European Sustainable Phosphorus Platform

SCOPE NEWSLETTER

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Special edition - Conferences

Sustainable Phosphorus Summit SPS 2014
The global Phosphorus Challenge

Researchers and stakeholders worldwide update knowledge on P sustainability at SPS 2014 and at International Symposium on Phosphorus in Soils and Plants PSP5.

World young scientists' message
The phosphorus trilemma

Young scientist at SPS2014 and PSP5 message for phosphorus sustainability:

Switzerland
Stakeholders discuss P-recycling obligation

The proposed new Swiss waste ordinance will make P-recovery from sewage sludge obligatory. Implications.

P-REX
Phosphorus recycling summer school

Young professionals and researchers discuss challenges of phosphorus management

New !

Sustainable P Initiative blog

Exchange, learn, discuss, participate …
http://sustainablep.wordpress.com/

Platform meetings

21 November, Berlin
German Phosphorus Platform (DPP).
P and planetary boundaries.
Vote of DPP statutes (establishment of a not for profit association).
www.deutsche-phosphor-plattform.de

European Sustainable Phosphorus Platform

Next meeting of the European Sustainable Phosphorus Platform

Brussels 2nd December 2014:
www.phosphorusplatform.eu

Define and adopt the Platform's statutes
(establish the Platform as a legal entity)

Fix the 2015 action plan and priorities

Discuss **Phosphate Rock/Phosphorus on the EU Critical Raw Materials list** (assessment currently underway)

If you cannot attend but wish to (remain or become) a member, then you can sign the statutes prior to the meeting.

The proposed ESPP statutes and 2015 action plan are available on the website
www.phosphorusplatform.eu
under Downloads

12 Nov, Leeds, UK, BioRefine / ESPP
UK nutrient network meeting
http://link2energy.co.uk/biorefine-nutrient-platform-event

Call

2nd European Sustainable Phosphorus Conference:
call for presentations, success stories, posters – deadline 15th November 2014
http://www.phosphorusplatform.eu

The partners of the European Sustainable Phosphorus Platform

Conferences

Sustainable Phosphorus Summit SPS 2014
The global Phosphorus Challenge

Over 200 researchers and stakeholders from across the world (around ¼ from developing and emerging countries) met in Montpellier, France, at the 4th global Sustainable Phosphorus Summit (SPS2014, 50 oral presentations, 90 posters), hosted by CIRAD and INRA, sponsored by Agropolis foundation, with presence of the French Ministry for Agriculture.

The conference took place immediately after the 5th International Symposium on Phosphorus in Soils and Plants (PSP5) and a young scientists' world phosphorus workshop.

The meetings showed that **phosphorus sustainability research is increasingly dynamic**, in response to stakeholder and government awareness, with new developments in areas such as phosphorus optimisation in crop production and animal feeds, phosphorus in diet and health, understanding of phosphorus flows, P in waste flows, phosphorus recycling and phosphorus sustainability policies.

As part of SPS2014 and PSP5, 42 **young scientists from 20 countries worldwide** met for a one-day workshop and defined their message for phosphorus sustainability, see below.

Philippe Hinsinger, INRA France, underlined that human impact on the phosphorus cycle is largely beyond **Planetary Boundaries** (see SCOPE Newsletter n° 103), posing the necessity to change management practices not only because of resource scarcity issues.

He reminded that the previous Sustainable Phosphorus Summits have led to the publication of the book "***Phosphorus, food and our future***" (a full and up-to-date overview of the global Phosphorus Challenge, 2013, see SCOPE Newsletter 97) and of the "***Blueprint for global phosphorus security***" (outcome of the 3rd SPS, Sydney, 1012, see also SCOPE Newsletter 97).

Valérie Maquère, French Ministry of Agriculture, Food Processing Industry and Forestry, indicated that phosphorus management is part of a holistic approach in France with bottom-up initiatives developed through the Agro-Ecology Project *http://agriculture.gouv.fr/definition-agroecologie* actively promoted by the Ministry.

Agro-Ecology

The French Agro-Ecology policy aims to shift agriculture towards the objective of **combining economic, environmental and social performance**. It involves optimizing resources and natural mechanisms through agronomy to make farms more competitive and sustainable and less dependent on resources. The new legal structure EEIG (Economic and Environmental Interest Grouping), instigated by French Law on the Future of Agriculture in 2014, enables specific access to EU funding for collective Agro-Ecology projects and will help promote initiatives including on-farm integrated fertilisation management (for livestock production and cropping systems) as well as territorial actions (circular economy approach).

Nutrient recycling, soil and food quality

France is also actively **promoting on-farm phosphorus management**, including fertiliser use, animal feeds, farmer training. The ministry is also working actively to improve recycling of organic materials, including manures, sewage biosolids, crop wastes, food wastes, food industry sidestreams. The objective is to **maintain and improve nutrient recycling levels, whilst maintaining soil quality** (for e.g. organic matter, pollutants, salinity, soil structure, pH …) and whilst guaranteeing crop quality and food safety. A specific program encourages circular economy actions for manures: the self-sufficiency methanisation and nitrogen plan (MAA Plan Énergie Méthanisation Autonomie Azote *http://www.developpement-durable.gouv.fr/Lancement-du-plan-Energie.html*).

Blueprint for global phosphorus security

Dana Cordell, Institute for Sustainable Futures Sydney, presented phosphorus sustainability progress since the 2012 Sustainable Phosphorus Summit (SPS3). The "Blueprint for global phosphorus security" (SCOPE Newsletter 97) adopted by SPS3 **defines a shared vision, identifies key actions, policy changes and stakeholder responsibilities and points to unresolved issues**, including global phosphorus governance, regulation and policy tools and communication – awareness.

Progress made since SPS3 (2012) include the development of Sustainable Phosphorus Platforms and work defining P sustainability tools.

Current questions to address include:

- How to integrate phosphorus into **Sustainable Development Goals** (United Nations Rio+20 process)
- Defining the **full externality costs of phosphate rock consumption** (e.g. eutrophication, life-cycle greenhouse gas emissions, waste generation from mine to field to fork, distribution impacts, finiteness of resources)
- Grappling with the many **phosphorus dichotomies**: Geographical concentration of phosphate rock reserves and related supply security; Regional differences in access to fertilisers needed for sustainable food production, including farm gate prices, nutrient poor soils / soil P accumulation, fertiliser overuse and eutrophication / inadequate fertiliser access, obesity / undernourishment

Phosphorus challenge in China

Fusuo Zhang, China Agriculture University and a member of **GPNM (Global Partnership for Nutrient Management** *http://www.gpa.unep.org/index.php/global-partnership-on-nutrient-management*) underlined the importance of phosphorus management to China, which is the world's biggest phosphate fertiliser producer and user. China also faces major eutrophication problems. China today has much higher phosphate land application rates than in North America or Europe and soil available phosphorus has increased from 7 mg/kg in 1980 to nearly 21 mg/kg in 2006. **China has accumulated c. 30 million tonnes of phosphorus (P) in its soils over the last two decades**. It is a feasible objective to stabilise China's fertiliser use at around 3-4 million tonnes P/year, considerably lower than industry projections of 20-25 mtP/y, whilst continuing to meet China's food requirements and reducing environmental impact:

- Government policy, which has already led to a **30% reduction in phosphate fertiliser use** since 2008
- Improve crop **utilisation of soil-accumulated phosphorus**, by stimulating root development and soil phosphorus mobilisation and intercropping. Objectives: +200% P efficiency, +40% N efficiency.
- Changing **trends in diet**: **Ma et al. 2013** indicate that animal protein content in China's diet increased from 9% in 1961 to 35% in 2010
- **Improve science – farm transfer**, to disseminate and implement better understanding and improved farm practices in phosphorus management, in particular through farm advisors and engagement processes

Jianbo Shen, China Agricultural University, also presented developments in phosphorus fertiliser use in China. He confirmed the considerable increase in phosphorus application since the 1980's, resulting in a doubling of soil plant available phosphorus (Olsen P). He underlined the **tendency to concentrate intensive agricultural production in South East China**, so accentuating phosphorus impacts in this region. He presented results of long-term field trials, over 15-30 years, showing that the current soil legacy phosphorus in China is adequate to achieve 80% crop yield for 5 years in northern China, but only 2-3 years in southern China. He also highlighted strategies for improving use efficiency of soil legacy phosphorus in China by root/rhizosphere management (Shen et al., 2013, Journal of Experimental Botany) to efficiently mobilise and use soil P across different agri-ecological zones with varied soil types.

Global phosphorus governance, GPNM and SPS5 in 2016

Dr Zhang indicated that **GPNM (Global Partnership for Nutrient Management) is currently looking at how to integrate a collaborative, worldwide approach to phosphorus sustainability**. An objective could be to integrate this into UNEP's current mission to define a 2050 Sustainable Development Plan, including -30% objectives and definition of indicators. Work on phosphorus could build on the experience and data of the International Nitrogen Initiative (INI).

Dr Zhang announced that the 5th Sustainable Phosphorus Summit could be hosted in China in 2016, providing a focal point for this global phosphorus governance objective.

Arno Rosemarin, Stockholm Environment Institute asked why the importance of phosphorus sustainability is so misunderstood and why there is **such a gap between the recognition of the phosphorus challenge and the coherent policies?** He called for increased transparency, management of phosphorus driven by policy and not only commercial objectives, better assessment of supply risks and for a United

Nations / international white paper, conference and convention conference on phosphorus management.

Jean-François Soussana, INRA France, underlined **links between the phosphorus cycle and climate change**, through soil P-carbon and P-nitrogen interactions, and eutrophication impacts. He underlined the need to engage phosphorus in the debate on global food security, structure local sustainable phosphorus initiatives and integrate phosphorus into the FAO Climate Smart Agriculture Alliance *http://www.fao.org/climate-smart-agriculture/85725/en/*

Marjolein de Ridder, The Hague Centre for Strategic Studies, underlined the **supply security risk for phosphorus, in particular for Europe**, because of geographical concentration of phosphate rock reserves and production and high EU dependency on imports. Europe should develop both internal policies to reduce phosphorus dependency (use efficiency, recycling) and external policies (reciprocity with phosphate rock producing countries, for example cooperation in areas such as water management, mining, food security, capacity building).

Kimo van Dijk, Wageningen University, The Netherlands, presented phosphorus flows in Europe and implications for phosphorus management and food security. **Today, some 160 000 tonnes P/year are recycled from sewage sludge, bio-waste and meat & bone meal to agriculture, compared to a total potential of 396 000 /y**. This is compared to annual imports of phosphorus for mineral fertilisers and animal feeds of over 1 400 000 tP/y: even complete recycling could not compensate if phosphorus import was no longer possible, and very significant reductions in food production would result. Further data is needed to assess to what extent this could be mitigated by agricultural best management practice for phosphorus, but the question of phosphorus scarcity/management and food supply security is clearly valid.

Michael Obersteiner, IIASA Austria, summarised different issues around long-term phosphorus sustainability and food security. Phosphorus demand is related to "PAT" = population x affluence x technology. Increasing urbanisation breaks local P-recycling loops. Issues raised are **global phosphorus security (phosphorus access is related to food security**, particularly in Africa with widely phosphorus-deficient soils) and the relation to land use (better P management enables reduced land use and so reduced forest and species habitat loss). **Possible ways forward identified include** algae production for food and energy (reducing land use), precision fertiliser use for small farmers, changes in consumer behaviour (meat and phosphorus in diet).

P in our world

A number of speakers addressed **phosphorus supply vulnerability, including economic and food security implications**, phosphorus supply criticality indicators, interactions with fertiliser quality supply and contaminant issues.

Emmanuel Frossard, ETH Zurich, reminded that phosphorus scarcity has been discussed ever since its use began in agriculture. Liebig, in 1876, pointed to phosphorus supply scarcity (referring at the time to guano resources), underlining trade equality issues and the need to recover and recycle phosphorus from wastewaters. Recent ten-fold variations in estimates of phosphate rock reserves are only coherent with other changes in estimates over the last 40 years.

Miia Kuisma, MTT Agrifood Research Finland, estimated that if phosphorus were used within planetary boundary limits then globally food supply of 250 kcal/person/day with current diet could be achieved, or 850 kcal with a vegetarian diet, compared to current food supply of over 2800 kcal. Avoiding all food waste would gain around 80 kcal.

Shamie Zingore, International Plant Nutrition Institute (IPNI), emphasised the fertiliser under-supply challenge faced by Africa: phosphorus application levels 10x lower than world average, P offtake currently often higher than input, infertile soils with a high P need, soil micronutrient and organic matter content deficiencies.

Marijn van der Velde, European Commission Joint Research Centre, also underlined the **need for a balanced application of nutrients**, while also emphasising the need for higher fertiliser input to Africa's soils, suggesting that an increase from 2.2 to 26 kgP/ha in fertiliser use is necessary to achieve 70% of crop productivity potential, as well as a five-fold nitrogen input increase. (M. van der Velde, et al., 2014. African crop yield reductions due to increasingly unbalanced Nitrogen and Phosphorus consumption, Global Change Biology, doi:10.1111/gcb.12481)

P in our fields

Speakers underlined the many **opportunities for improving phosphorus management on the farm**, so reducing phosphorus fertiliser consumption and phosphorus losses to surface waters, including:

Marc Stutter, James Hutton Institute, Scotland: improving the use of **buffer strips to reduce phosphate loss to water courses**. P is accumulated but a P-sink is needed, which can be achieved by harvesting biomass. Species can be identified which contribute to local natural biodiversity, intercept and accumulate P, and decompose on fields to give a useful organic and nutrient material. Farmers can then perceive the buffer strip as producing value, not simply as lost space.

Sylvain Pellerin, INRA France, Carmo Horta Castelo Branco Agricultural College, Spain, and Karen Daly, Teagasc Ireland: variability of different manures and the need to adapt application to the **plant availability of manure nutrients**, the interaction between manure organic carbon content and soil nutrients and specific local soil parameters.

Matthias Wissuwa, Japan International Research Center for Agricultural Sciences JIRCAS: challenges of plant breeding to **improve crop phosphorus efficiency and P uptake** in low-phosphorus soils. The objective is to maintain yield at reduced fertilizer application in high-input systems; and to increase yield with marginal P fertilizer use in low input agricultural systems. Developing cultivars with improved capacity to take up P from soil-bound P fractions would be a solution under both scenarios. Cultivars with improved efficiency of internal P utilization are of particular interest for low-input systems suffering from more acute P deficiency. Traditional local plant varieties often show more efficient root P uptake and phosphorus utilization compared to modern high-yielding cultivars and are therefore promising donors of tolerance mechanism and associated genes.

P in our food

Barbara Burlingame, FAO Food and Agriculture Organisation (Nutrition Division), pointed to the world's food inequality: 800 million undernourished, 2 billion suffering from micronutrient deficiencies, 2 billion obese. FAO's "sustainable diet" defined in 2010 does not mention phosphorus, because deficiency is not seen unless starvation is occurring.

FAO's recommendation for daily phosphorus intake is 1g/day, but this varies with age and is dependent on calcium intake. She notes that **lowering the daily phosphorus results in a lower daily calcium requirement, and so reduces environment footprint**. She also explains that current medical knowledge shows that higher blood phosphorus levels (serum P) are correlated to increased all-cause mortality, higher risk of cardio vascular disease, deterioration of kidney function and increase in bone disease. **Increased diet phosphorus may have these effects without showing detectable increased serum phosphorus**.

Ms Burlingame notes that **phosphorus contents of foods are very variable**, even within the same food type. For example, phosphorus levels were much higher in some brands of breakfast cereals analysed (e.g. Kellogs, Sun Country …) than in others. GCARD (Global Conference on Agricultural Research for Development) and CGIAR-A4NH (CGIAR Research Program on Agriculture for Nutrition and Health) make no mention of phosphorus. For this reason, FAO and medical associations are now pressing that phosphorus content should be included in food labelling.

Hadden Graham, AB Vista Feed Ingredients, explained the progress in animal feed phosphate use made over the last 20 years through **use of phytase enzyme dosing**. Phosphorus in vegetable matter, and particularly in seeds, is to a significant extent present as 'phytate' (see SCOPE Newsletter 78), which cannot be broken down by non-ruminants (e.g. pigs, chickens) and so is not available to their digestive system. Adding synthetic phytase enzyme can release the phosphorus from phytate, allowing levels of added inorganic phosphorus to animal feeds to be substantially reduced, which in turn reduces feed costs as well as P levels in manure and slurries. Currently this technology is not fully exploited, and thus there is scope for higher levels of phytase dosing, with further reductions of animal diet P.

Stuart White, University of Technology Sydney and **Elizabeth Webeck, Tohoku University Japan,** addressed the impact of dietary choices on the phosphorus footprint and on the environment. Increasing meat content in diet has a massive impact on phosphorus demand, but also on climate, land use, water consumption. Policy tools need to be developed to reduce meat in diet, including both education and regulation.

P in our wastes

A range of presentations showed that **phosphorus recycling is developing**, with technological progress, implementation full scale by frontrunners and active industry engagement.

Christian Kabbe, P-REX and Berlin Centre of Competence for Water, presented work for Berlin, showing that **90% recycling of phosphorus from sewage is feasible** if recycled fertiliser products are developed which correspond to user requirements and if driven by regulation.

Geneviève Metson, McGill University Montreal Canada, showed that in an urban area **phosphorus in food waste can be significant** and P-recycling can be synergistic with composting and with city urban agriculture.

Cynthia Carliell-Marquet, University of Birmingham UK, presented a **phosphorus flow analysis for UK waste water treatment. UK sewage** contains some 55 000 tP/year, compared to 77 000 tP/y imported in mineral fertilisers. Real agricultural P-recycling of treated sewage sludge phosphorus will be significantly improved by changes in sludge application regulations which limit P application (in the Sludge Index) since January 2014.

Laetitia Six, Fertilizers Europe, indicated that phosphorus recycling (use of secondary materials in fertiliser production) is one of the **European fertiliser industry's nutrient stewardship objectives**. Secondary phosphorus sources show however high variability in phosphorus content, P solubility, water content, physical parameters and contaminants. Sewage sludge incineration ashes pose questions with heavy metal content, iron (which interferes with acidulation) and granulation behaviour. Struvite poses questions with water content, organic contaminants and in some cases odour.

Fertilizers Europe underline that **the use of secondary materials must be compatible with producing high quality, reliable and safe fertilisers**, including safety for handling in fertiliser factories, and that material supply must be secure, reliable and at a competitive price.

PSP5

SPS 2014 took place immediately after the **5th International Symposium on Phosphorus in Soils and Plants (PSP5),** Montpellier, 26-29 August 2014 *http://psp5-2014.cirad.fr/* focused on "**Facing phosphorus scarcity**". 60 oral presentations and 180 posters were presented to 276 participants from 40 countries.

This Symposium was structured in five plenary sessions to highlight the **multidisciplinary** nature of the event, gathering plant nutritionists (plant physiology, genetics and systems biology), agronomists, ecologists, biogeochemists and soil scientists from worldwide, and to foster scientific exchanges across discipline boundaries, in order to face the challenge of phosphorus limitations in many agroecosystems and terrestrial ecosystems. Keynote presentations are summarized below.

Phosphorus forms, availability and cycling in soils

Federica Tamburini (ETHZ, Zürich, Switzerland) presented the pros and cons of using stable isotopes of oxygen to **evaluate the fate of phosphate**. Compared with nitrogen, the lack of a second stable isotope of phosphorus is indeed a major methodological limitation for tracing the fate of the various pools of phosphorus in soils as well as in the biota. The use of stable isotopes of oxygen cannot fully overcome this limitation.

A number of contributions in this session presented the **methodological advances** of various analytical techniques and approaches. Several papers addressed the roles of the soil biota, not just microorganisms, but also the macrofauna (earthworms), on top of plant roots, in altering the forms and availability of soil phosphorus.

Phosphorus acquisition by plants and microorganisms

Thierry Desnos (CEA, Cadarache, France) presented current understanding of how **root growth** responds to low phosphate concentration in the model plant *Arabidopsis thaliana*, thanks to the combination of genetics and chemical genetics dissection.

Maria Harrison (Cornell University, Ithaca, USA) presented the **central roles of the mycorrhizal symbiosis in the acquisition of phosphorus by plants**, and some new clues about the processes and molecular dialogue between the fungus and the plant, for the establishment and functioning of the symbiosis.

Other presentations addressed the various root traits (root hairs, root length, etc...) and processes (uptake, production of enzymes) involved in the **acquisition of phosphorus by plants**, their hormonal regulations and genetic control, and their importance for further understanding plant nutrition and perspective for improving it through breeding strategies.

Phosphorus utilization and signalling in plants

Terry Rose (Southern Cross University, Lismore, Australia) focused on the prospects for **improving internal phosphorus use efficiency in major crops** such as rice especially, both at a conceptual and methodological levels. This is a promising, but rather poorly studied domain in plant physiology and genetics to face the challenge of phosphorus scarcity.

Tzyy-Jen Chiou (Academia Sinica, Taipei, Taiwan) further elaborated on **phosphate homeostasis in plants**, stressing the role of novel molecular (microRNA) approaches to better understand the transport of phosphate inside the plants.

Other presentations further revealed the increasingly thorough understanding of **how phosphate starvation is sensed by plants** and how phosphate is being transported, especially in model plants.

Ecosystem dynamics and environmental impact of phosphorus

Val H. Smith (University of Kansas, Lawrence, USA) gave a comprehensive overview of the **landscape exports of phosphorus into aquatic ecosystems**, and their negative impacts as related to eutrophication of water bodies and resulting shifts in the aquatic foodchains and biodiversity.

Josep Peñuelas (CREAF-CSIC-UAB, Barcelona, Spain) presented the "**Imbalance-P project"** and the agricultural and environmental issues related to increasingly altered carbon/nitrogen/phosphorus ratios due to global changes, such as elevated CO_2 and increased atmospheric nitrogen deposition. Stoechiometric constraints suggest that phosphorus limitation is likely to be of increasing concern at the global level, not just in tropical regions of the world.

Other presentations further addressed the **ecological processes that play a key role in controlling the fate of phosphorus** in various types of ecosystems and ecosystem compartments, including food web approaches that are still fairly little studied in terrestrial ecosystems, compared to aquatic ecosystems.

Sustainable phosphorus use in agroecosystems

Generose Nziguheba (IITA, Nairobi, Kenya) presented the recent advances and limitations to tackle **the challenge of overcoming phosphorus deficiency in agricultural systems of sub-Sahara Africa**, where many soils are extremely phosphorus-deficient or show high phosphorus-fixing capacity, while many farmers can hardly afford phosphorus fertilizers in spite of the expected response to phosphorus fertilization in such soils.

Thomas Nesme (Bordeaux Sciences Agro, Bordeaux, France) addressed the issue of sustainable phosphorus use in agroecosystems, with a **global approach of phosphorus imbalances**, stressing the need to better achieve phosphorus resource use and recycling.

Other presentations in this session provided a large set of examples of **novel strategies for achieving a more sustainable intensification of agroecosystems**, through novel breeding strategies, through the use of multi-species cropping systems (intercropping or agro-forestry), or a better recycling of various phosphorus-rich by-products.

The next International Symposium on Phosphorus in Soils and Plants will be hosted by Erik Smolders and Roel Mercks at Katholieke Universiteit Leuven in Belgium in 2018.

4th Sustainable Phosphorus Summit (SPS 2014), Montpellier, France, 1-3 September 2014 http://sps2014.cirad.fr/ *Organised by INRA and CIRAD France. Abstracts of all papers available online.*

5th International Symposium on Phosphorus in Soils and Plants (PSP5), Montpellier, 26-29 August 2014 http://psp5-2014.cirad.fr/ *Abstracts of all papers available online.*

"Blueprint for Global Phosphorus Security", outcome of the 3rd Sustainable Phosphorus Summit http://sustainablepsummit.net/ *and see SCOPE Newsletter n°97*

"Phosphorus, food and our future" see SCOPE Newsletter 97 and http://ukcatalogue.oup.com/product/9780199916832.do

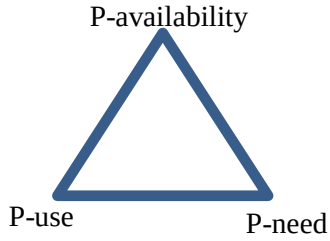
Selected papers from SPS 2014 and additional new papers on phosphorus sustainability will be published in special editions of Nutrient Cycling in Agroecosystems (guest editors Thomas Nesme and Paul Withers) and as a special Research Topic in Frontiers (editors Barbara Burlingame and Philippe Hinsinger)

World young scientists' message

The phosphorus trilemma P-producers / rich users / poor users:

As part of SPS2014 and PSP5, 42 **young scientists from 20 countries worldwide** met for a one-day workshop and defined their message for phosphorus sustainability:

- ***Multiple situations, different solutions***
- ***Phosphorus inequality***
- ***Vacuum of responsibility for implementing and disseminating P-sustainability: who is responsible for ensuring that change happens? Market or regulatory approach ?***



Objectives for action:

- ***Networking***
- ***Honest engagement of stakeholders***
- ***Need to communicate science at all levels***
- ***Coherence***
- ***International perspectives and global governance***

Switzerland

Stakeholders discuss P-recycling obligation

The Clean Technology symposium organised by FHNW (University of Applied Sciences and Arts Northwestern Switzerland) and i-net, with the EU P-REX project, Basel 11th September 1014, discussed how P-recovery for recycling from sewage sludge be implemented in Switzerland, as is expected to be required by the new Swiss federal waste ordinance currently under consultation (see SCOPE Newsletter n° 105).

Anders Nättorp, FHNW, summarised phosphorus flows in Switzerland. 5 900 tonnes P/year are used in mineral fertiliser, compared to a total of 5 100 tP/year present in municipal sewage sludges. **Incineration of sewage sludge is effectively virtually obligatory in Switzerland since 2006**. At present, a quarter of sewage sludges is burnt in the cement industry, a quarter in mixed incineration installations (with municipal wastes) and a half goes to mono-incineration (dedicated incinerators burning only sewage sludge).

Phosphorus in sewage

Christoph Egli, AVA Altenrhein (waste water treatment agency) presented treatment of sewage sludge by this organisation in the Bodensee area. Sludge is dried using recovered energy then used as fuel in cement works, **so effectively "losing" the phosphorus content**.

David Salzgeber, Holinger AG, presented an overview of phosphate removal in Swiss municipal waste water treatment works (wwtp). Swiss municipal **sewage phosphorus content is today around 1.8 g/person equivalent/day**. 1.4 g/pe/day come from human urine and faeces, 0.25g from household food wastes and 0.15 g/pe/day from other sources.

In Switzerland, **phosphorus removal is principally achieved by iron dosing** (chemical P-removal), using mainly iron III (3) chloride or sulphate salts. Iron II (2) salts are cheaper but are used only in larger wwtp because of handling issues. Phosphorus is removed in similar manner in the rest of the country. For chemical P-removal, iron is usually dosed around 1.5 – 2 x the molar ratio to phosphorus, in order to achieve discharge consents, so that sludge and discharge water will contain excess iron salts.

In Switzerland, biological P-removal plants do not usually achieve phosphorus discharge consents without additional iron dosing. Conversion of chemical P-removal to biological P-removal is difficult because the latter requires more space (footprint) which is often not available.

Roger Hurschler, Rhein Waste Water Treatment (ARA Rhein). The company operates one of Switzerland's biggest wwtps at Pratteln: 510 000 pe, of which most from the neighbouring chemical industry complex (Clariant, Novartis … in total 2400 jobs) and 30 000 pe municipal. **The plant produces 1 million tonnes of sewage sludge per year** with 0.8% dry

matter content. This is dewatered to 20% dry matter (of which c. 50% organic/50% inorganic) then incinerated, (mono-incineration plant) feeding energy into the municipal heat network and producing 4 000 tonnes/year of ash (100% inorganic dry matter).

Total wwtp phosphorus inflow is 188 tonnes P/year (including in external sludges taken for incineration), of which 25 tonnes P are added (required to feed the biological treatment of the industrial wastewater carbon content). Of this inflow phosphorus, 166 tP/year currently end up in sludge incineration ash and are landfilled, and 22 tP/year are lost to the Rhine in discharge. For the future it is planned to partly recover the phosphorus in the discharge flow. The mono-incineration ash is stored separately since 1975 accessible for a probable future phosphorus recycling.

P-recycling, quality and safety

Ludwig Hermann, Proman Management, explained that **the proposed new Swiss federal ordinance** on waste management (TVA) proposes to make obligatory phosphorus recovery from sewage sludge five years after publication. This proposal is currently open to public consultation until 30th November 2014 (see SCOPE Newsletter n° 105).

Ludwig Hermann also summarised the situation regarding placing on the market of recycled phosphate fertilisers, produced from e.g. sewage sludge incineration ashes. **Swiss regulations pose obstacles, because several contaminant limits are tighter for recycled fertilisers than for mineral fertilisers**, and Swiss regulatory constraints are not coherent with Europe (e.g. Swiss regulations nickel 30 mgNi/kg dry matter). The Swiss mineral fertiliser market is dominated by a small number of companies, in particular Lonza, CU Agro and FENACO group = Landor, Agroline. Average sale prices in Switzerland (c. 3.1 €/kgP) are significantly higher than in Germany (1.7 €/kgP). Lonza have successfully produced NPK granule fertilisers using ASH DEC recovered phosphates (recycled from sewage sludge incineration ash) in large scale (12t/h) test trials.

Samuel Vogel, Swiss Federal Agriculture Ministry, indicated that Swiss mineral fertiliser use has been reduced by 75% since 1990, due to implementation of a monitoring-obligation for the nutrient balance at the farms (as a part of ÖLN, ökologische Leistungsnachweis = ecological performance tracking). **Most Swiss farmland still has excess phosphorus application**. Several questions are raised about recycled fertilisers produced from sewage sludges: heavy metal content, heavy metal take-up by plants, real plant availability of the phosphorus content.

He also noted that **incineration of sewage sludge results in the loss of the valuable nitrogen nutrient content**.

Mr Vogel, presented developments in Swiss regulations for recycled fertilisers proposed by the Swiss Federal Agriculture Ministry. He emphasised that **the priority is to ensure food, farm and environmental safety**. Contaminant levels are defined with the objective of reducing heavy metal levels in soils (not only not increasing). Switzerland has concerns about fertiliser cadmium content. 45% of mineral fertilisers tested exceeded the Swiss cadmium limit (22 mgCd/kgP_2O_5).

Recycled fertilisers must meet both regulations for mineral fertilisers and regulations for recycled fertilisers (whichever is strictest). **The ministry considers that stricter limits are required for recycled organic fertilisers because products such as composts are spread to much higher doses than mineral fertilisers**. The ministry is therefore considering creating a new category for "recycled mineral fertilisers", applicable to this type of product only, perhaps from 2017.

Implementing phosphorus recycling

Leo Morf, Kanton Zurich, considers that, with the proposed new waste ordinance, Switzerland can reach a very high phosphorus resource efficiency. **Kanton Zurich anticipated this development in 2007 with local policy decision (Regierungsratsbeschluss RRB 572, 18th April 2007)** which requires that sludge management avoids loss of phosphorus from sewage sludge (which has to be incinerated under Swiss regulations): if technically possible P-recovery should be implemented, and if not seperative disposal must be ensured so that P-recovery can be possible in the future. The planned timetable for implementation is 2015, when serious bottlenecks are anticipated.

An assessment of different possible routes for P-recovery was carried out for the Canton Zurich in 2009 by FHNW. Wet oxidation of sewage sludge was

rejected, because the resulting waste stream is not compatible with landfilling and the technology was not validated for full scale application at the time. Disposal of sewage sludge in cement kilns or municipal sewage sludge incinerators is no longer considered because of P loss. **Therefore, the local policy decision (Regierungsratsbeschluss RRB 1035, 31/8/ 2011) implemented mono-incineration of sewage sludge.** The realisation of a centralised mono-incineration plant (KSV Werdhölzli, construction now nearing completion) and of storage and transport logistics are underway.

Kanton Zurich is currently carrying out testing and evaluation of mainly three possible technologies to recover and recycle P from the mono-incineration sewage sludge ashes: Leachphos, AshDec and RecoPhos, in particular looking at operating costs and at the final product (potential users and markets). The final process selection decision will be taken in Spring 2015. This is Kanton Zurich's "Urban Mining – Mineral Resources for the Future" policy.

At present, **optimisation of Leachphos is underway to improve the quality of the waste stream** with the objective of authorisation for use in construction (avoid landfill) and to generate a useful recycled P product (phosphoric acid, di sodium phosphate (DSP) or TSP (triple super phosphate), rather than calcium phosphate (DCP di calcium phosphate) which is considered by the agriculture sector to not be an effective fertiliser. Pending this, the mono-incineration sludge ash is being landfilled in separate compartments, so that extraction will be possible for P-recovery once this process is operational.

Jan Stemann, FHNW, presented calculations on costs of phosphorus recovery and market value of fertiliser phosphorus. He estimated that production costs of mineral fertilisers are 1.8 – 2.4 €/kgP (with the price to farmers being around 2 times higher after marketing and distribution costs). For comparison, presented calculations for production costs of recycled fertilisers are 2 – 8 €/kgP (before marketing and distribution costs).). **Recovery of mineral phosphate products from the wastewater stream is technically feasible with at least 10 different technologies** and would add around 2% to municipal waste water treatment costs.

Thomas Kläusli, AVA-CO2, presented **the new "AVA "Cleanphos" process which is based on hydrothermal carbonisation (wet-pyrolysis)**, as an innovative alternative to existing P-recovery routes.

The 3 sludge ash P-recovery processes considered by Kanton Zurich:

AshDec (now OutoTec)

- Thermal treatment of ash with acid at 1000°C, plus chlorine donor to remove heavy metals, SCOPE Newsletter n°78

RecoPhos *http://www.recophos.de*

- Chemical treatment of ash with phosphoric acid to produce a phosphate fertiliser
- This is not the thermal RecoPhos process *www.recophos.org* presented in SCOPE Newsletter 104

Leachphos

- based on FLUWA hydrometallic leaching process
- Chemical leaching with sulphuric acid to extract phosphorus and separate heavy metals
- Then precipitation of a phosphate product

The "AVA Cleanphos" process proposes to treat sewage sludge by HTC (hydrothermal carbonisation: 250°C at 200 bar) followed by a two-stage P-recovery process: acid leaching (extraction) of phosphorus from the HTC coal (using sulphuric acid, pH 1.5), followed by nano-filtration to separate the phosphoric acid from the metal sulfates. In a final process step the resulting 5% phosphoric acid is concentrated to approx. 20% or higher for transport or for fertiliser production.

He suggests that the phosphorus in HTC coal may not be as tightly bound (into minerals in the coal) as it is in incineration ashes, so that acid extraction may be more efficient and enable production of a phosphoric acid low in heavy metal concentrations. **The objective is also that the iron and aluminium salts may after the nano-filtration step be recycled back to sewage works** for use in phosphorus removal and so lower the costs of phosphorus removal from wastewaters. The HTC coal, after phosphorus recovery, could be used in co-firing to replace fossil coal, including if phosphorous recovery becomes mandatory by law. Finally such use in co-firing would mean that no new dedicated mono incineration plants would have to be built so reducing investments.

Nina Eicher, BSH Umweltservice, presented the **Leachphos process, currently being optimised for implementation for P-recovery for Kanton Zurich's sewage sludge incineration ash**. Dilute sulphuric acid is used to leach phosphorus from the ash. Flocculants and filtration are used to separate heavy metals, iron and aluminium. Neutralisation causes precipitation of a phosphate product which can be recovered, dried and pelletised, with a phosphorus content up to c 15%P.

Around 75-90% of phosphorus is currently recovered from the treated ash. **Calcium phosphate precipitated (lime neutralisation) has shown good plant availability in fertiliser tests**. Further work on reducing contaminants (e.g. copper, cadmium) is necessary to achieve conformity to Swiss recycled fertiliser contaminant limits.

At present, the waste filter cake has levels of copper and zinc too high for classification as "inert" for landfilling. A process to reduce contaminants in this filter cake is being developed (concentrated sulphuric acid (pH 1) followed by further neutralisation).

Sirja Hukari, FHNW, presented initial results for P-REX regional **scenarios for recovering and recycling 80% of phosphorus in sewage**. Such an objective is feasible, but will require implementation of a range of technologies, including P-recovery from sludge incineration ash alone or in combination with wwtp liquor streams. A move to mono-incineration of all sewage sludge as already implemented by Kanton Zurich (if sludge is not recycled through agricultural application) is required. A number of regulatory and infrastructure modifications are necessary to achieve this.

The workshop concluded with a discussion between stakeholders in which the feasibility of phosphorus recycling in which **the availability of appropriate technologies was confirmed**. The Swiss fertiliser SME **Hauert** emphasised that the priority must be food quality and safety. **Rob de Ruiter (EcoPhos)** and **Willem Schipper** (industry consultant) underlined that **known and tested industrial technologies**, other than the experimental processes currently looked at by Kanton Zurich, can use sewage sludge incineration ash as a raw material (Ecophos process producing di calcium phosphate for animal feed, thermal process to produce elemental P4 for industrial applications).

Participants emphasised that as well as P-recycling from sewage sludge, **nutrient recycling from incinerated animal wastes should be developed** because these offer high P and low contaminant content. This is proposed in the Swiss waste ordinance revision and should recover 3 000 tonnes P/year).

i-net Cleantech Technology Event "Rückgewinnung von Phosphor aus Abwässern in der Schweiz – Methoden, Chancen und Rahmenbedingungen" (recovery of phosphorus from wastewaters in Switzerland: processes, opportunities and conditions for success), Basel, 11th September 2014, organised with FHNW (University of Applied Sciences and Arts Northwestern Switzerland), and P-REX "Sustainable Sewage Sludge Management fostering phosphorus recovery and energy efficiency".

Presentations online: http://www.i-net.ch/en/event/i-net-technology-event-rueckgewinnung-von-phosphor-aus-abwaessern-in-der-schweiz-methoden-chancen-und-rahmenbedingungen/

P-REX
Phosphorus recycling summer school

The P-REX project (EU FP7, see SCOPE Newsletter n° 98) met at FHNW (University of Applied Sciences and Arts Northwestern Switzerland, Basel) to discuss project progress and results, followed by a 3-day 'summer school' for young researchers and professionals, at which phosphorus resource flows, P-recycling technologies and phosphorus in agricultural soils were explained by experts in the fields.

From 10 till 12 September 2014 the University of Applied Sciences and Arts Northwestern Switzerland (FHNW), Basel, hosted a **P-REX project partners meeting as well as a P-REX Summer School** bringing together 40 master and PhD students and young professionals out of 12 different countries.

The main objective of the **P-REX-project**, one of the **Biorefine Cluster Europe** members, is the **practical implementation of phosphorus recovery and recycling from wastewater in Europe**. P-REX is assessing technical and economic feasibility, life cycle analysis, and fertiliser value of recovered products (P fertilisers) for a number of P-recycling technologies. This meeting confirmed that P-REX has developed considerable data on these P-recycling processes and on the fertiliser value (pot trials and field demonstrations) of the recycled phosphorus fertiliser products.

The **European Sustainable Phosphorus Platform** representatives, participating in the P-REX expert advisory group, recommended that, once work is complete and full results delivered, **the project should prepare short summaries of conclusions, accessible to decision makers**. In particular, fact-sheets presenting the different P-recycling technologies would be very useful, including information about the form of the recovered phosphate product relevant to users such as farmers or fertiliser distributors (granulometry, delivery conditions, plant availability, regulatory authorisation status as fertiliser) and status of process implementation (number of plants operational, tonnage capacities, number of years operating experience). These fact sheets should include not only P-recycling technologies which are part of the P-REX project but also, for comparison, the **business models of P-recycling routes not covered by the P-REX project, such as agricultural application of sewage sludge after appropriate treatment (composting, digestion, sanitisation) or processing of manures to organic fertiliser products** (see SCOPE Newsletter 107 for case of Brittany, France).

Kimo Van Dijk, Wageningen University, presented updated data on the European phosphorus flows including better estimations for agricultural diffuse losses, pet food consumption and forestry industry/product flows. He noted that **the weighted average European P intake per citizen is around 0.5 kgP/person/year (1.4 gP/person/day),** compared to an average EU domestic food supply of around 1 kgP/cap/year. Pet food (and so excreta) is also an important phosphorus input and loss flow in society with a further 0.3 kgP/capita/year. The **phosphorus in human urine and faeces is worth around 1 Euro per year** at present common phosphorus fertiliser prices. To improve the business case for phosphorus recovery, companies can also focus on the recovery of other valuable elements in the waste flows, such as the micro-nutrients copper, zinc, etc.

Astrid Oberson, ETH Zurich, presented the **complexities of phosphorus – soil – plant systems**. She underlined the importance, in plant testing of fertilisers, of soil pH and of the residual effect of phosphorus left in the soil and not taken up during the first crop year. She presented isotopic nutrient uptake tests which show that sewage sludge incineration ash has a variable fertiliser value and is not as effective as mineral phosphate fertiliser, whereas struvite and a urine-recovered nutrient product (NitUr) perform as well as mineral fertiliser ("The plant availability of phosphorus from thermo-chemically treated sewage sludge ashes as studied by 33P labelling techniques", Nanzer et al., 2014 *http://link.springer.com/article/10.1007/s11104-013-1968-6* or *http://phdtree.org/pdf/48898978-the-plant-availability-of-phosphorus-from-thermo-chemically-treated-sewage-sludge-ashes-as-studied-by-33p-labeling-techniques/* in Plant and Soil, plus further results pending publication)

Ludwig Hermann, Proman Management, summarised the **different European and national legislations impacting phosphorus recycling** development, including fertiliser regulations, waste regulations, REACH (chemical regulations), wastewater and sludge regulations, plant operating permits and emission limits. **Christian Remy, KompetenzZentrum Wasser Berlin,** presented **Life Cycle Assessment** application to phosphorus recovery processes, and **Anders Nätttorp, FHNW,** presented an assessment of **phosphorus recycling costs and fertiliser markets**, both as developed in the P-REX project.

End-o-Sludge and EcoBioSim

The P-REX summer school also heard from other EU-funded projects working on P- recycling from sewage.

Ruben Sakrabani, Cranfield Univeristy UK, presented progress in the **End-o-Sludg project** (see SCOPE Newsletter n°s 100 and 105). This project is **producing a granulated, nutrient-balanced (by urea addition) organic fertiliser product** adapted for mechanical spreading using standard spinning disc equipment. The granules must not generate excessive dust when handled and when dropped onto the spinning disc, and must have reliable size and density to ensure even spreading.

Difficulties encountered with the **granulation process** have been successfully resolved, including abrasion issues. Further work is underway to optimise the process by **improving energy efficiency** (using waste heat from drying – granulation). An industrial pilot production plant has been tested at Ellsmere Port, England. Three year field trials have shown the fertiliser value of the product, providing evidence for End-of-Waste status (Deeks et al., Agronomy for Sustainable Development 33:539-549, 2013).

Johannes Messmer, Fraunhofer IGB, presented the EU-funded **BioEcoSim project** (see SCOPE Newsletter n° 100). This concept is to valorise manures using i) solid-liquid separation, ii) superheated steam drying and pyrolysis converting the solid fraction into biochar, iii) phosphorus recovery from the liquid fraction by struvite and calcium phosphate precipitation, iv) ammonia recovery as ammonium sulphate from the filtrate (liquid phase after phosphorus recovery) through selective separation and absorption techniques using gas permeable membrane, iv) pelletisation of the products as soil improvers and fertilisers. **The objective is to build a semi-mobile plant for continuous treatment of 100 kg/h pig manure** (manure wet weight).

Future challenges

With **Eva Stössel, Budenheim**, participants discussed optimisation of the **Budenheim process for phosphorus recovery from sewage sludge, using carbon dioxide under low pressure and without heat** (see SCOPE Newsletter n° 95). This process enables the extraction from the sewage sludge stream, by filtration, of a phosphoric acid solution from which phosphate products can be precipitated, recycling and reuse in the process of the carbon dioxide and production of a phosphate-reduced solid fraction which then goes to sewage sludge incineration. **A 1 m^3 capacity pilot plant is will be installed in 2015 at Mainz municipal sewage works.**

The **young scientists and professionals at the workshop** also discussed their **vision of the phosphorus challenge**, identifying issues and opportunities of sustainable phosphorus management. First of all, to close the phosphorus cycle, **cooperation** among the industry, government and knowledge institutes is essential, and more **research** on the recycling technologies is useful to obtain even lower **costs** and a lower **environmental impact**. The attendees agreed that **awareness raising** is essential. How many people do even know phosphorus? Besides, the current P-market does not encourage P-recovery, therefore **political actions** are necessary and regulations can act as a driver to start implementing the existing recovery technologies.

Young scientists and professionals discussion conclusions on "Why recycle phosphorus"
(collated by Marissa de Boer and Lies Declercq)

Pros	Cons
Reduce **environmental impact**	First reduce, then reuse and then recycle (waste hierarchy)
Reduced **dependence** on foreign mineral resources	P-recycling **is in many cases more expensive** than fossil P-production
Uncertain timeframe of availability of mined P	**Potential side effects** of some P-recovery processes: higher input of Zn and Cu
Might create long-term **economic opportunities**	P-trade = international relations
Saving the global phosphorus stocks	**Quality** of the products
Potential to recover **other nutrients**	High energy and chemical demand of some processes
Reduce the U and Cd pollution created by using P-rock	**Acceptance** of secondary products
Low tech countries get access to local P-fertilizers	
Less costs for EU to import raw material	
Potential to close the regional P-cycle	

On the final day of the P-REX Summer School, FHNW organized an **excursion to Hauert HBG Dünger AG** and the P-REX field trials. Hauert is Switzerland's leading producer of fertilizers used in gardening and organic agriculture. After an introduction on the origin of the company and the diversity of products, the Summer School participants got a guided tour through the different production process steps. After this, the participants visited **maize fields where different types of recovered materials are being tested** and saw in the field the effects of recycled phosphorus on plant growth.

P- REX phosphorus recycling Summer School http://www.p-rex.eu/

Agenda

- 3-5 Nov 2014, Long Beach, California **ASA, CSSA, SSSA** (US & Canada soil and agronomy) meetings, Water Food, Energy, Innovation for a Sustainable World *www.acsmeetings.org*
- 4 Nov 2014, Paris, French Chambers of Agriculture (APCA) **bio-economy valorising crops and nutrients** *http://www.chambres-agriculture.fr/outils-et-modules/agenda/agenda/article/journee-bioeconomie/*
- 4 Nov 2014, Brussels **ACR+ Circular Economy** for cities and regions working group *info@acrplus.org*
- 7 Nov, Lucerne, Switzerland **Swiss Water Association (VSA) P-recycling and waste water treatment** *http://www.svut.ch/up/files/20141107_P-Recycling_Ausschreibung.pdf*
- 12 Nov, Leeds, UK, BioRefine / ESPP **UK nutrient network meeting** *http://link2energy.co.uk/biorefine-nutrient-platform-event*
- 17-19th Nov, Manchester UK, 19th **European Biosolids & Organic Resources Conference**. Session on energy and resource recovery *www.european-biosolids.com*
- 18 Nov, Brussels, **Closing Mineral Cycles: resource efficiency in practice.** EU DG Environment funded project *http://mineral-cycles.eu*
- 21 Nov, Berlin, **German Phosphorus Platform (DPP)**. P and planetary boundaries. Vote of DPP statutes (not for profit association). *www.deutsche-phosphor-plattform.de*
- 27 Nov., Strasbourg, 13° RITTMO professional workshop: **European Harmonisation of fertilisers & growing media**, in French *http://www.rittmo.com/IMG/pdf/programme_des_23emes_rencontres_professionnelles_rittmo.pdf*
- 2 December, Brussels: **ESPP (European Sustainable Phosphorus Platform) meeting**: legal establishment of the Platform, P as an EU Critical Raw Material *www.phosphorusplatform.eu*
- 4-5 December, Florence, Italy: 1st International **Conference on Sustainable P Chemistry** *www.susphos.eu/ICSPC*
- 6-8 December 2014, Lisbon, Portugal **Nutriplanta2014** *www.congressos.abreu.pt/Nutriplanta2014*
- 11-12 December, Cambridge, England., IFS **International Fertiliser Society Conference** 2014 *http://fertiliser-society.org*
- 5-6 March 2015, Berlin: **2nd European Sustainable Phosphorus Conference** *www.phosphorusplatform.eu*
- 23-25 Mar 2015, Tampa, Florida: **Phosphates 2015** (CRU) *www.phosphatesconference.com*
- 29 March – 3 April 2015, Australia. **Beneficiation of phosphates VII** *http://www.engconf.org/conferences/mining-and-metallurgy/beneficiation-of-phosphates-vii/*
- 4-8 May 2015, Morocco: **SYMPHOS** (dates to be confirmed) *www.symphos.com*
- 1 May – 31 Oct. **Expo2015** Feeding the planet, energy for life, Milano *http://en.expo2015.org/*
- 18-22 May 2015, Washington DC: P-RCN synthesis workshop and **launch of the North America Phosphorus Partnership (NAPPs)** *https://sustainablep.asu.edu/*

Calls for papers

20th October 2014: call for papers - **Resources, Conservation and Recycling**: Losses and Efficiencies in P Management http://www.journals.elsevier.com/resources-conservation-and-recycling/

15th November 2014: call for presentations, success stories, posters – **2nd European Sustainable Phosphorus Conference** http://www.phosphorusplatform.eu/conference/espc2015.html

December 2014: call for papers – **Science of the Total Environment** - Taking stock: Phosphorus supply from natural and anthropogenic pools in the 21st http://www.journals.elsevier.com/science-of-the-total-environment/call-for-papers/special-issue-on-sustainable-phosphorus/

Nutrient Platforms

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

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

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

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

North America Partnership on Phosphorus Sustainability NAPPS ***j.elser@asu.edu***