European Sustainable Phosphorus Platform

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Review papers on new fertilisers

Fertilisers presented as "environmentally friendly". Slow release, containment and placement, fertiliser coatings.

State of science on sewage biosolids

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Assessment of biosolids on farmland

UK water industry evidence-based review of biosolids recycling to land.

P-removal technology trials results published

UKWIR publishes results of full-scale trials in sewage works of seven phosphorus removal technologies, assessing reliability of low P discharge in real operating conditions.

IFS Conference: leading science in sustainable farming

The International Fertiliser Society agronomy conference brought together papers at the forefront of science for sustainable soil management, soil carbon and plant nutrition.

Calcium phosphate food additives and health

Human tests suggest calcium phosphate diet supplements do not impact blood phosphorus and improve lipids.

Phosphorus recycling technology tour

Representatives of Scandinavian Governments visit P-recovery installations. Tour organised by ESPP and DPP.

Summary of German and Swiss legislations relevant to phosphorus recycling

German sludge and fertilisers regulations. Phosphorus recovery regulation. Swiss phosphorus recovery ordinance. Swiss ordinance on mineral fertilisers from recycling.

Organic fertilisers SOFIEurope 1st summit

The programme for the **1st Summit of the Organic Fertiliser Industry** in Europe (SOFIE, 5-6 June 2019, Brussels) includes leading organic and organo-mineral fertiliser manufacturers CEOs, agronomists, legal experts and the European Commission. The summit will enable dialogue on the agronomic proof of benefits of these products, market developments and new products for farmers in Europe and for export, and opportunities and challenges of European regulation, in particular the new EU Fertilising Products Regulation (with European Commission DG GROW).

The summit is organised by ESPP, in partnership with IFS (International Fertiliser Society), back-to-back to the IFS technical conference 4-5 June

Programme: www.phosphorusplatform.eu/SOFIE2019

Registration SOFIE www.eventbrite.co.uk/e/sofie-organic-fertilizers-summit-tickets-55703185728

IFS Technical Conference June www.fertiliser-society.org/event/2019-ifs-technical-conference.aspx

Waste water phosphorus removal tomorrow: ambitions and reality

9th October 2019, Liège. in the context of revision of EU water policy (WFD, UWWTD), with participation of the European Commission (DG ENVI, DG RTI), this workshop will look at phosphorus removal low discharge consents, flexible permitting / emissions trading, P-removal in small sewage works.

Information info@phosphorusplatform.eu

Liège 9 October 2019 . In partnership with / supported by: IWA, Eureau, CIWEM, Université de Liège and ECSM'19 (6-8 October) https://events.uliege.be/ecsm2019

The partners of the European Sustainable Phosphorus Platform

Review papers on new fertilisers

Review of "environmentally friendly fertilizers"

Chen et al. (Lanzhou, China) review different materials used in "environmentally friendly fertilizers" and their agronomic and environmental effects.

The review covers **bio-sourced and biodegradable materials which can be used to coat mineral fertilisers to ensure slow- or controlled release of nutrients**.

These include natural polymers (chitosan, sodium alginate, starch, cellulose and lignin and polydopamine. Polydopamine is a naturally occurring pigment, used by mussels for binding to surfaces. It can be used as a coating film on fertiliser particles, for slow-release of nutrients, and can be functionalised in polymerisation to provide specific pH or temperature dependent release properties.

The paper also considers agricultural residues and biochars, because these can be combined with mineral fertilisers by adsorption of nutrients into the residue or biochar matrix or chemically modified to produce coating materials. The paper notes that **control-release fertilisers can improve fertiliser nutrient use efficiency and reduce nutrient leaching / run-off,** as well as reducing costs of fertiliser application, but can also have the following beneficial effects: reduce urea exposure to water, and so reduce atmospheric nitrogen oxide NO_x emissions, increase soil organic matter, buffer soil acidity or alkalinity so improving pH for plants or improve soil water retention (e.g. superabsorbent or hydrogel materials).

The authors note that a key challenge is the considerably **higher cost** of these different fertilisers (estimated to be 2.5 – 8 times higher than mineral fertilisers), because the cost of coating materials is high, production processes are complicated, particle size sorting is necessary.

Another challenge is the **degradation of organic coatings over time**. Further research is needed into the behaviour of these fertilisers in different conditions (temperature, humidity, pH …), to adapt nutrient release to the pattern over time of crop nutrient requirements and into cost-effective production methods.

"Environmentally friendly fertilizers: A review of materials used and their effects on the environment", J. Chen et al., Science of the Total Environment 613–614 (2018) 829–839 http://dx.doi.org/10.1016/j.scitotenv.2017.09.186

Review of "slow controlled release fertilizers"

Fu et al. (Zhejiang, China) review types of "slow controlled release fertilizers" (SRFs) and proposes a classification system, in order to support scientific studies, fertiliser product selection and further research and innovation.

The authors note that key obstacles to the adoption of SRFs are **high cost** and **issues with the degradation** of materials used.

The authors classify slow release fertilisers as follows:

Physical	Chemical	Compound
Coated - inorganic coating - organic polymer coating (synthetic or natural polymers) - multifunctional composite coating	Chemically inhibited	Physically combined
Matrix-based	Chemically bonded	Chemically combined
		Physically and chemically combined

Only around 10% of total SRF (slow release fertilisers) sales are in agriculture, and most are used in high value applications such as lawns, golf courses, gardens. Non-agricultural use is growing around +5%/year and agricultural use +10%/year (Sazzad 2013). Some 95% of controlled release fertilisers are coated types, and the most commonly used coatings are polymers (including humic acid, starch, resins, lignin, cellulose, polyvinyl alcohol, polyacrylamide …) and sulfur coatings.

Natural coatings can be derived from plant materials, food industry by-products (e.g. glycerine), slaughterhouse wastes (horn), phosphogypsum.

Chemical slow-release fertilisers cited in the paper concern nitrogen fertiliser only, with various urea-reacted molecules and nitrogen inhibitor chemicals, but these tend to have high costs.

"Classification research and types of slow controlled release fertilizers (SRFs) used - a review", J. Fu et al., Communications in Soil Science and Plant Analysis, 49:17, 2219-2230, http://dx.doi.org/10.1080/00103624.2018.1499757

Hydrogel for fertiliser containment and placement

Davidson et al. (Waterloo, Canada) tested, at the lab scale, a slow-release fertiliser produced by fixing an NPK mineral fertiliser (chemical formulation not specified) into 5 x 3 x 1 cm sections of carboxymethyl cellulose polymer crosslinked by exposure to mineral ions (calcium chloride, iron II and iron III chloride).

The fertiliser loaded hydrogel was placed below wheat seeds in pots, in low nutrient artificial medium, then greenhouse tested in comparison with no fertiliser or daily application of the NPK fertiliser (dissolved in water) for around 8 weeks. The wheat plants generated total dry mass significantly lower than for the soluble fertiliser application, but increased height (from around 6 weeks and grain yield around two times higher.

The authors conclude that **this method of controlled delivery could enable a reduction of fertiliser use** of -3/4 or even higher.

ESPP comment: the effectiveness of this system may result from a combination of slow-release of the fertiliser, and of holding of the nutrients in a limited root zone (the hydrogel), however it is not clear how such "slabs" of hydrogel could be implanted into soil below crop seeds in real field conditions.

"Controlled root targeted delivery of fertilizer using an ionically crosslinked carboxymethyl cellulose hydrogel matrix", Drew Davidson et al., SpringerPlus 2013, 2:318 http://www.springerplus.com/content/2/1/318

Bio-based sulfur coating for controlled release

Mann et al. (Australia and the UK) present lab-scale production of a sulfur- polymer / NPK fertiliser composite and its testing in soil columns and pot trials as a controlled-release fertiliser.

The authors note that slow- or controlled-release fertilisers can **enable higher crop nutrient uptake efficiency and reduce nutrient leaching losses**, which represent both an economic loss and a cause of eutrophication.

Coating or encapsulation of mineral fertilisers can achieve this objective of controlled-release, but finding appropriate coating materials poses challenges: synthetic polymers may not be sufficiently biodegradable (so environmentally persistent), natural polymers tend to be too hydrophilic to control water permeability and so nutrient leaching, inorganic coatings tend to be brittle, leading to fractures and so uncontrolled nutrient release.

Consequently, <1% of NPK fertilisers are sold as controlled release (Timilsena et al. 2015).

In this study, sulfur was inverse vulcanised with a bio-sourced triglyceride (canola oil) as crosslinker (recycled cooking oil could also be used) and with NPK fertiliser. The resulting polysulfide polymer – NPK composite showed well controlled nutrient release over time, not impacted by increased irrigation, but faster with smaller composite particles. 10 week pot trials with tomatoes showed that plants were greener, taller and yielded more fruit with the composite than with one comparable application of mineral NPK fertiliser.

"Sulfur polymer composites as controlled-release fertilisers", Mamimilian Mann et al., Organic & Biomolecular Chemistry (RSC), 2019, 17.1929 https://doi.org/10.1039/c8ob02130a

State of science on sewage biosolids

ESPP organised 4th December 2018 a meeting between scientists, stakeholders and industry on questions around the use of sewage biosolids in agriculture. We summarise below the presentations (available here) and the conclusions.

The objective was to enable dialogue, based on science, concerning the safety, life cycle assessment and sustainability of recycling phosphorus, nitrogen and carbon by application of sewage biosolids in agriculture, after appropriate treatment (such as composting and/or anaerobic digestion).

Bertrand Vallet, Eureau (European water industry federation), summarised the current status of sewage sludge management in Europe: **nearly 50% is today used in agriculture**, and a further 12% goes to land restoration, that is a total of nearly 6 million tonnes/year (dry solids).

The expert opinion of the **European Committee on Wastewater expects agricultural use to reduce or be stable**, and that phosphorus recovery will increase. Important driving forces are:

- perceived risks related to contaminants in sludge
- questions about the phosphorus availability to plants in sludges resulting from P-removal using iron or aluminium salts
- energy recovery, by digestion or optimised incineration
- difficulties to find sites accepting the installation of incinerators
- questions about the market for recovered phosphates

LCA and risk assessments

Fabian Kraus, KWB Berlin, summarised LCA studies comparing sewage sludge application to land to phosphorus recycling technologies.

The highest potential for LCA improvement regarding energy savings and greenhouse gas mitigation potential in sludge treatment is offered by **anaerobic digestion of sludge** (with combined heat and power). Co-incineration of sludge with other waste streams offers the best residual energy recovery but is not compatible with phosphorus recovery from ashes. However if salts as struvite are recovered via sludge treatment, this option could enable phosphorus recovery to some extend and energy recovery at the same time. Agricultural valorisation of sludge may offer better overall energy balance than mono-incineration in combination with phosphorus recovery from ashes, because of valorisation of nitrogen content as fertiliser and no chemicals consumed for recovery.

In terms of greenhouse gas emissions, sewage sludge spreading on land generates significant nitrogen oxide emissions, but **emissions from sludge mono-incineration are higher if N_2O stripping is not installed**.

No risk from organic contaminants to the environment, to soil organisms or to human health (TDI) was identified, in sewage sludge through agricultural application, including no risk to soil organisms from antibiotics. Levels of 17β-estradiol (oestrogen female hormone) may be problematic in some sludges (risk to groundwaters), but it is rapidly broken down.

The principal risks identified by LCA are heavy metals, in particular **copper and zinc**, for which legal sludge application rates in agriculture in many countries can result in soil accumulation to problematic levels. These metals should be carefully monitored, and sewage sludge application should be limited to avoid possible risk.

Dominique Patureau, INRA, France, summarised current scientific knowledge on pharmaceuticals in sewage sludge, and their fate in sludge processing and in soil, including data from 20 years of field tests near Paris (SOERE).

France generates 1.4 million tonnes of sewage sludge dry matter (c. 5 Mt wet weight) per year, and **60% of French sewage biosolids** are valorised in agriculture. Sludge production has increased significantly from 0.9 Mt in 2001 (increased proportion of sewage collected and treated, extension of tertiary treatment). However, sewage sludge is **only around 6% of the total input of organic materials to agriculture**, in particular 300 Mt/y manure (wet weight).

Sewage sludge contains a wide range of organic contaminants, including all types of pharmaceuticals, but many are below current levels of detection. Concentrations of some pharmaceuticals will increase with anaerobic digestion, because they are not broken down whereas the quantity of sludge material is reduced and also they become more analysis extractable, whereas some other compounds are reduced. Composting seems to reduce a number of pharmaceuticals. For both treatments, there is today a **lack of data**.

Fate of pharmaceuticals in soil is complex, including sorption to soil particles, biological metabolism and losses to water or air. Most compounds disappear within a short period after application, but some are persistent for several years. Again more data is needed.

Overall, risk assessments of pharmaceuticals in sludge valorisation in agriculture suggest a **low-medium risk of toxicity to soil organisms or in soil pore water, a low level of transfer to plants, and no significant accumulation** in soil or loss to surface or ground water.

Fabio Kaczala, Kalmar Municipality, Sweden, discussed the wider challenges posed by pharmaceuticals to the environment. **Pharmaceutical use is increasing rapidly**: the EU market for (human) prescription and non-prescription drugs increased from 48 billion € in 1990 to 214 billion € in 2007 (Bio IS, 2013).

Although the market for farm livestock pharmaceuticals in the EU is of much lower value (4.3 billion €), **around one third of EU antibiotics consumption is in livestock**, and manure can contain significant concentrations of veterinary pharmaceuticals (European Commission, 2010).

A priority action should be to **reduce human antibiotic use**: some countries' antibiotics consumption is two times higher than the European average.

Other areas where action is needed include improving collection of unused pharmaceuticals, the implementation of take-back programmes, design of more readily biodegradable molecules with higher absorption rates within the human body, adapting design and operation of wastewater treatment plants to improve pharmaceuticals breakdown, research into the analysis and chemistry of pharmaceutical molecule metabolites (breakdown products), monitoring and risk analysis including realistic hazard identification and exposure assessment.

The inclusion of some pharmaceuticals in the **EU Water Framework Directive "Watch List"** such as the anti-inflammatory Diclofenac and the contraceptive Ethinylestradiol will enable better data.

Microplastics

Sindre Langaas, NIVA, Norway, summarised knowledge on microplastics in sewage. Up to 99% of microplastics in sewage are trapped in sewage sludge, so avoiding discharge into surface waters. This results in 1 000 – 20 000 particles/kgDM in sludge or up to 500 000 particles if nano-plastics (< 5 000 µm) are also considered, although there is little data about nano-plastics.

In total, **sewage sludge inputs 63 000 – 430 000 t/y of microplastics to farmland**.

Anaerobic digestion seems to reduce microplastics levels in sewage sludge, but the mechanism for this is unclear.

The number of scientific publications on microplastics in sewage has increased rapidly over the last two years, but to date there is **nearly no data on impact on soils or soil organisms**. Transfer of microplastics from soils to plants is shown not to occur, transfer of nanoplastics is possible but has not been shown.

Participants questionned whether microplastics in sewage sludge are a significant input to farmland compared to other inputs from e.g. atmospheric deposition, car tyre wear and dust, use of plastics in farming.

Optimising sewage sludge incineration

Stefan Salzmann, Outotec, showed how energy efficiency of sewage sludge mono-incineration can be improved, with the example of Zurich Kanton, Switzerland. With the objective of enabling phosphorus recovery from the ash, conform to Switzerland's legislation requiring phosphorus recovery, the Kanton has modified its sewage sludge incineration routes, building one centralised sewage sludge mono-incinerator (sewage sludge is not mixed with other wastes) treating 100 000 t/y wet weight sludge, with Outotec technology and know-how..

The incinerator is in the city of Zurich, next to the river beach, **demonstrating that clean operation and public acceptability of incinerators are possible**.

Sludge is mixed to ensure homogeneity (around 30% of the sludge comes from the city sewage works and 70% is imported from other Kanton sewage works), dried to around 40% DM, then incinerated in a fluidised bed at >900°C. Ash is recovered in an electrostatic filter and **a phosphorus recovery process is being developed**.

The heat from the incinerator drives electricity generation (CHP), with electricity production roughly balancing the installation's consumption. Around 2/3 of the heat produced is used for drying the sludge before input to the incinerator and the remainder is used onsite in the sewage works.

Total cost of sewage sludge dewatering, transport and incineration is just below 100 CHF/tonne of sludge.

Stakeholder positions

Arne Haarr, Norsk Vann, Norway, for the water industry EUREAU, explained that **VKM (Norwegian Scientific Committee for Food Safety,** which carries out independent risk assessments for the Norwegian Food Safety Authority (Mattilsynet) and the Norwegian Environment Agency (Miljødirektoratet) carried out an **extensive risk assessment of sewage sludge use in agriculture** in 2009. This covered heavy metals, organic contaminants and pharmaceuticals, concluding that there is no risk to the food chain, nor to the ecosystem (plants, animals, soil organisms …). VKM is currently preparing a data call to update this report.

Concerning **microplastics**, more data is needed. However, widespread use of sewage sludge to date suggests no negative impacts. A 2018 study in Sweden shows that although 99% of microplastics are removed in sewage works, 60% end up in de-gritting sand and only 40% in sewage sludge. 35 years of test field application of sludge (+30% higher than standard loadings) shows no increase in soil microplastics after 35 years.

The water industry also emphasises that the Urban Waste Water Treatment Directive (art. 14) specifies that "*Sludge arising from waste water treatment shall be re-used whenever appropriate. Disposal routes shall minimize the adverse effects on the environment*" and that the Sewage Sludge Directive also states that it is "*justified to encourage its application in agriculture provided it is used correctly*".

Pénélope Vincent-Sweet, European Environmental Bureau (EEB, federation of European environmental NGOs) noted that **agricultural application of treated sewage biosolids ensures recycling of valuable nutrients and returns organic carbon to soil**, so contributing to the circular economy, whereas incineration is only more or less energy neutral. It should be borne in mind that there are many sources of pollution to agricultural land, and that **animal manures contain antibiotics, possibly more than human sewage**.

However, sewage sludge does contain a range of **contaminants** including metals, pharmaceuticals, problematic POP chemicals, nanomaterials, microplastics. Treatment is essential to remove pathogens and odour, and composting and anaerobic digestion are increasingly used to ensure this.

The **priority should be reduction of pollution at source**, including further actions to avoid release of industry discharge to municipal sewers, public education to not put household chemicals down the sink. Actions at source should also target reducing pharmaceutical consumption and separation of sewage in hospitals or similar where feasible. Preventive actions should also be engaged to reduce microplastics, for example eco-design of textiles or car tyres.

Tackling pollution at source is key to the Circular Economy, as is science and monitoring to address knowledge gaps.

Eugen Köhler, Deutscher Bauernverband (farmers' organisation) underlined the need to **move from a linear agri-food system to circularity,** but that nutrient recycling implies risks related to contaminants, which must be managed. Concerns include heavy metals, organic substances and plant diseases.

Around 25% of German sewage sludge today goes to agriculture, and a further 10% to landscaping. Despite continuing improvements in sewage sludge quality, agricultural recycling of sludge is threated by rejection by the sugar industry and other food industry purchasing policy, and by farmers positions.

The new German phosphorus recovery regulation will probably result in less sludge use in agriculture, but smaller sewage works (< 50 000 p.e.) will continue to be able to use sludge in agriculture on condition that quality is conform to the anticipated new German sewage sludge regulations.

Farmers need not only nutrients, but also organic carbon and liming materials. **Clear information on nutrient content and plant availability is necessary** to enable farmers to make the right choices.

DBV regrets that 2/3 of German sewage sludge is incinerated, because this today means than nutrients are lost. DBV therefore supports the new German phosphorus recovery regulation. Incineration conditions must ensure that PAH are not generated and incineration ash must be processed to produce fertiliser products with plant available nutrients. **DBV also supports strict rules for agricultural application of sewage biosolids, to limit contaminant risks**.

Frank de Ruijter, Wageningen University & Research and researcher for The Sustainability Consortium (TSC) explained that the Consortium has over one hundred company members including many of the world's leading food and beverage companies. TSC identifies sustainability hotspots for environmental and social sustainability for different product categories. **Phosphorus is one of TSC's sustainability Key Performance Indicators**, focusing mainly on use efficiency.

The Sustainability Consortium has no position on the question of sewage biosolids recycling to agriculture. However, many supermarket chains use the Global GAP *criteria* for food crop purchasing and these specify that "*No human sludge is used on the farm for the production of GLOBAL G.A.P. registered crops*".

Precautionary principle

Herman Walthaus, Netherlands Ministry for Infrastructure and Water Management, indicated that sewage sludge use in agriculture is not banned in The Netherlands, but all sludge is in fact incinerated. The Government has in place demanding specifications for agricultural use covering pathogens, organic matter content (must be >50%), heavy metals, application conditions. The Government also has concerns about other substances (microplastics, pharmaceuticals and their metabolites, antibiotic resistance), both regarding possible risks and regarding **prevention of accumulation in soils or groundwater**.

Jochen Mayer, Agroscope / Swiss Centre of Excellence for Agricultural Research (within the Swiss Federal Office for the Agriculture FOAG) indicates that Switzerland banned agricultural use of sewage sludge in 2003 stating at the time "*although this will mean breaking a nutrient cycle which is in itself useful. Prevention – a key principle of the law on health and the environment – requires, however, that any consequences for the environment which could be damaging or negative must be limited as early as possible, even there is no conclusive scientific evidence for such damage being caused*".

Switzerland has now passed **legislation making phosphorus recovery obligatory** (1/1/2016 VVEA) from sewage and animal by-products (meat and bone meals, including the equivalent of Cat.1 materials). The **Fertiliser Ordinance** (DüV or OEng 01/01/2019 defines a new category of **Recycled Mineral Fertilisers.** The **Chemical Risk Reduction Ordinance** (ChemRRV or ORRCim 01/01/2019 see ESPP eNews n°28) fixes contaminant levels for recycled materials calculated to avoid accumulation in soil (assuming standard Swiss fertiliser application rate of 34.3 kgP/ha/y) – ALARA principle - and to ensure that organic contaminant levels do not exceed limits fixed by the Soil Ordinance.

Quality assurance schemes

Herbert Brunet, SEDE (Veolia) and Horst Müller (Müller Umwelttechnik Austria), for **EFAR, the Biosolids Land Application and Food Crop Quality Assurance Scheme**, showed that a considerable number of studies, in different countries in Europe and the USA have concluded that agricultural application of sewage biosolids

- enables crop yields comparable to mineral fertilisers
- improves soil quality over the long term and does not deteriorate soil biology
- contaminants do not pose identified risks
- organic contaminant levels return to background levels within a year of sludge application
- plant uptake of organic contaminants is negligible

Risk assessments in the US (EPA), UK (Imperial College), Norway (see above), France (INERS-CNRS), Italy (Catania University) conclude **low risk to soil, ecosystems or health**.

Quality assurance schemes, such as EFAR, can both ensure optimal and safe application of sewage biosolids, and also communicate advantages to farmers and stakeholders, including resource savings and greenhouse emissions/carbon sequestration.

Simon Black, Anglian Water, for **UK Biosolids Assurance Scheme** BAS explained that **78% of the UK's 23 Mt/y sewage sludge (wet weight) is valorised on agricultural land** (and a further 5% on other land). This quantity is increasing, as sewage sludge production continues to increase. Agricultural use is considered the Best Practicable Environmental Option (BPEO) by the UK Government.

Nearly ¾ of UK sludge is today anaerobically digested (AD), producing enough energy (as biogas) for more than a quarter of a million homes. This could be potentially be multiplied by around 2 ½ if incentives were sufficient (replacing mesophilic AD and liming by advanced AD).

Sewage biosolids used on farmland in the UK are today worth 25 million UK£/y nutrient value. Sewage valorisation in agriculture also brings significant cost savings to the public (water costs / local taxes) compared to other disposal routes

The UK Biosolids Assurance Scheme (BAS) https://assuredbiosolids.co.uk is NSF Certified and UKAS accredited (UK National Accreditation Body). The Scheme covers sludge source material risk assessment, sludge treatment, transport, storage and agricultural application. A "multiple barrier approach" ensures safety, for example reduction of E. coli in sludge treatment, monitoring and maximum concentrations at application, and intervals before food crop harvest.

Quality of sewage sludges is improving. Concentrations of heavy metals, inc. zinc, copper and lead, have fallen by factors of 1/3 – 2/3 since the early 1980's.The UK water industry's commitment is to achieve 100% of sewage works certified and 96% was achieved by end 2018.

Matt Taylor, Grieve Strategic for Assured Biosolids Limited, presented the conclusions of a UK Water Industry Research **UKWIR "Biosolids to Market"** study (see article below) looking at the whole range of contaminants possibly present in treated sewage sludge (i.e. biosolids), including chemicals, pharmaceuticals and antimicrobial resistance, radionuclides, pathogens, microplastics and nanoparticles, pathogens, invasive plant species, asbestos and polymers used in sludge dewatering.

Overall, the report concludes that current management of sewage biosolids use in agriculture (with quality assurance scheme) **poses low risks and does not require modification,** that sewage is often not the most important source of contaminants to farmland, **but that there is a need for continued research and monitoring** along with more data on their behaviour in wastewater treatment, in soil and in the environment, and on possible risks. **Priority research needs are identified for microplastics, antibiotic resistance, and pharmaceuticals and personal care products (PPCPs)**, as well as a need for monitoring of emerging organic contaminants and emerging metals (tin, silver, antimony).

The importance of **full transparency** towards the public, farmers and the food industry, and regulators is emphasised.

Discussion

From the questions and discussion, it was clear that **different stakeholders, industries and countries have widely varying positions** regarding the agricultural recycling of sewage biosolids:

- on the one hand, there are concerns about the **proven presence of different contaminants**, and the "**precautionary principle**" suggests to not disseminate these
- **accumulation of contaminants** or leaching to groundwater should also be avoided, including heavy metals, organic contaminants and microplastics.
- however, there seems to be **no evidence that these contaminants pose significant risk to health or to the environment where sewage biosolids are appropriately managed**
- on the other hand, agricultural valorisation of sewage biosolids offers benefits: **recycling of phosphorus, nitrogen and other nutrients; return of carbon to soil**
- and agricultural recycling is **cost-effective for both taxpayers and farmers**.

Attention must be paid to levels of **zinc and copper**, and limiting spreading as a function of their levels if necessary, whereas this is not ensured by legal spreading limits in most countries.

Technical phosphorus recovery processes enable recycling of phosphorus without release of contaminants to the environment, so ensuring depollution and safety.

Some phosphorus recovery processes, such as struvite precipitation, are compatible with both thermal sludge valorisation or agronomic application of biosolids organic content. **Anaerobic digestion** of sewage biosolids is effective for energy recovery, as well as sanitising and stabilising sewage sludge.

Some participants considered that agricultural recycling of sewage biosolids implies risks and unknowns, and that technical processing offers safer, higher quality recycled nutrient products. Other participants underlined that a pragmatic approach should be based on risk-assessment and take into account the benefits of sewage sludge use in agriculture, in particular recycling of all nutrients not only phosphorus, return of organic carbon to soil, benefits for the farmer and the taxpayer .

Most participants however agreed that there is no one best solution: **different options for sewage biosolids management fit different local contexts**. Thermal valorisation responds to the needs of regions with low agricultural demand, for example densely urban areas and regions with significant supply of animal manures. In countries with high agricultural demand, farmland application of biosolids under strict quality control conditions can enable nutrient and organic carbon recycling. Agricultural recycling of biosolids can be an appropriate local phosphorus recycling solution for small sewage works.

In any case, **image and perception problems** pose an important challenge to the future of sewage recycling to farmland, including with consumers, supermarkets, the food industry.

Many of the contaminants which currently generate concerns in sewage sludge are **also found in animal manures and other organic secondary materials** (in particular pharmaceuticals and antibiotic resistance genes).

Further research and monitoring are strongly needed, including into improving organic contaminants removal in biosolids treatment, optimisation of energy recovery, and development and implementation of nutrient recovery processes. Research should also address improving the nutrient balance and crop nutrient efficiency of sewage sludge, to improve agronomic value and reduce risk of nutrient losses.

In all cases, the **priority should be reduction at source** and preventing that contaminants enter municipal sewage.

It was underlined that a strong point of ESPP is to bring together in dialogue a heterogeneous range of industries and stakeholders. **ESPP should not promote a particular route or technologies for sewage biosolids management and phosphorus recycling, but should promote the advantages of different approaches appropriate to different regional contexts**, subject in all cases to quality control, transparency and to effective nutrient recycling.

Meeting presentation slides are available at www.phosphorusplatform.eu/activities/conference/meeting-archive/1788-espp-meeting-sludge-2018

Assessment of biosolids on farmland

The UK water industry research association UKWIR has published a report which provides a comprehensive review of the range of substances that could be present in biosolids (i.e. treated sewage sludge), based on a literature assessment of over 400 published studies and reports. This was done to assess the effectiveness of current biosolids management practices and identify future research requirements.

The report considers the **full range of different contaminants and substances** coming from industrial and domestic sources that could be found in sewage sludge including organic chemicals, pharmaceuticals (and also antimicrobial resistance AMR), microplastics and fibres, nanoparticles, potentially toxic elements (PTEs = in particular heavy metals), chemicals used in wastewater treatment (e.g. polyacrylamide PAM polymers), invasive non-native species (INNS) and pathogens

400 references

The 200 page literature assessment (published as an annexe to the report) groups and **analyses a total of over 400 scientific studies and reports** according to these different types of contaminant and substance.

For each type of contaminant, **the level of priority for research is identified**, key data/knowledge needs are indicated, and current ongoing research is specified. Additionally, the effectiveness in addressing risks of existing biosolids management practices arising from the UK regulatory framework and biosolids quality standards schemes (e.g. the Safe Sludge Matrix 2001 and the Biosolids Assurance Scheme BAS) were assessed.

A shortlist of substances is identified where there is a **lack of evidence** such that any perceived risks to biosolids recycling practices could not be adequately assessed:

- **Industrial chemicals**: perfluorochemicals (PFCs, in particular PFOS and PFOA), halogenated flame retardants and other halogenated industrial chemicals (including chlorinated paraffins and naphthalenes and a list of brominated flame retardants), brominated dioxins/furans, benzothiazoles and dertivatives (BTHs)
- **Pharmaceuticals** and personal care products: triclosan, triclocarban, estradiol
- **Nanoparticles** of silver, titanium, zinc
- **Antimicrobial resistance** (AMR) and possible virus exposure
- Certain **emerging potentially toxic elements**

Research needs identified

The report concludes that **research should be engaged concerning microplastics, nanoparticles, antimicrobial resistance, pharmaceuticals/personal care products (PPCPs)** and on **possible interactions** between different contaminants. Furthermore, a watching brief should be engaged for other emerging contaminants.

Overall, the report concludes for all the substances that could be present in biosolids that no change to current biosolids recycling practices is necessary today (nearly all of the UK's sewage sludge currently goes to farmland). Biosolids are indicated to be a valuable source of phosphorus and nitrogen to agriculture, as well as micronutrients and organic carbon to soil. The report considers that **recycling of biosolids to land should continue to be recognised by the UK as the best practicable environmental option**.

Report 18/SL/01/9 (2018) ISBN 1 84057 864 5 "Biosolids to market – a strategic proposal to explore the threats to biosolids to land – now and in the future" UK£100 https://ukwir.org/biosolids-to-market-a-strategic-proposal-to-explore-the-threats-to-biosolids-to-land-now-and-in-the-future-sl-850/sl-1072-sl-1060-combined-0 UKWIR reports purchase online: https://ukwir.org/eng/water-research-reports

P-removal technology trials results published

UK Water Industry Research, UKWIR, has published reports of the "CIP2" (Chemical Investigations Programme 2) assessment of phosphorus removal technologies in 31 different trial configurations.

Trials by ten UK water companies, including full scale for several months at sewage works across England and Wales, aimed to assess the feasibility of reliably achieving low phosphorus discharge consents (see SCOPE Newsletter n°125, eNews n°26 and n°7).

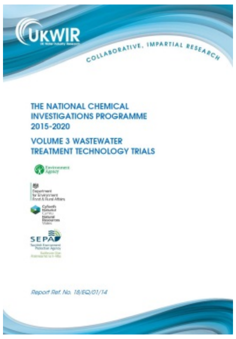
The CIP2 programme has a total budget of nearly UK£200 million, of which **UK£50 million for the phosphorus removal trials**.

Technologies tested in real operating conditions

The following technologies were tested in sewage works with average flow rates (discharge flow = to the P-removal technology) of up to 750 l/s:

- optimisation of iron or aluminium salt dosing in various technology configurations
- Blue PRO or similar modified COUF (continuously operated upflow filter)
- Mecana (rotating disc filter)
- Fuzzy Filter
- Co-Mag/Bio-Mag
- Adsorption Media
- FilterClear
- Dynasand Oxy
- TNTF (tertiary nitrifying trickling filter)
- reedbeds with steel slag media
- algae bioreactor and biological nutrient removal (BNR).

The water companies engaged in the CIP2 phosphorus removal trials are: Anglian Water, Dwr Cymru (Welsh Water), Northumbrian Water, Severn Trent Water, Southern Water, South West Water, Thames Water, United Utilities, Wessex Water and Yorkshire Water.



The **published report provides average results of all of the trials, as well as indicative CAPEX and OPEX costs** (related to size of installation trialled = flow) and estimated carbon balance (construction and operating carbon emissions).

More detailed information for each technology trial can be obtained directly from the water companies concerned.

Iron dosing

Most of the technologies tested involved dosing of metal salts (iron: ferric sulphate, ferric chloride or ferrous chloride; or aluminium: polyaluminium chloride). Two or three point dosing of iron in the sewage works enables optimal adjustment and mixing.

However, optimisation of iron or aluminium dosing did not achieve 0.2 mgP_{-total}/l without **use of tertiary filtration systems** to remove iron phosphate containing flocs down to very low levels (removal of small flocs).

A question is the increased level of **nickel** identified in discharges, probably coming from nickel contamination in the iron salts. Other challenges include possible increases in **iron** levels in discharge, and possible negative impacts of metals on the nitrification process (ammonia removal).

Three out of four Mecana trials achieved <0.2 mgP_{-total}/l (the fourth achieved <0.25 mgP_{-total}/l). The Mecana system uses hollow 2-metre rotating discs, covered with filter fabric (pile cloth media). The secondary treated wastewater flows through the filter into the interior of the disc, then out through the axis. Backwash is by a mechanical water suction system (like an aquatic vacuum cleaner on the carpet) and is continuous (some disks cleaned whilst others function). See ESPP eNews n°26. Two out of three trials with **BluePRO** also achieved <0.25 mgP_{-total}/l.

The **processes which achieved <0.2 mgP_{-total}/l in at least some cases** were Mecana, Filterclear, CoMag, biological nutrient removal (BNR), continuously operated upflow filter (COUF) with ferric dosing, COUF with hydrous ferric oxide (HFO) sand, and a steel slag reedbed (with two day retention time).

Limitations of reliable low levels of P removal

The trials showed the **difficulties of achieving such low phosphorus discharge levels reliably, in real operating conditions** with varying inflow and sewage works conditions. In particular, consistent achievement of low levels requires operator training, engagement with the technology supplier to optimise the process to local conditions, and increased operator involvement for monitoring and maintenance. At such low levels, temporary drop-offs in P-removal performance can have a severe impact on overall phosphorus discharge averages.

The trials also confirmed that **iron dosing combined with tertiary filtration systems**, as well as achieving low phosphorus discharge, also reduces both organic carbon (4 – 90% reductions in dissolved and total organic carbon, BOD and COD – biological and chemical oxygen demand), and also some priority chemicals. The Mecana filters combined with chemical dosing, for example, reduced HBCDD and BDE 47 / 99 brominated flame retardants, fluoranthene and benzo(a)pyrene by 60 – 80%, and significantly reduced some pharmaceuticals but others not at all.

Priority substances

The other objective of CIP2 was **sampling of 74 different chemicals at 600 sewage works across the UK and assessment of technologies to reduce organic contaminant** levels in discharge. Chemicals analysed include metals, pharmaceuticals and steroids, flame retardants, consumer chemicals and combustion-generated substances. Initial conclusions are that the principal source of most chemicals is domestic, not trade or industrial connections. Also, chemicals are often already significantly present in rivers upstream of sewage works discharge. This work has not yet concluded.

CIP2 has identified around eight substances of interest : **perfluorinated chemicals (PFOS, PFOA) and fluoranthene, PBDEs and HBCDD (brominated flame retardants), cypermethrin, TBT, dissolved zinc and cadmium**, which are often found in the environment at concentrations higher than Environmental Quality Standards (EQS).

Of twenty **pharmaceuticals** analysed, a number are also often found at concentrations higher than proposed Environmental Quality Standards including some analgesics, antibiotics and steroid hormones (natural and synthetic).

CIP2 assessed the ability of **15 different processes to remove the 74 analysed chemicals**, in 31 different trial configurations. Results suggest that fully nitrifying processes and granular sludge processes offer potential for removal of priority chemicals from sewage works discharges.

At a number of sites, the trialled phosphorus removal technologies were also assessed for removal of the priority chemicals, including of pharmaceuticals, see above.

Report 18/EQ/01/14 (2018) ISBN 1 84057 853 X "The National Chemical Investigations Programme 2015-2020. Volume 3 Wastewater Treatment Technology Trials" UKE100 https://ukwir.org/the-national-chemical-investigations-programme-2015-2020-volume-3-wastewater-treatment-technology-trials *UKWIR reports – purchase online:* https://ukwir.org/eng/water-research-reports

The UKWIR CIP2 results will be presented at the **ESPP workshop: Waste water phosphorus removal tomorrow: ambitions and reality**, **9th October 2019, Liège**, in partnership with / supported by: IWA, Eureau, CIWEM, Université de Liège and ECSM'19

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IFS Conference: leading science in sustainable farming

Some 140 plant nutrient and farming experts from 22 countries worldwide met at the 26th annual agronomy conference of the International Fertiliser Society (IFS), Cambridge UK, 6-7 December 2018, including agronomy scientists, farm advisors, fertiliser industry and distributer experts and policy makers. Eleven speakers and a total of nearly 40 posters presented science updates in key areas for agricultural sustainability: soil health and soil erosion, crop nutrient availability and uptake, soil carbon sequestration and impacts of soil organic matter on productivity.

The conference was opened by **Thibaut Theys, Prayon**, who underlined the interest of the IFS Agronomy conference for his company and the fertiliser industry, in providing information on important developments in nutrient management in agriculture in Europe and worldwide, with overview presentations of current topics.

Later in the conference, he also presented the prizes to the winners of the **Brian Chambers Award for Early Career Researchers in Crop Nutrition** and for the posters voted best at the Conference by participants:

- The judges of the **Brian Chambers award** gave the first prize of £1,000 to **Klara Gunnarsen, of the University of Copenhagen, Denmark**. Her research is looking at the use of Greenland glacial rock flour (GRF) to rejuvenate nutrient poor soil. Of the two 2018 Runners up, **Linxi Jiang, of the University of Nottingham, UK**, is studying how to minimise the antagonist blocking effect of sulphur fertilisers on the uptake of selenium by plants. The second runner up, **Bradley Cooper, also of the University of Copenhagen**, is studying the potential for the bio-acidification of manure by adding sugar to stimulate bacterial production of organic acids through anaerobic fermentation (*photo of prize winners above*).
- Separately, the **poster voted by conference delegates** to be 'the most noteworthy' was by **Alison Carswell, of Rothamsted Research**. This reported on an assessment of the environmental and economic performance of three N-fertilisers, urea (U), ammonium-nitrate (AN), and urea with urease inhibitor (IU), at two grassland sites in the UK

Posters presented at the Conference also covered: precision fertiliser application and spreading technology, use of natural materials as fertilisers (polyhalite, glacial rock), use of straw length to estimate yield gaps and fertiliser needs, soil mycorrhiza, bioactivators to improve soil nutrient performance, grassland and crop rotation systems, nutrient use efficiency, sulphur amendments, potassium fertiliser response, zinc micronutrients, cover crops, bio-acidification of livestock slurry and organic fertilisers.

IFS is a scientific society of individuals, with some 490 members across the world, in industry, science and other organisations. The Society's objectives are to develop and communicate **leading science on nutrient agronomy and developments in fertilisers technology**, in particular through its two annual conferences on agronomy and on industry processes, and through the published papers from these conferences.

The next IFS Conferences are: Technical 4-5 June 2019, Brussels, and Agronomy 12-13 December, Cambridge, UK https://fertiliser-society.org/event/2019-ifs-technical-conference.aspx

Potential for increasing production by fertilisation

Achim Dobermann, Rothamsted Research, UK, opened the conference underlining the potential for significant improvement in nutrient management and correspondingly in crop productivity in Europe.

Wheat yields in the UK have only slightly increased since 1985 and nitrogen application rates have not increased, at below 200 kgN/ha, whereas agronomic science suggests that **increasing N input to 240 kgN/ha could increase wheat yield by +60%.**

This would require careful management of risks of increasing nitrogen pollution, but today **less than 60% of UK farmers have nutrient management plans in place** (<10% in the USA), and only 55% say that they are taking actions to reduce greenhouse emissions.

The proposal for 'FaST' (Farm Sustainability Tool for Nutrients), under the future CAP (EU Common Agricultural Policy), making nutrient management plans obligatory, would thus be of considerable value.

Major opportunities for progress in nitrogen use do exist. The US National Academy of Sciences Consensus Report "Science Breakthroughs to Advance Food and Agricultural Research by 2030" (2018) identifies as opportunities:

- system nutrient optimisation,
- rapid soil and plant nutrient analysis to support precision fertilisation,
- use of big data,
- genetic crop developments to increase nitrogen uptake and enable better use efficiency at high nitrogen fertilisation levels,
- better understanding of soil microbiome and significance of micronutrients.
- a challenge however is the slow uptake of innovation by farmers.

David Wall, Teagasc, Ireland, presented the nutrient balance of Ireland's grass based dairy farming systems: currently approximately 1.4 million dairy cows (in total seven million cattle nationally) with dairy herds rapidly expanding since 2015 with an objective of +50% milk production by 2020 (Ireland's milk production per cow is around 60% that of The Netherlands with much less concentrate feed input). Phosphorus is the most expensive nutrient, in terms of litres of milk per kg applied. In this grass based system **over half of Ireland's soils are low in phosphorus**, half is low in potassium, and two-thirds has pH <6.3. Currently phosphorus fertiliser application is less than half of optimal needs for the last decade, and potassium less than one third. The situation is however variable: generally phosphorus is being 'mined' from soils on land producing grass silage (balance – 20 kg P/ha/year) but positive on grazing land where much P is recycled by the grazing animal.

Key challenges identified by TEAGASC include:

- increasing **early spring grass** productivity (early grazing of grassland represents a major economic, animal health and labour saving benefits for the farmer compared to use of silage and concentrate feeding indoors),
- improving **nutrient use efficiency** (NUE currently around 46% for nitrogen across the whole farm),
- increasing **appropriate phosphorus application** to match grass and soil build-up requirements,
- **liming to increase soil pH** (rendering soil and applied fertiliser nutrients better available),
- **avoiding structural damage on poorly drained soils** as pasture based dairy production levels increase (intensive farming shown to have greater structural, chemical and biological impact on heavier textured soils with impeded drainage characteristics compared to lighter textured soils with free-drainage),
- encouraging healthy soils (for example, **earthworms** have been shown to release 50 – 190 N kg/ha/year)

Davey Jones, Bangor University, Wales, also underlined that nutrient use efficiency (NUE) for nitrogen is today not high: around half of nitrogen applied is lost to the atmosphere or to surface or ground waters. Key to improving NUE is implementation of farm nutrient balances and testing of soil and crops to assess nutrient needs.

Real-time monitoring of crop nitrogen status is today operational, based on sensors of leaf colour and enabling instant adjustment of fertiliser application rate, for example on-tractor sensor systems, drone-based Normalized Difference Vegetation Index (NDVI) or hand-held monitors. However yellowing of leaves are not always indicative of insufficient nitrogen, and discolouration means that it is already "too late": ideally nutrient needs should be identified before the plant begins to show symptoms.

Crop sensor systems therefore need to be completed with in-field soil monitoring. This can be achieved by **ion-sensitive electrodes, enabling continuous, non-invasive monitoring at different points in fields**, close to crop roots. Such sensors are now under development and field trial at Bangor University, with a 'prototype' cost of around UK£20 per sensor. Currently sensors are available for nitrate + ammonium, with the project to develop also a phosphate sensor. Challenges include ensuring that the wires from the sensors to recording equipment are robust to storms, rodents, etc. and developing economic systems for either storing the data at a transportable monitoring station in the field, or transmitting by mobile devices.

Philip White, James Hutton Institute, Scotland, provided an overview of the **biological importance of calcium in plants**, including its roles in cell wall structure, signalling (both within cells and between plant organs), and ionic charge balance (including its interactions with nitrate or ammonium uptake and metabolism). Calcium deficiency results in various physiological disorders, reducing the quality of edible crops and their shelf life, and impacts plant growth and development, especially in drought, and crop production.

Liming is decreasing in the UK, and consequently the extent of acidic soils is increasing. This reduces fertiliser nutrient efficiency because plant availability of phosphorus, nitrogen, potassium, magnesium and sulphur are all lower in acidic soils. Liming is also important because it improves the resilience of soil structure, provides calcium and micronutrients (present in liming materials) to crops, and because it influences the soil microbe community involved in nitrogen cycling.

Jens Blomquist, Swedish University of Agricultural Sciences, also discussed the interest of liming. In clay soils, calcium can stabilise structure by reducing distances between negatively charged clay particles (Ca2+), and also by pozzolanic reactions producing cement-like materials if the liming product also contains CaO or $Ca(OH)_2$. This also reduces run-off of clay particles, which can transport particulate phosphorus. For this reason, **the Swedish government subsidises structure liming, as a way to reduce phosphorus losses to surface waters**. In some crops, calcium application has also been shown to reduce risk of fungal infection.

However, structure liming has shown inconsistent crop responses depending on e.g. type of crop, initial pH, clay mineralogy, micro nutrient content in soils, so that financial compensation to farmers may be appropriate.

Soil quality and soil erosion

Gerard Govers, Catholic University of Leuven, Belgium, underlined the need for better data and understanding of soil erosion. Recent models (PESERA – JRC) suggest **average soil erosion of 3.6 t/ha/year for arable land in the EU** (around 1 t/ha/y for all land surface), somewhat lower than previous estimates, but still a real problem. Much of the eroded soil is in fact retained at the lower ends of fields. Soil erosion is quantitatively lower in Mediterranean regions, probably because soils are stony, but this may nonetheless be locally important: UNEP estimates **productivity losses of 3-4% in 100 years due to soil erosion** for wheat in Mediterranean EU countries.

Productivity is 40% dependent on soil depth, which also impacts water retention (drought resilience), but soil erosion only impacts average soil depth very slowly.

Nutrient losses linked to soil erosion are significant, estimated at 0.5-0.7 ktN/y and 0.3-0.5 ktP/y for the EU, that is over a third of total nutrient application in fertilisers. Soil erosion poses real challenges of pollution of rivers with sediments and nutrients.

Reducing soil erosion can be correlated to **storage of organic carbon in soil**. Dr. Govers' estimates of carbon sequestration by management practices such as conservation tillage or permanent grassland are both around <0.3 tC/y (in temperature climates). Conservation tillage can be economically neutral in temperate climates, but generally has a significant cost in tropical climates.

Storage of carbon implies also storage of nutrients, around 0.14 tN/tC and 0.02 tP/tC stored. These 'sequestered' nutrients can represent a significant **cost to farmers**. Carbon sequestration and soil erosion prevention actions will thus only be engaged by farmers if sufficient financial compensation is ensured, or if they are rendered obligatory.

Anne Bhogal, ADAS, UK, summarised assessments of the structural quality of UK soils, based on visual soil assessment methodologies. Soil structure assessment should consider both visible physical form (arrangement of particles and aggregates) and the stability of this form (resilience to degradation). Overall **up to 30% of UK agricultural soils are severely structurally degraded, and 40-60% are in only moderate condition**. Late harvested and root crop production are particularly impacted, whereas grassland shows less deterioration.

The principle problem is **compaction, resulting from traffic of agricultural machinery**. Poor soil structure can lead to yield loss (often -20% or more), poor drainage, increased fuel consumption by machinery and reduced soil aeration (increased greenhouse gas emissions). "No-traffic" management has been shown to lead to 10 – 35% yield increases. Other positive actions can include addition of organic matter to improve the resilience of soil to degradation, use of low ground pressure tyres to avoid/minimise compaction. Where compaction occurs, subsoiling/deep cultivation is often necessary (but only in appropriate conditions).

Paul Hallett, Aberdeen University, Scotland, explained the **links between soil structure and nutrient use efficiency (NUE).** Poor soil structure means less pore space and lower aeration, leading to loss of nitrogen to air (as greenhouse gas N_2O), increased nitrogen leaching risk and less nitrogen availability for crops.

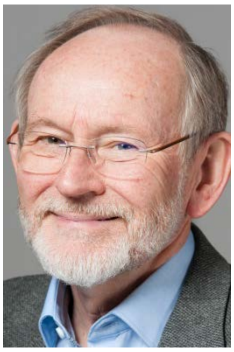
Over 100 years of field data from **Bad Lauchstädt, Germany**, show that a combination of organic application (compost) and NPK fertiliser to arable fields improves soil structure. Creation of soil pores by roots is an important mechanism, with fertilisers improving root growth. However, impacts of roots on soil are variable between crops and even for the same crop, traits of plant roots can be different. Traits like root hairs may help re-build compacted soil. Impacts also depend on fertiliser use: in a low phosphorus situation, roots have more hairs and release exudates and mucilages to access phosphorus, and these reduce soil surface tension, modifying soil structure and water movements. Root architecture is also highly affected by soil management, such as ploughing depth and hard-pans.

Crops can play a significant role in improving and maintaining soil structure, and **better knowledge is needed** on how nutrients can stimulate this but also how to avoid nutrient loss to deeper soils. There is great capacity to use root architecture and chemistry to influence soil structure. How to optimise this by may be by selecting crop breeds to target root systems and optimising agricultural management methods.

Elizabeth Stockdale, NIAB , UK, discussed development of a "soil health toolkit" for the use of farmers and advisers in the field in the UK. This requires not only the selection of indicator measures but also definition of standardised methodology and an appropriate reference system, together with the necessary guidance and tools to **support adoption of appropriate farm practices to improve soil health.** This is being tested for use in research trials and on-farm over the next 3 years.

The indicators in the initial scorecard include both field observations and laboratory measures: soil pH, nutrients and minerals, organic matter (Loss on Ignition test), structure (penetration, visual criteria), earthworms, biological activity (using a lab-based Solvita test kit for CO_2 respiration). A key challenge is defining where to take soil samples, because soil can vary widely within fields. The data are then benchmarked with regard to soil texture, climate region and cropping systems. The **engagement of farmers** is of critical importance in the development and evaluation of the toolkit.

Organic inputs and soil carbon sequestration



David Powlson, Rothamsted Research, UK, discussed the **Paris Climate Change objective of "4 per mille",** that is sequestration in soil of atmospheric carbon (C) annually equivalent to 0.4% of the initial organic C stock (given that around 50% of soil organic matter is carbon). He noted that the Paris objective was initially proposed using the unrealistic assumption of 2m depth of soil and for the entire global land surface, ignoring the fact that much land is not under human management.

A significant question is whether carbon sequestered to soil is really additional C coming from the atmosphere; for manure, it is mainly a relocation of C from one site to another. With some management practices the C benefits are already occurring: e.g. half of the UK's straw is already returned to soil with the rest mostly used for animal bedding and later returned to soil as manure. On the other hand, increasing **soil organic carbon (SOC) content is almost invariably beneficial for soil properties – even if it often does not lead to increased crop yields**. SOC improves soil structure and water retention (drought resilience), supports earthworms and soil biota, makes phosphorus more plant available, in particular by facilitating root penetration, and makes nitrogen available. However, SOC also contains nutrients, so soil carbon sequestration will also sequester phosphorus and nitrogen.

Various trials show that **some agricultural practices do effectively increase SOC by transferring additional C from atmosphere to soil.** These include conversion to woodland and conversion from continuous arable to crop rotation but only if long-term pasture (8+ years) is included in the rotation.

But these practices have implications for food security. Reduced tillage and increased use of cover crops are practices that frequently benefit soil quality and concurrently mitigate climate change to some extent.

However, the practical limitations of SOC sequestration must be recognised, to avoid loss of credibility with the "4 per mille" message, and it should be underlined that **more significant climate emission gains are possible by improving nitrogen fertiliser management**. For example, in a system receiving 200 kgN/ha, a 50% cut in losses of nitrous oxide to the atmosphere would have a climate benefit similar to "4 per mille" SOC sequestration.

Renske Hijbeek, Wageningen University, The Netherlands, presented data from a number of published studies suggesting significant **correlation between soil organic matter (SOM) and grain yields** (e.g. 0.4% increase in SOC corresponding to +1.3% grain yield). However, these are correlations on observed data, and do not prove cause – effect as the inverse relation (higher yields increase SOM) can also be hypothesized and there might be confounding factors of such as climates or soil types which increase both SOM and yields. More importantly however, these results do not account for underlying mechanisms (such as nutrient supply) and can therefore not be extrapolated to other regions or farming systems.

Based on 14 meta-analyses, worldwide, 7/7 studies where nutrients (NPK) are not factored out, show a positive mean crop yield increase with SOM, whereas **9/10 studies where nutrient effects are taken into account show either no correlation or negative effect of soil organic matter on mean crop yield**. Results however differ between crop types, soil types and climates.

In practice local conditions, soil type and specific crop needs are critical. For example, long-term studies at Rothamsted UK indicate that **manure nitrogen is more effective for spring barley** (short growing season) than mineral fertiliser, but that there is no performance difference for winter barley. Also, biochar organic matter has shown to improve yields in tropical conditions, but not in temperate.

IFS 26th Annual Conference, Robinson College, Cambridge University, UK 6-7 December 2018.

International Fertiliser Society conference proceedings, future events, library of previous conference papers: *https://fertiliser-society.org*

Calcium phosphate food additives and health

Pooled results of four human volunteer tests plus a literature assessment suggest that daily diet addition of calcium phosphate does not increase blood (serum) phosphorus levels and may positively modulate blood lipid and gut parameters.

Trautvetter et al. published in 2016 results of 8 week human volunteer cross-over control tests dosing calcium carbonate (0, +0,5g or +1 g Ca/d on top of normal diet) and monosodium phosphate (+1gP/day), **showing that this food additive phosphorus intake did not modify blood serum phosphorus (fasting levels), nor blood hormone levels** (FGF23, parathyroid hormone PTH, other than transiently). Phosphorus levels increased in urine showing **additional phosphorus intake was excreted, ensuring metabolic balance**. This study is summarised in ESPP SCOPE Newsletter n°119.

This new 2018 publication pools the results of four other Jena University **human volunteer studies looking at effects of calcium phosphate additive intake** (as hydroxyapatite) and involving 31, 31, 60 and 10 volunteers. It also includes a literature assessment of human studies of calcium phosphate diet supplementation, with 940 literature papers identified of which 22 were found to contain relevant data.

The Jena studies data shows that (fasting) **blood serum phosphorus and calcium levels were not significantly modified by calcium phosphate diet supplementation**. The literature assessment also shows mostly also no impact on fasting serum phosphate levels of phosphorus supplementation alone (without calcium, e.g. sodium phosphate) - 8 studies: no impact, 1 = increase, 1 = decrease).

Metabolic nutrient balance

The Jena studies suggest that a significant part of the calcium phosphate supplement is **not in fact being taken into the body,** because both calcium and phosphorus increase significantly in faeces (probably insoluble amorphous calcium phosphates ACP), whereas calcium increases significantly in urine (but not phosphorus).

The literature shows that with phosphate-only supplementation (no calcium, e.g. sodium phosphates), phosphorus excretion is significantly increased in urine, showing that in this case the phosphorus is **taken into the body, then excreted by kidneys** to maintain metabolic balance.

Blood lipids and intestinal health

The Jena experiments show, with calcium phosphate supplement intake, a **significant reduction in low density lipoprotein cholesterol (LDL, considered to be linked to cardiovascular disease CVD)** whereas high density HDL cholesterol and triacylglycerides were unchanged. Also, excretion of total and secondary bile acids in faeces were increased (this may reduce possible carcinogens and may also contribute to cholesterol reductions) whereas faeces excretion of neutral sterols was not modified.

The only two literature studies confirming reductions in blood lipids following calcium phosphate intakes, and one confirming decreased LDL-cholesterol, were reports by the Jena University group of the same studies pooled here.

One of the previous Jena studies, and one other literature study (Dahl et al. 2016) reported **improved intestinal health** (increased lactobacilli and probiotic strains in faeces).

Overall the studies reported and literature assessed show the **limited available information**, underline the importance of distinguishing between food additives or supplements bringing only phosphorus (e.g. sodium phosphates) versus calcium phosphates and the **importance of maintaining a diet phosphorus – calcium balance**, and suggest the **absence of negative health impacts and some possible positive impacts (reduced blood lipids) from calcium phosphate diet intakes**.

Both this 2018 study and the 2016 study indicated above were registered with medical authorisation authorities and were funded by PAPA, the European Phosphoric Acid and Phosphate Producers Association

"Calcium and Phosphate Metabolism, Blood Lipids and Intestinal Sterols in Human Intervention Studies Using Different Sources of Phosphate as Supplements—Pooled Results and Literature Search", U. Trautvetter et al. Nutrients 2018, 10, 936 https://doi.org/10.3390/nu10070936

See also "Trautvetter 2018: High phosphorus intake and gut-related parameters – results of a randomized placebo-controlled human intervention study, U. Trautvetter , A. Camarinha-Silva, G. Jahreis, S. Lorkowski M. Glei, Nutrition Journal (2018) 17:23 https://doi.org/10.1186/s12937-018-0331-4

and also: "Consequences of a high phosphorus intake on mineral metabolism and bone remodeling in dependence of calcium intake in healthy subjects – a randomized placebo-controlled human intervention study", U. Trautvetter et al., Nutrition Journal 15:7, 2016 http://dx.doi.org/10.1186/s12937-016-0125-5 *summarised in SCOPE Newsletter* n°119

Phosphorus recycling technology tour

A tour of the Remondis TetraPhos® pilot in Elverlingsen, the EuPhoRe pilot Dinslaken and the CNP-Technology AirPrex® struvite installation at Mönchengladbach, all situated near Düsseldorf, was organised 20-21st March by ESPP and the German Phosphorus Platform (DPP) for members of the Sweden government inquiry into phosphorus (P) recycling, and representatives of Danish and Finnish ministries.

A government mandated official 'Inquiry' in Sweden is currently working on regulatory proposals to require phosphorus recovery from sewage and ban use of sewage sludge on farmland, see ESPP eNews n°24. To input to this process, **ESPP** and the **German Phosphorus Platform (DPP)** organised a **study tour of phosphorus recovery sites and a meeting to discuss regulation**. Tour participants were representatives of the "Swedish national inquiry on non-toxic and circular reuse of phosphorus from sewage sludge", of the Finnish Ministries for Environment and for Agriculture, of the Danish Ministry for Environment and Food and of a Danish regional water utility.

The sites visited enabled to understand some of the technologies today available for phosphorus recovery from sewage:

- **Remondis TetraPhos®**: pilot in Elverlingsen. Based on the experience of this pilot, previously tested at Köhlbrandhöft sewage treatment plant Hamburg, a full-scale TetraPhos® plant is now under construction at Hamburg. The technology enables recovery of phosphoric acid from sewage sludge incineration ash. Similar concepts are being developed by EasyMining ESPP eNews n°11 and Zurich Phos4Life ESPP eNews n°12
- **EuPhoRe**: in addition to the pilot visited in Dinslaken, full scale plants based on a similar design but so far without magnesium chloride ($MgCl_2$) addition, are operational in Oftringen and Uvrier in Switzerland. The addition of $MgCl_2$ is intended to generate a sewage sludge an ash in which phosphorus is plant available and which has reduced heavy metals
- **CNP-Technology AirPrex® struvite recovery** from sewage sludge digestate in the sewage works, Mönchengladbach. Around one hundred struvite recovery plants are today operational worldwide, with technology suppliers including Ostara, Suez and Veolia

Other phosphorus recovery technology routes were not visited for reasons of distance, for example: use of sludge incineration ash in existing mineral fertiliser production (e.g. ICL), Ecophos, Budenheim Extraphos.

Dinslaken sewage works

The study tour was welcomed by **Daniel Klein** of **Emschergenossenschaft and Lippeverband (EGLV)**, the regional water companies (public water boards) of the Lippe and Emscher rivers, in the Ruhr region, which operate 59 waste water treatment works serving a total of 7 million p.e. Currently **Dinslaken sewage works** takes as inflow the whole flow of the Emscher river, which in fact functions as an open sewer for approx. 55 km of its length. The outlet flows towards the Rhine river. Emschergenossenschaft is leading one of **Germany's biggest infrastructure** projects, replacing this open sewer system with a sewerage pipe, separating rainwater, and restoring the Emscher river. Another major challenge is that 35% of the Emscher catchment is today below the water level of the Rhine river, because of mining subsidence, so requiring permanent drainage pumping.

Most of EGLV's sewage sludge is treated by anaerobic digestion, pumped to centralised dewatering installations, then goes to **incineration in two sewage sludge incinerators at Bottrop and at Lünen**, currently also with some industrial sludge. Much of the region's sludge is impacted by industrial contamination and is unsuitable for use in agriculture, but quality is improving.

At Dinslaken, EGLV operate a **research and testing installation**. This is a two-line, full-scale 1 000 p.e. sewage works, fed by municipal sewage, currently investigating removal of micropollutants or new processes such as Annamox.

EuPhoRe: plant available ash

EuPhoRe is sewage sludge thermal treatment (at over 1000°C, similar to mono-incineration) which uses a **specific kiln configuration (pyrolysis zone + incineration zone), secondary heat (e.g. from another incinerator). Addition of magnesium chloride** aims to generate a sludge ash in which the phosphorus is plant available and which has reduced heavy metal content.

The Dinslaken EuRhoRe pilot, presented by **Siegfried Klose** and **Frank Zepke**, has a capacity of 100 kg dewatered sewage sludge per hour. Full scale installations based on a similar plant design and operating at **Oftringen** and **Uvrier** in Switzerland have capacities of 30 000 and 15 000 t/y. Testing of $MgCl_2$ addition is planned at the Oftringen plant (including corrosion assessment). Three further installations of 100 000 and 2 x 135 000 t/y dewatered sludge/year are now under planning in Germany (start of operation planned for 2020).

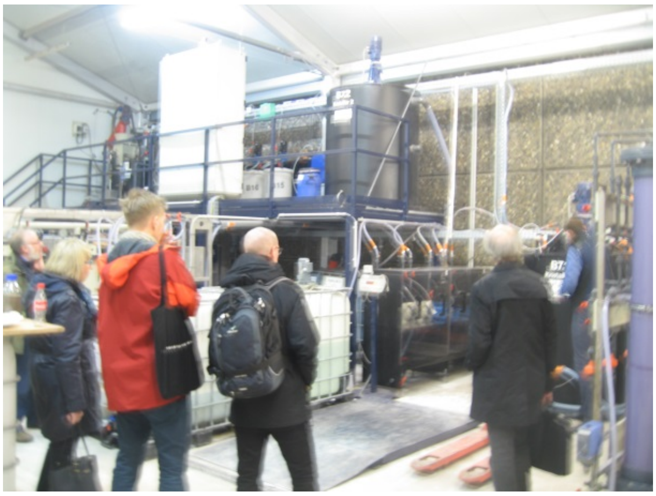
The EuPhoRe installation is a sewage sludge incinerator using a rotary kiln (a technology widely used for hazardous or municipal solid waste incineration) rather than a fluidized bed as generally used for sewage sludge mono-incineration (mono-incineration = incineration of sewage sludge alone, not mixed with municipal solid waste, industrial or other waste).

The EuPhoRe process can use the flue gas from a municipal waste incinerator **municipal waste incinerator** (e.g. this is the case in Oftringen). The flue gas has high temperature and lower oxygen content than air (e.g. 900°C, 5-8% vol. oxygen) and serves to dry the sewage sludge and to provide reductive conditions in the EuPhoRe process. The flue gas is fed into the EuPhoRe kiln in counterflow (flue gas fed into rotary kiln output end) so that the sewage sludge moves progressively through three zones in the rotary kiln: drying, pyrolysis, oxidation, reaching finally over 1000°C. The EuPhoRe process ensures near complete oxidation of carbon in sewage sludge (95% ignition loss, see http://sfcu.at/wp-content/uploads/2018/11/EuPhoRe-Process1.pdf).

Magnesium chloride (32% solution) is input to the kiln with the sewage sludge. This causes heavy metals to volatilise as chlorides, and these are removed by adsorbents in kiln offgas treatment. The magnesium chloride also contributes to the phosphorus availability in the final ash.

The EuPhoRe incinerator with magnesium chloride dosing enables (see link above) >95% reduction in cadmium, lead and mercury, and 20-85% reduction in copper, chrome, nickel and zinc. **Results meet the German fertilisers regulation specifications** (DüMV) but, to date, **do not meet the limits specified by the new Swiss ordinance on mineral fertilisers from recycling** (DüV / OEng) for some heavy metals but **work is underway to try to improve heavy metal removal**, in particular by magnesium chloride dosing. At the same time, release of heavy metals from furnace corrosion must also be avoided.

Iron and aluminium concentrations in EuPhoRe ash are the same as with standard mono-incineration, but with phosphorus solubility of 80% in 2% citric acid (compared to less than 50% for standards sewage sludge mono-incineration ash). After milling to reduce particle size, pot trials (University of Bonn, unpublished to date) showed fertiliser effectiveness of EuPhoRe ash of 80% compared to mineral fertiliser (TSP) for rye grass over 7-8 months. Additionally, the EuPhoRe ash has some liming value (10% CaO equivalent).



Remondis TetraPhos®

The **Remondis Tetraphos** full-scale pilot plant at **Elverlingsen**, designed to treat ash for 40 000 p.e. (50 kg/h of ash), was presented by **Andreas Rak** and **André Walther**. The **ash is leached using phosphoric acid, so solubilising calcium but not most of the iron or heavy metals** (residence time = order of minutes). Addition of sulphite precipitates heavy metals and maximises the proportion of these which stay in the leached ash. In a second stage, calcium is precipitated by addition of sulphuric acid, and clean gypsum separated out by vacuum belt filter and water washing. The resulting phosphoric acid is partially returned back to leaching process. The additional acid production is purified by ion-exchanger and optionally nano-filtration membrane. The phosphoric acid must be concentrated (preferably requiring secondary heat to be available, e.g. from the sludge incinerator).

The leaching process is continuous and is controlled by e.g. residence time, temperature (waste heat can be used), ash/acid ratio, mixing.

This pilot plant was operated for around 2 years in Hamburg and then 8 months in Elverlingsen, where it was supplied with **sewage sludge incineration ash from Lippeverband's Bottrop mono-incinerator**. On this experience, a full scale plant is now being built in Hamburg, capacity 2.5 million p.e. see Hamburg Wasser 1st march 2019.

The Tetraphos process enables **recovery of 85-90% of the phosphorus in ash**: the Hamburg plant will recover 7 000 t/y of phosphoric acid (75%) from 20 000 t/y of ash, requiring as inputs sulphuric acid, hydrochloric acid for the ion exchanger and steam for the acid concentration. Other products generated include clean gypsum, which can be sold to the construction industry, recovered ferric chloride solution from the ion-exchanger backwash (which is returned to the sewage works and replaces purchase of ferric) and leached ash, which must go to landfill.

The **ion exchanger system** uses columns of specific resin-coated plastic beads, with highly controlled flow rate. Saturation and regeneration cycles are of the order of hours. Regeneration by hydrochloric acid backwash generates a **dilute solution of ferric chloride**.

Heavy metal levels in this recycled ferric are similar to commercial ferric chemicals. This recycling of ferric is expected to reduce by around 20% the commercial ferric consumption at Hamburg.

Because the recovered ferric solution is dilute, in order to avoid transport costs, the TetraPhos® should preferably be installed at a sewage works which can use this ferric directly to replace P-removal chemicals purchase. Proximity of an incinerator with secondary heat, necessary to concentrate the phosphoric acid product, is also preferable.

Remondis has developed a nano-filtration process (membrane under pressure) to further purify the phosphoric acid by separating out 2+ ions, after the ion-exchanger, in order to produce a highly purified acid with higher market value.

Although the TetraPhos® process removes phosphorus and calcium from ash, one tonne of dry ash input results in approximately one tonne of wet leached ash output (50% water), to go to landfill. Most of the heavy metals and ferric present in the input ash remain there. Nearly all the rest of the heavy metals are in the ferric recycling flow (see above).

AirPrex® struvite recovery

Bernhard Ortwein, CNP, presented the **AirPrex®** struvite recovery installation at the **Mönchengladbach** municipal sewage treatment works (Niersverband water board). This sewage works was modified a decade ago from chemical to **biological phosphorus removal** and has also been downsized from 1 million to 630 000 p.e. due to disconnection of industrial wastewaters. These changes led to a deterioration in sludge dewatering from 28% DM down to 22% DM. Also, **important struvite deposit problems** were encountered in the 350m pipe from the anaerobic sludge digesters to the sludge dewatering centrifuges.

The AirPrex® installation includes an initial struvite precipitation tank at the digester outflow (before the pipe) and larger precipitation and settling tanks at the end of the pipe, before the centrifuges. This enabled **improvement of sludge dewatering to 26% DM and reduced polymer consumption necessary for dewatering**.

At present, the AirPrex® installation only recovers around 5% of sewage works influent phosphorus, because the design objective was improvement of sewage works operation, not P-recovery. The recovered struvite is small crystals, with organic particles and is mixed into composts. CNP-Technology indicate that improvements could be possible to increase crystal size, so enabling a purer product, and also increasing the proportion of inflow phosphorus recovered (with 25% considered feasible). Modifications will include higher magnesium chloride dosing ratio, increased retention time, recycling of particles, washing of struvite to remove impurities.

The Mönchengladbach sewage works has been **achieving 0.3 mgP_{-total}/l discharge** with only occasional use of metal salts to adjust for load changes, plus low dosing of aluminium coagulant to improve settling. However, chemical dosing for P-removal has become necessary at times since recent installation of wastewater treatment at a connected brewery, possibly because this has reduced readily available organic carbon necessary to feed biological phosphorus removal.

Most other struvite recovery processes (e.g. Ostara, Veolia, Suez) are installed downstream of digester liquor dewatering, thus facilitating the struvite process and enabling production of a clean, high quality fertiliser product (much less organic particles in the liquor after dewatering).

Photos: the pipe between the anaerobic digesters and the dewatering centrifuges at Mönchengladbach, the small AirPrex® *pre-reaction tank at the digesters outflow, the* AirPrex® *recovered struvite*

Update on phosphorus recovery regulations and policy

A meeting hosted by **Michael Oberdörfer, North Rhine-Westphalia Land Environment & Agriculture Ministry**, enabled discussion between the different countries represented and the phosphorus platforms about current status of regulations and policies for phosphorus recovery:

- **Germany and Switzerland** today have national regulations requiring phosphorus recovery from sewage / sewage sludge / sludge incineration ash. See detail elsewhere in this Newsletter.

- **Austria** (information from Arabel Amann, TU Wien). Austria has a government political commitment to introduce P-recycling legislation. Today, three regions have banned sludge use in agriculture, six still allow it. Around three quarters of the country's sewage sludge goes to one mono-incineration plant in Vienna, and the City is moving to implement phosphorus recovery. Around one quarter of sludge goes to co-incineration, 17% to agriculture, and the rest to landscaping after composting.

- **Denmark** (presentation by **Jóannes Jørgen Gaard, Ministry of Environment and** Food). Around three quarters of sewage sludge in Denmark goes to agriculture, considered by the Environment Ministry to be the best use route. Organic farmers wish to be able to use sewage sludge, perceived as positive recycling, and the objective is to reduce contaminant levels to those specified for organic farming. Denmark's previous Waste Plan fixed an objective of 80% sewage sludge phosphorus recycling by 2018, but only 73% was achieved by agricultural use. The new Waste Plan includes struvite recovered in the sewage works and maintains the 80% objective. Landfill tax is 63 €/tonne and changes are underway to ensure that this incentive is applicable to water companies (currently the tax falls outside the water price cap). Copenhagen is actively assessing feasibility of P-recovery from sludge ash, both future produced ash and an ash landfill, because of landfill tax. Also, Denmark has a tax of 22 €/kg on phosphorus in sewage works discharge, leading today to an average discharge of 0.46 mgP_{-total}/l for the whole country.

See: Aarhus University report on phosphorus in secondary raw materials, 2018, in Danish ("Godningsvaerdi af fosfor i restprodukter") http://web.agrsci.dk/djfpublikation/djfpdf/DCArapport141_2.pdf

- **Finland** (presentation by **Ari Kangas, Ministry of the Environment**) has just over 500 permitted sewage works (> 100 p.e.), but only around seventy are 10 000 – 100 000 p.e. and only 13 > 100 000 p.e. Total sludge production is one million m^3 (160 000 t/yDM). EU statistics indicate that only 5% of sludge goes to agriculture, but a recent survey suggests that in fact it is 35-40%. A recent report in Finland suggests that micropollutants in sewage sludge pose no risk to crops, but there may be questions about soil accumulation (http://jukuri.luke.fi/handle/10024/543281 in Finnish) An important current question in Finland is that some large food industry companies are excluding use of sewage sludge in their product purchasing policies

- **Sweden** (presentation by **Folke K Larsson, Head secretary, Swedish national inquiry** on non-toxic and circular reuse of phosphorus from sewage sludge) currently uses around one third of its sewage sludge in agriculture, and a further third in landscaping and green spaces. Sweden has over two thousand small sewage works < 2 000 p.e. but only eighty 20 000 - 100 000 p.e. and only nineteen > 100 000 p.e. Moving sewage sludge from smaller sewage works in Northern Sweden or in other low density population regions to mono-incinerators would pose major logistic and economic issues, even if sludge is already transported from many small works for centralised sludge processing. Additionally, most of the agricultural land is in Southern Sweden. Sweden has a landfill tax of around 50 €/tonne and the government has proposed to further introduce a new tax on incineration of waste.

Summary of German and Swiss legislations relevant to phosphorus recycling

1. Germany

1.1 Polymers in sewage sludge and their sludge use in agriculture

In §10 (4), the fertilising materials ordinance (Düngemittelverordnung DüMV[i]) can be considered to regulate some specific materials, within the more general manure ordinance (Düngeverordnung DüV) see below.

The DüMV was updated on 26th May 2017, stipulates that synthetic polymers may not be used as an additive in sewage sludge after the end of 2018 if the sewage sludge is to be used in agriculture, unless the polymers show at least 20% biodegradation within 2 years. The regulation specifies that the Ministry of Agriculture will evaluate the regulation on the use of polymers by end 2019 and adjust it again if necessary.

Comment: one recent publication (Hennecke 2018[ii], funded by the polymers industry) suggests that polyacrylamide copolymer (PAM), as synthesised for this study, and corresponding to the type of polymer currently widely used in sewage sludge dewatering, achieve this biodegradability criteria (full mineralisation of 22.5% in two years, suggesting a higher percentage of biodegradation).

1.2 Tightening limits on use on fertiliser application, leading to constraints on sludge use

On 26th May 2017, the manure ordinance (Düngeverordnung DüV[iii], which is the German implementation of the EU Nitrates Directive 1991/676/EC) was tightened and amended due to the European Commission Nitrates Directive infringement proceedings against Germany. The following measures were introduced:

- §6(4) - The 170 kg N/ha application limit is extended to all organic fertiliser (before the 2017 modification, sewage sludge was excluded).
- §9(3) - Application limits now also apply to phosphorus: maximum phosphorus balance (total input > offtake) of 10 kg P_2O_5 /ha per year (from 2018 onwards), applicable where average soil phosphorus levels are above specified limits, depending on the analysis methods, see §3(6)
- §6(8) - Restriction periods: all fertilisers with > 1,5 % N in DM may not be applied, after the harvest of the last main crop until the end of January, as well as on grassland in the period from November to the end of January.

Comment: currently (2019), the manure ordinance is again being reconsidered, with further tightening expected to be imposed in 2020, probably including:

- *compulsory intercropping before summer crops to remove more nutrients from the soil*
- *a ban on autumn fertilisation of winter barley and winter rape, and*
- *separate rules for areas with high nitrate pollution: lower levels of nitrogen application and possibility of more demanding restrictions to be defined regionally*

- *compliance with the nitrogen limit of 170 kg/ha/year should no longer be based on average values, but on actual levels of nitrogen applied*
- *nutrient balance required per field, and no longer at the whole farm level*

Comment: The 2017 changes and the further expected changes will result in reduced agricultural application of sewage sludge and lower acceptance of sewage sludge by farmers, who tend to prefer manure if application of organic fertilisers is limited.

1.3 Phosphorus recovery obligation in the German sewage sludge ordinance

The German sewage sludge[iv] ordinance (AbfKlärV[v], as updated on 27th September 2017, requires that from 2032 sewage treatment plants > 50 000 p.e. (population equivalent) where the sewage sludge phosphorus content is higher than 20 g P/kg dry matter must carry out phosphorus recovery.

To understand the legal text and its interpretation, it is noted that the AbfKlärV is a waste regulation, addressing sewage sludge, but is not water regulation, and so does not "cover" sewage treatment plant operation. This means that the AbfKlärV may be considered applicable only to sewage sludge leaving the sewage works, but not to processing within the sewage works. The interpretation of and implications of this remain to be clarified.

Sewage works of < 50 000 p.e. can use sewage sludge "on or in soils" §3(1)[vi]. Also, the general requirement to recycle phosphorus as far as is "technically feasible and economically viable" (see below) applies also to these smaller sewage works (*Comment: the interpretation of this remains open*).

The deadline for implementation of phosphorus recovery is 2032 for sewage treatment plants 50 000 – 100 000 p.e. and 2029 for sewage works > 100 000 p.e.

For these larger sewage works, phosphorus recovery is required as follows, under §3(1):

- from sewage sludge if the phosphorus content of the sludge has phosphorus levels > 20 mgP/kgDM (that is 2% P/DM). In this case, §3(a), P-recovery must ensure that either at least 50% of phosphorus is recovered[vii], or that phosphorus levels in the sludge are reduced below 20 mgP/kgDM

or:

- from ash from mono- or co-incineration of such sewage sludge. In this case, §3(b), at least 80% of the phosphorus must be recovered[viii].

Comments:
- The 50% recovery from sewage sludge is considered not feasible by many operators today
- The 80% P-recovery obligation from ash will effectively exclude co-incineration of sewage sludge (of >2%P) with other wastes (low phosphorus industrial wastes, municipal solid wastes) or incineration in cement kilns, because P-recovery would not then be feasible.

For information: around 500 sewage works (out of a total of 9 300 in Germany) are > 50 000 p.e., treating around 2/3 of German sewage. At present, around 18% of German sewage sludge is spread on arable land and this is expected to be reduced considerably as a consequence of the 2017 manure ordinance (DüV) constraints indicated above.

The obligations in Germany can thus be summarised as follows[ix]:

Larger sewage works (100 000 p.e. from 2029 and 50 000 p.e. from 2032)			**Smaller sewage works**
If P in sludge **<2%P**	If P in sludge **>2%P**	If sludge **>2%P** is **mono- or co-incinerated***	Sludge can still be used "in or on" soil.
No P-recovery obligation (other than the general recycling clause) unless sludge is incinerated	Three options: - recover 50% of P from sludge - recover P from sludge sufficiently to reduce below 20 gP/kgDM - incinerate* sludge	Obligation to recover 80% of the P content in the ash	If sludge is incinerated and P>2%*, then obligation to recover 80% of the P content in the ash **
All sewage works must prepare a phosphorus recovery plan by end 2023 **			
In all cases, the general requirement to recycle phosphorus as far as is "technically feasible and economically viable" applies **			
* *see comment above: the phosphorus recovery requirement from ash effectively excludes co-incineration*			
** *It is our understanding that these requirements were not expected to be applicable to sewage works < 50 000 p.e. but that the adopted legal text makes them applicable. This may be modified in the future, but at present is applicable as above. It is also not clear at what date these requirements become applicable to smaller sewage works.*			

Storage: it is also possible to store the incineration ash in separated storage, such that it can be extracted from storage for P-recovery at a later date. *Comment: it seems unlikely that operators will choose to do this, because it would imply paying twice, for both storage and P-recovery costs.*

Mixing of sewage sludge: §3(1) mixing of sewage sludge (>2%P) prior to P-recovery is only authorised if the sludges all contain >2%P. *Comment: this in effect presents mixing with low phosphorus sludges to pass below the 20 mgP/kgDM limit*[x].

Definition of phosphorus recovery: in §2(4a)[xi], phosphorus recovery is defined as being any process by which phosphorous is recovered from sewage sludge or from ash from incineration of sewage sludge alone (mono-incineration) or with other residues (co-incineration).

Overall recycling objective: in §3(1)[xii], it is specified, for all sewage sludge, that "Wherever possible, sewage sludge producers shall utilise the high-grade materials from the sewage sludge accruing in their waste water treatment plant provided this is technically feasible and economically viable. In so doing, the aim is to recover ("Rückgewinnung") phosphorus and return the sewage sludge incineration ash containing phosphorus to the economic cycle."

All Sewage works must present to the competent authority, by the end of 2023, a plan specifying how they intend to ensure phosphorus recovery, if they intend to apply sludge on soils or if they intend a different disposal/recovery of their sludge.

Official German Federal Ministry "Guidelines" for implementation of this ordinance are expected to be published before end 2019

2. Switzerland

2.1 Ordinance waste requiring phosphorus recycling

Switzerland banned direct use of sewage sludge on land in 2006, the Swiss regulations requiring phosphorus recovery however appears to leave open to recover phosphorus either in the sewage works or after incineration of sludge (from the ash). In practice, this will be influenced by the percentage of recovery required, which is not yet defined (see below).

The Swiss ordinance[xiii] on limitation and elimination of waste of 4th December 2015 specifies (note that art. 15-3 below is as further modified by the fertilisers ordinance of 2018, see below)

"Art. 15: wastes rich in phosphorus

1 – phosphorus contained in municipal waste waters, sewage sludge from central treatment plants or ashes resulting from thermal treatment of such sludges, must be recovered and materials must be valorised

2 – phosphorus contained in animal flours and bone meal must be recovered and valorised, unless used in animal feed

3 – in recycling phosphorus from the wastes indicated in 1. and 2. above, pollutants present must be eliminated according to best available technology. If the recovered phosphorus is used for fertiliser production, it must further satisfy the requirements set out in Annex 2.6 ch. 2.2 of the Ordinance of 18/5/2005[xiv] concerning chemical products."

This ordinance entered into force on 1st January 2016 with a 10 year implementation deadline, so that the above phosphorus recycling requirements are applicable from 1st January 2026 (art. 51).

Notes:

- *Switzerland banned direct use of sewage sludge on land in 2006, however the regulation wording leaves open the possibility to recover phosphorus directly from the sewage sludge before incineration.*
- *Swiss sludge and slaughterhouse waste together represent annual flows of around 6000 tP/year and 3600 tP/y in Switzerland*[xv]
- *Important specifications concerning phosphorus recovery under the Swiss legislation today remain non-defined, in particular what percentage of phosphorus must be recovered. Proposals for these specifications are currently (March 2019) under consultation with the Swiss Cantons, and are expected to be formally adopted and published before end 2019.*

2.2 Ordinance on mineral fertilisers from recycling

The Swiss federal government published 31st October 2018 a new ordinance[xvi] on mineral fertilisers from recycling (modifying the Swiss fertilisers regulation RS916.171: in German DüV, in French OEng) defining some of the conditions for recovery of phosphorus from sewage and from meat and bone meal ("animal flours and bone powders"), as required by the Swiss ordinance on waste treatment (4/12/2015, see above).

The 2018 ordinance specifies[xvii] that phosphorus recovery from both sewage and from meat and bone meal must "eliminate pollutants present … according to state of technology" (*comment: that is, BAT*).

The ordinance modifies the Swiss fertilisers regulations to define these mineral fertilisers from recycling as those for which "part or all of the nutrients are obtained from municipal waste water treatment, sewage sludge or sewage sludge incineration ash" (comment: animal bone meal is not mentioned here). These mineral fertilisers from recycling must be authorised by OFAG (Swiss Federal Offices for Environment and for Agriculture) and must respect certain contaminant limits: (NOTE: all as mg/kgP NOT mg/kg-product[xviii]*): arsenic 100, cadmium 25, chrome (Cr-total) 1000, copper 3000, lead 500, mercury 2, nickel 500, zinc 10000, and also aromatic hydrocarbons 25, PCB 0.5 and dioxins/furans 120 ngI-TEQ/tonneP.*

[i] *Verordnung über das Inverkehrbringen von Düngemitteln, Bodenhilfsstoffen, Kultursubstraten und Pflanzenhilfsmitteln (Düngemittelverordnung - DüMV) = Regulation on the placing on the market of fertilizers, soil improvers, growing media and plant additives (fertilising materials ordinance - DüMV) as updated 26th May 2017* https://www.gesetze-im-internet.de/d_mv_2012/

[ii] *"Cationic polyacrylamide copolymers (PAMs): environmental half-life determination in sludge-treated soil", D. Hennecke et al., Environ Sci Eur (2018) 30:* https://doi.org/10.1186/s12302-018-0143-3 *Funded by the polymers industry association Polyelectrolyte Producers Group (PPG)* www.polyelectrolyte.org

[iii] *Verordnung über die Anwendung von Düngemitteln, Bodenhilfsstoffen, Kultursubstraten und Pflanzenhilfsmitteln nach den Grundsätzen der guten fachlichen Praxis beim Düngen (Düngeverordnung - DüV) = Regulation on the use of fertilizers, soil additives, growing media and plant additives according to the principles of good practice in fertilising (manure ordinance - DüV) as updated 26th May 2017* https://www.gesetze-im-internet.de/d_v_2017/

[iv] *Comment: The fact that this is a "sewage sludge" regulation, and not part of water treatment regulations, causes some legal complexity.*

[v] *Verordnung über die Verwertung von Klärschlamm, Klärschlammgemisch und Klärschlammkompost (Klärschlammverordnung - AbfKlärV) = Regulation on the recovery of sewage sludge, sewage sludge mixture and sewage sludge compost (sewage sludge ordinance - Klärschlammverordnung - AbfKlärV). The modifications of this regulation of 27th September 2017 are published in the Bundesgesetzblatt 3457, Teil I, G5702, 2017 n°65 available here* http://www.bgbl.de/xaver/bgbl/start.xav?startbk=Bundesanzeiger_BGBl&jumpTo=bgbl117065.pdf *An English translation is available here – however this was the version submitted for "notification" to Europe before final adoption in Germany and may not exactly correspond to the final version adopted: English translation of German sewage sludge ordinance (EU Notification 2016/514/D (Germany)* http://ec.europa.eu/growth/tools-databases/tris/en/search/?trisaction=search.detail&year=2016&num=514 *However, as at March 2019, the consolidated version of this regulation is not updated and does not take account of these modifications, see here* https://www.gesetze-im-internet.de/abfkl_rv_2017/

[vi] *Art 5.4 of the ordinance of 27/9/17 modifying §3 of the sewage sludge ordinance AbfKlärV*

[vii] *that is, 50% of the phosphorus in the sewage sludge (not 50% of the phosphorus in the sewage works inflow)*

[viii] *Note: There is still (2019) some legal discussion underway concerning the interpretation of the 80% requirement*

[ix] *This table is indicative : no such table is included in the regulation*

[x] *Note: Discussions are currently underway concerning mixing with other materials in incineration, e.g. co-fuels for energy input or other phosphorus rich waste streams such as animal by-products.*

[xi] *Art 5.3(2) of the ordinance of 27/9/17 modifying §2(4a) of the sewage sludge ordinance AbfKlärV*

[xii] *Page 3467 of the ordinance of 27/9/17*

[xiii] *Swiss ordinance on limitation and elimination of waste 4th December 2015 in French (OLED)* www.admin.ch/opc/fr/official-compilation/2015/5699.pdf *and in German (Abfallverordnung, VVEA)* www.admin.ch/opc/de/official-compilation/2015/5699.pdf

[xiv] *Ordinance on the reduction of risks related to chemical products, RS 814.81 : ORRChem in French* https://www.admin.ch/opc/fr/classified-compilation/20021520/index.html *or ChemRRV in German* https://www.admin.ch/opc/de/classified-compilation/20021520/index.html

[xv] *"Transition of the Swiss Phosphorus System towards a Circular Economy — Part 1 : Current State and Historical Developments" J. Mehr, M. Jedelhauser, C. Binder, Sustainability 2018, 10, 1479;* http://dx.doi.org/10.3390/su10051479

[xvi] *Swiss ordonnance of 31st October 2018, modifying the Swiss fertilisers regulation RS 916.171 of 2001: OEng in French* www.blw.admin.ch/blw/fr/home/politik/agrarpolitik/agrarpakete-aktuell/verordnungspaket-2018.html *and DûV in German* www.blw.admin.ch/blw/de/home/politik/agrarpolitik/agrarpakete-aktuell/verordnungspaket-2018.html *The modified fertilisers regulation (compiled) is available in French here* https://www.admin.ch/opc/fr/classified-compilation/20002050/201901010000/916.171.pdf *and in German here* https://www.admin.ch/opc/de/classified-compilation/20002050/201901010000/916.171.pdf

[xvii] *The 2018 ordonnance on fertilisers (OEng / DüV) modifies art. 15(3) of the 2015 waste ordinance (OLED / VVEA)*

[xviii] *The new EU Fertilisers Regulation contaminants limits are expressed as mg/kg of product (dry), not as mg/kgP (except for cadmium)*