Source: Cabeza Perez, 2010.

- **2 plant residue combustion ashes, from biomass to energy plants**
  Tested in field trials using corn and maize.
  The products tested were ash of the residue of rape extraction process (REASA) and cereals combustion ash.
  Both showed phosphorus uptake by crops 103-116 % compared to zero fertilizer addition, but a calculation of efficiency of P-uptake is not possible, because SSP was not used in this experiments, but it **can be concluded that the plant ashes were not effective fertilisers**.
  Source: Schiemenz 2010

Low P value of calcium based recovered P

The calcium-based products recovered from wastewaters also showed **low plant availability of phosphorus**:

- **1 calcium silicate hydrate (CSH) adsorbed phosphate, recovered from wastewater.**
  This product showed only 15 – 87% crop P uptake compared to triple super phosphate, with the 87% being achieved in very acid soil (pH 4.4) and only 25% being achieved in slightly acid soil (pH 6.8).
  Source: Cabeza Perez 2010.

- **2 further CSH recovered phosphates were tested (P-Roc x 2 samples, Fix-Phos)**
  These products showed low P-availability (34% compared to TSP) in sandy soils and zero P availability in loamy soil
  Source: Waida 2011

- **2 other recovered Ca- phosphate products:**
  - 1 x SESAL – recovered using calcium chloride
  - Pasch – recovered using calcium hydroxide (lime) – 3 samples
  These recovered phosphates showed zero P availability in loamy soil for SESAL or relatively low P availability (45 – 55% compared to triple super phosphate) for Pasch.
  Source: Waida 2011

Struvite and magnesium based recovered P

- **Struvites**:
  in 11 experiments struvite was tested on sandy and loamy soils.
  Struvites showed similar fertiliser efficiency to TSP provided that that the struvite was extensively free from iron compounds (Fe

phosphate)
Source: Cabeza Perez 2010, 2011; Waida 2011

- **3 Seaborne recovered phosphates, precipitated using magnesium, calcium and iron**
These were tested for phosphorus uptake by rye seedlings (3 weeks old) in comparison not to a phosphate fertilizer but to Monocalcium phosphate MCP $Ca(H_2PO_4)_2.H_2O$
Additionally, a number of other reagent calcium, magnesium, iron and aluminium phosphates were tested at the same time.
The results for the Seaborne recovered phosphates showed that the magnesium-recovered product had the highest P availability (110% compared to MCP), the calcium product 67% and the iron-recovered phosphate only 13%.
Results were similar with the reagent phosphates, showing high P-availability for the magnesium phosphates, low to intermediate availability for the calcium and aluminium phosphates, and **near zero plant availability for the iron phosphate ($FePO_4$).**
Source: Römer 2006

To summarise: **very low plant phosphorus availability is demonstrated for sewage sludge incineration ash recovered phosphates, iron containing phosphate products and calcium silicate hydrate recovered phosphates**. Phosphates recovered as calcium phosphates show limited plant P availability. **Magnesium phosphates, in particular struvite, show good plant availability**.

The authors conclude that further work is needed to complete short-term field tests and pot trials by long-term field tests, to understand the reactions between the different binding reactions of these phosphate products in the soil and interactions with nitrogen fertilizers

"Phosphor-Düngewirkung von P-Recyclingprodukten", Korrespondenz Abwasser, Abfall, 60(3), p202-215, 2013
http://de.dwa.de/tl_files/_media/content/PDFs/Abteilung_WAW/mj/01Dockhorn1.pdf

W. Römer, Universität Göttingen, Dept. für Nutzpflanzenwissenschaften, Abteilung Pflanzenernährung und Ertragsphysiologie, Carl-Sprengel-Weg 1, 37075 Göttingen, Germany awroemer@web.de

References cited in the paper:

Schick J. 2010: Untersuchungen zur P-Düngerwirkung und Schwermetallgehalten thermochemisch behandelter Klärschlammaschen, Dissertation, TU Braunschweig

Cabeza Perez, R. A., 2010: Phosphorus dynamics in soil and plant availability of fertilizers from phosphorus recycling evaluated in field and pot experiments, Dissertation, Cuvillier Verlag Göttingen

Cabeza Perez, R. A. et al., 2011:Effectiveness of recycled P products as fertilizers, as evaluated in pot experiments. Nutr. Cycl.Agroecosyst. 91, 173-184

Römer, W. 2006: Vergleichende Untersuchungen zur Pflanzenverfügbarkeit von Phosphat aus verschiedenen P-Recycling-Produkten im Keimpflanzenversuch, J. Plant Nutr. Soil Sci. 2006, 169, 826–832, see SCOPE Newsletter n° 68

Kratz, S. et al. 2008, Agronomical Potenzial of P fertilisers Made from Sewage Sludge Ashes – The EU-Project SUSAN, Vortrag EUROSOIL-Kongress, Wien, 25–29 August 2008

Waida, C et al. 2011: Untersuchung der in der Förderinitiative erzeugten Produkte, in: Abschlussbericht: Phosphorrecycling – Ökologische und wirtschaftliche Bewertung verschiedener Verfahren und Entwicklung eines strategischen Verwertungskonzeptes für Deutschland (PhoBe), Aachen, 2011, 97–162

Beaker tests

Precipitation of struvite and other minerals

Precipitation was tested in beakers using pure magnesium, calcium, ammonium and phosphate solutions. Beakers were mixed, shaken by hand, then settled for one day. Filtered solute was analysed and precipitates were analysed by XRD and SEM. A matrix of compositions was explored: pH from 5 – 11 and Mg:Ca ratios from 5:0 to 0:5 were tested. Results were compared to PHREECQ modelling.

Results showed that **seven different crystal minerals were precipitated in different conditions**: struvite, brushite, hydroxylapatite, newberyite, merrilite/whitlockite, octacalcium phosphate and monetite. Only in one case was an amorphous precipitate observed.

Observation suggested that with relatively high magnesium/calcium ratios, larger precipitate crystals tended to form with better settling properties, mainly struvite, whereas in high calcium/magnesium ratios much finer precipitates formed, mainly hydroxylapatite.

The precipitated minerals differ considerably from the PHREECQ model predictions. The model predicts the formation of bobierrite and cattiite, for example, and does not predict the precipitation of any of the minerals which do in fact form other than struvite and hydroxylapatite.

Brushite calcium removal ?

The formation of brushite at pH < 7 shown by the experiments is, the authors suggest, worth examining further. This could provide a mechanism to **reduce calcium concentrations (and so increase Mg/Ca ratio) in wastewaters, prior to struvite precipitation**, so improving the purity of the precipitated struvite.

Chemical costs and fertiliser value

The authors indicate that chemical costs will depend strongly on whether very **soluble magnesium or calcium sources** are required ($CaCl_2$, $MgCl_2$), which are expensive and necessitate dosing of sodium hydroxide to adjust pH (further cost), or whether adequate precipitation can be achieved with cheaper, poorly soluble reagents (lime CaOH, magnesium oxide MgO). Seawater concentrates can provide a cost-effective magnesium source (eg. discharge bittern liquors from desalination plants).

In some soils, low Mg/Ca ratio influences soil structure, resulting in a looser soil, improving oxygen ingress and drainage, so that magnesium addition as struvite should be avoided. In saline soils, addition of either calcium or magnesium may reduce the sodium absorption ratio, which will decrease fertility.

The **choice of chemical for phosphate precipitation** for P-recovery and recycling as fertiliser, should therefore take into account both the availability of cheap local calcium or magnesium sources, but also local agronomic requirements.

"Towards effective phosphorus recycling from wastewater: quantity and quality", Chemosphere (Elsevier), in print 2013
www.elsevier.com/locate/chemosphere

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Meetings

Brussels, 3 October 2013

Decadmiation workshop

Organised by Fertilizers Europe

With the European Sustainable Phosphorus Platform being launched, the new Fertilisers Regulation being drafted by the European Commission and the Green Paper on Phosphorus becoming available in the near future, phosphorus has become the centre of attention and feeds many discussions.

Together with the increased focus on phosphorus (P), came the attention for cadmium (Cd). Cadmium is a heavy metal that naturally occurs in phosphate rocks, albeit at different concentrations depending on the origin of the phosphate rock. Several cadmium removal (decadmiation) technologies exist but none is used at industrial scale for fertilizer production.

The objectives of this decadmiation workshop are to:

- **bring together** technology providers, companies active in phosphate fertilizer production or the agricultural sector, knowledge institutes and regulators (both at European as national level)
- **provide information** on the state of the art in decadmiation technologies and give the platform to P fertilizer producers to demonstrate their developments in this area.
- give an update of the current and future **cadmium balance in European agricultural soils**

To participate or for more information:
www.fertilizerstewardship.com

Nutrient Platforms

Europe: ***www.phosphorusplatform.org***

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

Flanders (Belgium): ***dh@vlakwa.be***

Agenda 2013 - 2014

- 3rd October, Brussels,
  Fertilisers Europe decadmiation meeting
  www.fertilizerstewardship.com

- 27-31 October, Berlin
  Global Soil Week "Losing Ground?"
  www.globalsoilweek.org

- 3-8 November, Tampa, Florida
  ASA/CSSA/SSSA + Canada SA + SERA17
  Water, food, energy and innovation for a sustainable world
  www.acsmeetings.org and *http://www.sera17.ext.vt.edu/*

- 6 November, Amsterdam, The Netherlands
  Resource recovery from the water cycle
  part of International Water Week
  http://www.internationalwaterweek.com/events/programme-iww-conference/resource-recovery-from-the-water-cycle/

- 6-7 November, Braunschweig , Germany
  Re-Water *www.re-water-braunschweig.de*

- 15 November, Berlin , Germany, 15h00
  Launch of German Phosphorus Platform

- 19-20 November, Manchester
  Biorefine *http://www.biorefine.org/*

- 3 December 2013, London: **End-o-Sludg : Sludge and phosphorus management in Europe, present and future (UK)**
  eoslondon@gyronllp.co.uk

- 5-6 December 2013, Bruges:
  ManuResource 2013
  (manure management and valorisation)
  http://www.manuresource2013.org/registration

- 11 December 2013, Brussels: **End-o-Sludg : Sludge and phosphorus management in Europe, present and future (EU)**
  eosbrussels@gyronllp.co.uk

- 7-10 January 2014, Phoenix Arizona
  2nd **Sustainable Phosphorus RCN** (US Research Coordination Network) meeting.
  http://sustainability.asu.edu/research/project.php?id=704

- 23-25 March 2014, Paris: **Phosphates 2014** (CRU) *www.phosphatesconference.com*

- 26-29 August 2014, Montpellier, France:
  5th Phosphorus in Soils and Plants symposium *http://psp5-2014.cirad.fr/*

- 1 - 3 Sept. 2014, Montpellier, France
  4th world **Sustainable Phosphorus Summit**
  http://SPS2014.cirad.fr

- 3rd-4th March 2015, Berlin: **2nd European Sustainable Phosphorus Conference**

- 23-25 March 2015, Florida:
  Phosphates 2015 (CRU)

- May 2015, Morocco: **SYMPHOS**
  www.symphos.com

Phosphates 2014

Symphos