Phosphorus and Global Food Security: A Synthesis

Proceedings from the
International Workshop on Phosphorus
and Global Food Security
24th - 26th February, 2010

Editors:
Tina Schmid Neset & Dana Cordell

Organised by the Global Phosphorus Research Initiative (GPRI)

Hosted by GPRI member:
Department of Thematic Studies – Water and Environmental Studies,
Linköping University, Sweden

Copyright

Linköping Electronic Conference Proceedings, 53
Linköping University Electronic Press
Linköping, Sweden, 2010

http://www.ep.liu.se/ecp_home/index.en.aspx?issue=053
ISSN 1650-3740 (online)
ISSN 1650-3686 (print)

Table of Contents

Editorial

Dr. Tina Schmid Neset and Dr. Dana Cordell

Phosphorus scarcity is an emerging global environmental challenge of the 21st century. Unlike water or energy scarcity, there is a concerning lack of existing research and policy discussion on the implications of global phosphorus scarcity. In February 2010, an international group of researchers in the field of phosphorus and global food security gathered at a workshop at Linköping University, Sweden, to generate a joint dialogue and shared understanding of the research (and policy) related challenges, opportunities and priorities regarding phosphorus security and its implications for global food security. The workshop resulted in the following key outcomes:

1. Deepened and broadened collective understanding of the key issues and *challenges* to global phosphorus security in the context of global food security, as well as of the ongoing and future research *opportunities* in this field;
2. An outline for a *priority research* and *policy* agenda;
3. Networking between a disparate group of researchers and the establishment of a consortium for future international co-operation; and
4. A scientific publication: Proceedings from the Workshop (including short papers by participants and an Editorial by GPRI Workshop organisers).

This document presents the proceedings from this workshop, compiling a brief synthesis of workshop discussions and a number of short papers from workshop participants on one or more key aspect of the challenges and potential solutions to address the global issue of phosphorus scarcity. These papers range in focus from identifying the global challenge of a sustainable diet to local solutions for phosphorus recycling from urine in Nepal.

The depletion of key resources that humanity depends on for survival has frequented the global environmental change debates over the last few decades. Phosphorus has though mainly been noted as a global pollutant, originating from either agriculture or wastewater and causing eutrophication in coastal and inland waters. Recent research has however identified the resource phosphorus as one of the most crucial questions for global food security, and further argued for the need for swift responses to avoid a 'hard landing' (Cordell, 2010) when high quality phosphate rock reserves are being depleted. Agricultural production today demands continual inputs of non-renewable phosphate rock as fertilizer to keep up current productivity. Close to 90% of mined phosphate globally is used for food production (Cordell et al. 2009a). Current global reserves are expected to be depleted within the next 50 to 100 years (Smil 2000, Steen 1998). Yet, there is little research on the long-term security of global phosphorus resources for food production, despite an 800% spike in the price of phosphate rock over the last two years (World Bank 2009). Due to our dependence on the availability of phosphorus in order to sustain global food security we are facing an acute need for research and solutions. A sustainable phosphorus future needs to consider both the global, inter-regional and local flows and strategies of consumption, production and trade.

While the debate often focuses on the time frame of depletion and the current minable quantities (frequently disregarding the issues of quality and accessibility), the main question for sustainability and environmental research should be 'how are we responding to this challenge?' or more specifically, 'what would it take to ensure all farmers have access to sufficient phosphorus to grow enough food, while maintaining ecosystem and societal functions?'. Several contributions to and discussions at the workshop considered solutions for single sectors, from decreasing the consumption of resource intensive foods in the human diet to agricultural phosphorus use efficiency, re-use of organic phosphorus within agriculture to the reuse of phosphorus from wastewater streams.

In order to capture the full extent and potential in phosphorus losses to increase efficiency and recycling along the entire food chain, phosphorus can even be considered in its 'virtual' form. As with the principle of the 'virtual water' where the export of a water-intensive product from one country to another is used to capture the direct and indirect use of water (Allan, 1997), embodied phosphorus in food products could be tracked from mining to human urine and feaces. As such, the flow of phosphorus will not only be considered in a local perspective or within agriculture or waste management, but captured on a global and regional scale. As this issue is of a vast complexity, there is an evident need for an integrated approach to cope with future challenges and to define synergies with other global sustainability challenges.

References

Allan, J.A. (1997) Virtual water: a long term solution for water short Middle Eastern economies? *Paper presented at the 1997 British Association Festival of Science*, University of Leeds, 9 September 1997.

Cordell, D. (2010) *The story of phosphorus: sustainability implications of global phosphorus scarcity for food security*. Doctoral thesis. Collaborative PhD between the Institute for Sustainable Futures, University of Technology, Sydney (UTS) & Department of Thematic Studies - Water and Environmental, Linköping University, Sweden. No.509. Linköping University Press, ISBN 978-91-7393-440-4, Linköping.

Cordell, D., Drangert, J.-O. & White, S. (2009) The story of phosphorus: global food security and food for thought. *Global Environmental Change*, 19, May 2009, 292–305.

Smil, V. (2000) Phosphorus in the environment: natural flows and human interferences, *Annual Review of Energy and the Environment* , 25**,** 53–88.

Steen, I. (1998) Phosphorus availability in the 21st century: management of a non-renewable resource. *Phosphorus and Potassium*, 217, 25–31.

World Bank (2009). Commodity Price Data (Pink Sheet), Prospects for the Global Economy. World Bank, Available: http://go.worldbank.org/5AT3JHWYU0.

Workshop Structure and Objectives

Workshop Host and Organisers

The workshop was hosted by Linköping University's Department for Thematic Studies - Water and Environmental Studies in Sweden. Funding was provided by the Swedish Research Council for Environment, Agricultural Sciences and Spatial Planning (FORMAS), the Faculty of Arts and Sciences, Linköping University and the Department of Thematic Studies – Water and Environmental Studies.

The workshop was organised by the Global Phosphorus Research Initiative (GPRI). GPRI is a collaboration between independent research institutes in Europe, Australia and North America. The main objective of the GPRI is to facilitate quality interdisciplinary research on global phosphorus security for future food production. In addition to research, the GPRI also facilitates networking, dialogue and awareness-raising among policy makers, industry, scientists and the community on the implications of global phosphorus scarcity and possible solutions.

The GPRI was co-founded in early 2008 by researchers at the Institute for Sustainable Futures at the University of Technology, Sydney (UTS), and the Department of Water and Environmental Studies at Linköping University, Sweden. Today, GPRI members also include the Stockholm Environment Institute (SEI) in Sweden, the University of British Columbia (UBC) in Canada and Wageningen University in The Netherlands. More information and resources can be found at the GPRI website: www.phosphorusfutures.net.

Workshop Aims

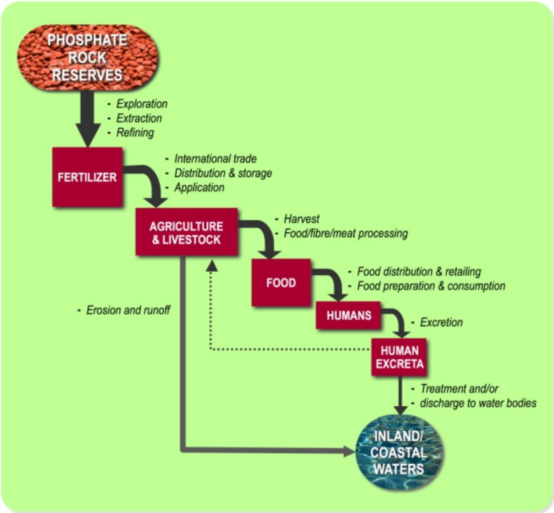
The specific aim of this workshop was to generate a joint dialogue and shared understanding of the research (and policy) related challenges, opportunities and priorities regarding phosphorus security and its implications for global food security.
The intended outcomes of this workshop were:

i. an overview and shared understanding of *challenges* to global phosphorus security in the context of global food security;
ii. an overview of ongoing and future research *opportunities* in this field;
iii. recommendations/outline for a *priority research* and *policy* agenda;
iv. strengthen existing and develop new *networks;*
v. a published *proceedings* from the Workshop; and
vi. a plan of action for *future activities* including implementing the Global Phosphorus Network.

Workshop participants

The participants came from a vast number of research institutes and universities from: Germany, Switzerland, Great Britain, Norway, the Netherlands, China, the United States, Australia, Canada and Sweden.
The collective expertise of participants covered key sustainability aspects of the phosphorus cycle through the global food production and consumption system, including:

- Global phosphorus resources & flows
- Global food security
- Efficient nutrient use in agriculture & the livestock sector
- Food production & consumption
- Diet, health and nutrition
- P in ecological and biological systems
- Sustainable water & sanitation systems
- Nutrient recovery
- Nutrient pollution



For the workshop programme and list of participants please see appendix.

Short Papers on Key Challenges & Opportunities

The short papers cover a diverse range of issues from multiple disciplinarily and interdisciplinary perspectives, beginning with papers that focuses on possibilities for improved phosphorus use efficiency in agriculture from an agronomic perspective, while the second paper provides a nutritional perspective on phosphorus and sustainable diets. Five papers then discuss the challenges and opportunities of phosphorus recovery and sanitation, from a global, developing country, UK and Chinese perspective respectively. The nature of the phosphorus pollution challenge is then addressed (using Baltic Sea as a case study) in the 8^{th} paper. The final two papers address the potentials of specific theories and methods (social sciences and material flows analysis respectively) to address the global phosphorus scarcity dilemma.

Which Role has Agriculture to Play in the Sustainable Use of Phosphorus?

Jaap Schröder[1] & Bert Smit[2]

Agrosystems Research, Plant Research International, Wageningen University and Research Centre, P.O. Box 616, 6700 AP, Wageningen, The Netherlands

[1] email: jaap.schroder@wur.nl

[2] email: bert.smit@wur.nl

Key Challenges

Plants will not grow if their roots can not find phosphorus (P) in the soil. That is why most farmers apply P in the form of manures, composts, biosolids or mineral fertilizer, if alone to compensate for the P that has left the field in produce (i.e. crops, milk, meat, wool). In the 'South' more P is exported than applied and, consequently, soils will become depleted of P if the natural compensation via e.g. flooding and weathering is insufficient. Generally, food production in this part of the world is strongly limited by lack of P. In the 'North', however, more P is added than exported from farms. This practice is mainly based on sound economical considerations and to a lesser extent on unjustified fears for yield penalties (Neeteson et al., 2006). Yields of crops, in particular those of shallowly rooting species grown in rows, are maximized if the soil P status is high. This status can be kept at that level by applying ample P to compensate not just for the P taken up by the crop, but also for the P that tends to be bound by the soil matrix. Moreover, soils with a high P status may, unfortunately, be exposed to greater P losses due to erosion, leaching and run-off, as a result of which excess P is needed to maintain that high status. Over-applying P may also stem from the profitability to dump P containing residues (e.g. manure) on nearby fields instead of returning them to the remote fields where these residues originated from. The latter imbalance can be observed at the scale of individual farms, regions, countries and even continents (Smit et al., 2009).

Production, processing and consumption of crops do no longer take place in each others vicinity. The attending decline of P recycling was, among other factors, facilitated by the advent of mineral fertilizer P (Schröder & Bos, 2008). This P is generally derived from finite fossil reserves. The depletion rate of these reserves is expected to increase as the world population will grow by another 3 billion people in 40 years from now. Moreover, more fertilizer P will be needed due to a gradual change of diets towards more meat and dairy products for which more forage crops must be produced. And if that's not a challenge on its own, an additional need for fertilizer P may be triggered by political pressure to grow bio-energy crops, in particular if these crops are to be grown on 'marginal' soils in order to avoid competition with food and feed production (Smit et al., 2009). From these perspectives, present agriculture is absolutely unsustainable. The time left for the required conversion is determined by our (in)ability to change the demand for P.

Research-Supported Solutions

Whenever a resource is nearing depletion, people typically call for a more efficient use. There is nothing wrong with this pursuit but in the case of P, one should already now acknowledge that an improved efficiency (i.e. an increase of the output to input ratio) will only buy time to work on sustainable solutions, i.e. a complete recycling of P from societies back to agriculture. Recycling definitely becomes easier the lower the throughput of P, so improving the use efficiency should be part of any solution, but efficient use does not suffice on its own.

Many changes at the level of individual crops, animals, farms and societies are needed for a better efficiency and recycling. First of all, efforts should be strongly directed to the abatement of soil degradation, as a large quantity of P is lost to the environment via wind and water erosion. Consequently, eroded land may be abandoned for long if not permanently, requiring the reclamation of new areas that often need ample P supplementation before becoming productive at all (Smit et al., 2009). Generally, statistics on net land use do not reveal this turnover rate and its implication for P demand.

Secondly, links between livestock farming and animal feed production should be re-established by either a reduction of local livestock densities or by returning the P in their excrements to remote fields, regions and continents. Note, that the latter solution has a trade-off in terms of transport needs. In regions with manure surpluses, particularly horticultural farms are inclined to cover their need for organic matter (OM) and N with ‘free’ manure. Due to the relatively low N to P ratio and OM to P ratio, this may easily lead to P accumulation. This can only be avoided by adjusting the rotation with crops supplying OM and N such as cereals or legumes, notwithstanding their lower profitability (Neeteson et al., 2006). Farms in need of N rather than P could still use manures without the risk of P accumulation, if they would only use the so-called liquid fraction resulting from manure slurry separation. The associated solid fraction, rich in P, is less bulky and can thus be more easily exported to remote farms in need of P.

At the crop level too, there is room for a better utilization of soil P. Crops capture most of their P via interception i.e. via growing roots exploring the surrounding soil volume. Especially at a young stage crops can thus be short of P. The match between demand and supply can be strongly improved by either positioning manures or fertilizers close to the expanding root system (‘P-starters’), or by extending the root length at an early growth stage via plant breeding. In specific cases the symbiosis between crops and proliferous fungi (mycorrhizae) may have a similar effect. In more general terms one could say that P utilization could be strongly improved if uniform blanket dressings would be replaced by differentiated applications, tuned to specific needs of individual crops and fields, of patches within fields, of particular positions within the bulk soil , and of periods within seasons (‘precision farming’).

Utilization within the animal can be improved as well (Pfeffer et al., 2005; Steen, 2006). Adding enzymes (phytases) to the feed and differentiating the P contents according to the needs of individual (groups of) animals, allows for a reduction of P contents. This will reduce the throughput of P in farms as well as the associated losses and can, hence, increase the P utilization. On each of the above issues Wageningen University and Research Centre is working.

Recommendations for Policy Makers

Any policy assuring that less mineral P is used in the ‘North’ and made available to ‘Southern’ farmers in desperate need of P, should be welcomed. Moreover, policy makers should create handling systems rendering industrial and urban residues of which the contamination with heavy metals, pharmaceuticals, hormones and infectious bacteria remains below acceptable levels. Farmers should be stimulated to use these clean residues as a source of P instead of fertilizers based on fossil reserves, via smart combinations of 'sticks and carrots'. Such a re-integration directed at full recycling, may also ask from policy makers to re-evaluate how we have presently segregated the production, processing and consumption of crop products (Brown, 2003). The answer to this type of question is not obvious. One could argue, for instance, that urbanization has on the one hand frustrated recycling due to increased transport distances and the consequential energy consumption. Urbanization has on the other hand supported the establishment of efficient collection systems for residues including human excrements. It is as difficult to judge whether our production systems should be extensified or intensified. From the perspective of resource use efficiency (land, water, labour, energy) and wildlife conservation, intensification seems the way forward. However, from the perspective of local environmental quality requirements and 'wholeness', there is need for extensification. Additional research is needed to support decisions on the optimal position on this axis in view of P utilization (Schröder & Bos, 2008). Moreover, rethinking the use of bio-energy crops is needed to use the available natural resources more efficiently. Finally, policy makers could consider to discourage the use of meat and energy and stimulate birth control.

Conclusions

Sooner or later a full recycling of P will be needed. The urgency of the attending measures will be determined by the P reserves considered minable, the prevention of accumulation and losses, the size of the global population and its preferences in terms of food, feed, fibres and fuels, and our appreciation of biodiversity. Both food security and biodiversity require that nutrients are not dissipated but stay where they are needed, that is in the fields devoted to agricultural production. This does not only require drastic adjustments of the way we organize our agriculture, but also for adjustments of our society as a whole. A truly holistic view is needed to address this problem.

Biography

Dr Jaap Schröder (1957) is a senior scientist in management strategies directed at an efficient use of nutrients, those from manures in particular, at the scale of fields, farms and regions. He has a special interest in the trade-offs between use efficiency and local environmental quality, biodiversity, landscape quality and proximity. He is a member of Council of the International Fertiliser Society and chairing one of the working groups on the implementation of the EU Nitrates Directive in The Netherlands

Dr Bert Smit (1950) is a senior scientist with particular interest in the rooting dynamics of crops and their implications for the uptake of nutrients and subsequent yield formation. He is coordinator of an ongoing project of the European Commission directed at the sustainable use of phosphorus. He has put phosphorus on the political agenda in The Netherlands and has hence been commissioned by Dutch authorities to analyse regional and global P flows in preparation for future scarcity of P.

References

Brown, A.D. (2003), Feed of feedback. Agriculture, population dynamics and the state of the planet. International Books, Utrecht, The Netherlands, 431 pp.

Neeteson, J.J., J.J. Schröder, A.L. Smit, J.F.F.P. Bos & J. Verloop (2006), Need and opportunities to reduce phosphorus inputs, soil supply and loss from agriculture in The Netherlands. Proceedings 595. The International Fertiliser Society, York, United Kingdom, 24 pp.

Pfeffer, E., D.K. Beede & H. Valk (2005) Phosphorus metabolism in ruminants and requirements of cattle. In: Pfeffer, E. & A.N. Hristov (Eds.) Nitrogen and phosphorus nutrition of cattle. CABI, Wallingford United Kingdom, pp 195-231.

Schröder, J.J. & J.F.F.P. Bos (2008), Relationships between nutrient recycling, environmental impacts and agricultural production. Proceedings 624, International Fertiliser Society, York, United Kingdom, 28 pp.

Smit, A.L., P.S. Bindraban, J.J. Schröder, J.G. Conijn & H.G. van der Meer (2009), Phosphorus in agriculture: global resources, trends and developments. Report 282, Plant Research International, Wageningen, The Netherlands, 36 pp.

Steen, I. (2006) Phosphorus use by livestock: requirements, efficient use and excretion. Proceedings 594, International Fertiliser Society, York, United Kingdom, 48 pp.

Phosphorus and food

Rosemary Stanton
School of Medical Sciences, University of New South Wales

Phosphorus is essential for the production of energy within every cell in the body and it also plays a vital extracellular role in the formation and strength of bones and teeth. About 85 per cent of the body's phosphorus is found within the skeleton. In spite of its obvious importance in human health, however, nutritionists generally pay little attention to phosphorus because it is so widely distributed in foods that virtually everyone who has enough food to eat easily meets the recommended dietary intake (RDI). In Australia this is 1000mg/day for men and women and 1250mg/day during pregnancy and lactation and for children over the age of nine. The safe upper limit for phosphorus intake is set at 3000mg/day for young children and those over 70 years of age, and 4000mg/day for older children and adults.

The small intestine and the kidneys maintain appropriate blood and cellular levels of phosphorus. The parathyroid gland also plays a role in maintaining phosphorus levels within bone, in conjunction with calcium and vitamin D. Problems with the balance of phosphorus within the body usually arise in certain renal diseases or in some rare genetic disorders.

The major dietary sources of phosphorus include the natural phosphorus content in foods as well as phosphate compounds used in many drinks and processed foods. Over the last 40 years, the quantity of phosphate additives used in processed foods and drinks has increased substantially and there is specific concern that higher levels of phosphoric acid from cola soft drinks may cause problems with bone density (Tucker, 2009) and also renal function (Ogur, 2007). Some dietary supplements may also provide phosphorus.

Phosphorus in foods is derived from phosphorus in soils. In countries such as Australia, where soils are naturally low in phosphorus, superphosphate is widely used to increase phosphate levels. As supplies of phosphate rock diminish, changes are inevitable. These may occur in several ways. We can establish systems that lead to re-use of phosphorus. We could also change the diet towards foods that can be produced with lower quantities of phosphorus.

In general, plant foods require less phosphorus than foods such as meat. Dietary guidelines also promote more plant foods, emphasising the importance of vegetables, fruits, wholegrains, nuts and seeds.

Within the meat category, options include lower consumption of meat or moving to meat from animals that require a smaller uptake of phosphorus. Rabbit and various types of poultry are smaller and require less phosphorus than larger animals. Beef cattle require large amounts of phosphorus to develop their big heavy skeletons. Feeding grain or pasture that uses superphosphate fertiliser to cattle further increases the need for phosphorus. Sheep, goats and pigs are smaller than steers and thus require somewhat less phosphorus. Sheep and goats also graze on land that is unsuitable for growing crops and is fertilised only with the animals' excreta. In Australia, kangaroos feed on native grasses that grow under trees and are not fertilised. They may therefore be preferable to using meat from cattle.

There is good evidence that a lower consumption of red meat is beneficial, reducing deaths from cardiovascular disease and some cancers (Sinha, 2009), especially colorectal cancer (Larsson, 2006). White meats such as rabbit and chicken are not associated with cardiovascular disease or cancer. By switching to a diet that favours plant foods, we could thus create benefits for health and encourage a more sustainable use of phosphorus.

These dietary changes are theoretically feasible, but there is currently little quantitative data to support the phosphorus needs in production of various foods. The challenge is to collect data showing how much phosphorus is required for various types of meat, other animal products and for different types of plant-based foods. We also need to know if some varieties of nuts or seeds or legumes are more efficient in their needs for phosphorus.

The possible benefits of organic production of foods also needs further research. Currently, organic growers are not permitted to use superphosphate, although phosphate rock is allowable, in spite of its higher levels of radioactive material. The organic industry in the United States is also running a campaign against the use of sludge in farming (Organic Consumers Association, 2010). Whether this is reasonable requires investigation and research.

It is easy to talk about changing diets but more difficult to actually achieve results. The food industry successfully uses marketing to change people's eating habits and diets. Those working in public health are much less effective in promoting healthier diets, partly because the message is less popular, but also because the total yearly funds spent on health education in most countries are eclipsed by the amount spent on advertising a single soft drink each week.

Could we perhaps achieve better results for public health by emphasising the environmental advantages of shifting the diet towards more plant foods? Would people be more prepared to change their diet for the health of the planet than when the goal is better health? To promote the synergy between sustainable and healthier diets, we urgently need more specific data concerning phosphorus requirements of specific foods. This will be essential in defending a bias towards plant foods against the likely strong opposition from meat and dairy industries, especially in view of their political influence in many countries.

Another area demanding attention is food waste. Wealthy countries waste huge amounts of food and this represents a waste of phosphorus as well as other resources. Food waste is being addressed by some conservation groups, although they do not currently include loss of phosphorus in their arguments. Again, there is an opportunity for synergy.

Biblography

Rosemary Stanton is a nutritionist and visiting fellow at the School of Medical Sciences, University of New South Wales.

References

Tucker KL. (2009) 'Osteoporosis prevention and nutrition'. *Cirr Osteroporos Rep*; 7(4): 111-117.

Ogur R, Uysal B, Ogur T, Yaman H, Oztas E, Ozdemir A, Hasde M. (2007) 'Evaluation of the effect of cola drinks on bone mineral density and associated factors', *Basic Clin Pharmacol Toxicol*.; 100(5): 334-338.

Sinha R, Cross AJ, Graubard BI, Leitzmann MF, Schatzkin A. (2009) 'Meat intake and mortality: a prospective study of over half a million people'. *Arch Intern Med*. 23;169(6):562-571.

Larsson SC, Wolk A. (2006) 'Meat consumption and risk of colorectal cancer: A meta-analysis of prospective studies'. *Int J Cancer*; 119(11):2657-2664.

Organic Consumers Association (2010) http://www.organicconsumers.org/articles/article_20540.cfm accessed 6 April 2010.

Phosphorus and Sanitation

Elizabeth Tilley

Department of Water and Sanitation in Developing Countries, Swiss Federal Institute of Aquatic Science and Technology, Dübendorf, Switzerland

elizabeth.tilley@eawag.ch

The key challenges and opportunities

As Cordell shows (Cordell et al, 2009) the contribution of human waste to the future scenario of phosphorus supply is not large. However, the recovery of nutrients from human waste is not only necessary for phosphorus security, it is necessary to address two other growing problems: the recovery of value from waste acts as a driver for sanitation, which is so desperately needed by over 2.5 billion people (WHO and UNICEF, 2010), and to prevent the eutrophication of water for human and environmental services (Barnard, 2009).

Although phosphorus recovery from wastewater has been in practice for over 15 years (Abe, 1995), there are still numerous challenges with linking, operating and optimizing joint sanitation-nutrient recovery systems:

- robust, available technologies
- economic feasibility
- integration of animals waste

The technologies available for nutrient recovery are limited with limited commercial success; one type of reactor for recovering struvite from digestor supernatant from Ostara (Britton et al, 2009) and some smaller commercial varieties (Battistoni et al, 2002) are the few exceptions. There are numerous examples of site-specific, proprietary designs which are usually for research purposes (Battistoni et al, 2006). Because of the simple reaction process, struvite reactors have become an obvious solution for phosphorus precipitation, but the concept has monopolized the school of nutrient recovery from wastewater and has resulted in a paucity of competing technologies and products. Furthermore, few of the technologies developed (if any?) have been developed in, or for a developing country context. If real achievements are to be made in both the fields of sanitation and phosphorus recycling, then much of the attention must focus on the growing megacities of the developing world.

Realistically, the development of technology has been limited by the lack of economic and policy incentives. There has been, until recently, an embarrassing lack of investment in sanitation though the International Year of Sanitation has moved sanitation further up the agenda. Still now, as sanitation becomes a 'cause célèbre', the priority is on household service, not the level of treatment, despite the fact that though the environmental consequences are high. At a decentralized, i.e. household level, the benefits of urine application have been shown (Schuen & Parkinson, 2009). However, a description of the scale and operating conditions for different technologies and operating systems, which demonstrate profitability, are generally lacking.

Most obviously, the price of nutrients- especially phosphorus, has not been sufficiently high, for sufficiently long, so as to act as a reasonable incentive for investment (Dockhorn, 2009); indeed the fine for pollution was the classic reason for nutrient recovery from wastewater (Metcalf and Eddy, 2003).

Though needed for reasons of dignity and health, nutrient recovery from human waste is a small opportunity compared to that of the recovery of waste from animals. With 63 billion animals in the world, many of them eating enriched food and excreting a large part of it, the potential for recovery is huge. Product and site-specific technologies are developing rapidly for a cow, pig and other farm wastes (e.g. Bowers et al, 2009), but concentrated efforts to standardize or market a process, have not been made.

Current Research and Future Research

Research at Eawag examines the technical, social and economic aspects of nutrient recovery from sanitation. The Novaquatis project generated a significant amount of information related to urine separation and struvite recovery (e.g. Ronteltap et al, 2010) but current research is focused on technologies for capturing nitrogen (Udert et al, 2005) and decentralized reactors (Abegglen et al, submitted). A growing body of work addresses the issues of scale and economy when designing innovative systems (Larsen et al, 2009; Zurbrügg et al, 2009). Research in developing countries, addresses the technical, social and economic opportunities and limitations of community managed systems, and the potential for local entrepreneurship (Tilley et al, 2009).

Future work will address the sustainability of different nutrient recovery schemes in developing countries, taking into account the financial and economic costs and benefits for public and private stakeholders.

Key Research and Policy Priorities

Though research continues, it is stalled by a lack of proven experience and market demand. Improved technologies must be developed, but the development must be facilitated by clear policies for operators and market opportunities for investors.

Policies which would allow operators (public and/or private) to access waste streams and harvest nutrients would, with due cooperation, ease treatment requirements and provide entrepreneur opportunities. The Ostara model will likely define a precedent for public-private partnerships in nutrient recovery, but progressive policies must allow for competition and innovation.

Including nutrient recovery as a parameter for sustainability when considering the implementation of new sanitation technologies in developing countries, should be mandatory- there is no point in investing billions of dollars in 'development' which will only need re-development in 15 years. This will not only provide some level of cost recovery to the operator, but will spur innovation and investment in technology development if it becomes a mandatory condition.

A significant amount of research is needed to assess the financial and economic costs and benefits of nutrient recovery from sanitation systems. So little is known about logistical and technical operating conditions of decentralized nutrient recovery- especially in a developing country context-that future scenarios are difficult to demonstrate to potential investors.

Biography

Elizabeth Tilley is a Project Officer in Sandec: the Department of Water and Sanitation in Developing Countries at the Swiss Federal Institute of Aquatic Science and Technology in Dübendorf, Switzerland. She is working on decentralized sanitation technologies and nutrient recovery possibilities in urban and peri-urban areas throughout the developing world.

References

Abe, S. (1995), 'Phosphate removal from dewatering filtrate by MAP process at Seibu treatment plant in Fukuoka City', *Sewage Works in Japan*, 59–64.

Abegglen, C., Sigrist, A., Siegrist, H. 'Electrochemical Phosphate Removal for Small-Scale Wastewater Treatment Plants', *Water Science and Technology*, (submitted).

Barnard, J.L. (2009), 'Elimination of eutrophication through resource recovery' in Mavinic, Don, Ken Ashley and Fred Koch (eds), *International Conference on Nutrient Recovery from Wastewater Streams*, *Vancouver, 10-13th May, 2009*. London, UK: IWA Publishing, pp 1-22.

Battistoni P., De Angelis, A., Prisciandaro, M., Boccadoro R., Bolzonella, D. (2002). 'P removal from anaerobic supernatants by struvite crystallization: long term validation and process modelling', *Water Research*, 36(8), 1927-1938.

Battistoni, P., Paci, B., Fatone, F., Pavan, P. (2006), 'Phosphorus Removal from Anaerobic Supernatants: Start-Up and Steady-State Conditions of a Fluidized Bed Reactor Full-Scale Plant', *Industrial & Engineering Chemistry Research,* 45(2),663-669.

Britton, A., Prasad, R., Balzer, B., Cubbage, L., (2009), 'Pilot testing and economic evaluation of struvite recovery from dewatering centrate at HRSD's Nansemond WWTP' in Mavinic, Don, Ken Ashley and Fred Koch (eds), *International Conference on Nutrient Recovery from Wastewater Streams*, *Vancouver, 10-13th May, 2009*. London, UK: IWA Publishing, pp 193-202.

Bowers, K., Zhang, T and Harrison, J.H. (2009), 'Full-Scale Test of a Fluidized-Bed Struvite Crystallizer for Phosphorus Reduction in Dairy Lagoon Water' in Mavinic, Don, Ken Ashley and Fred Koch (eds), *International Conference on Nutrient Recovery from Wastewater Streams*, *Vancouver, 10-13th May, 2009*. London, UK: IWA Publishing, pp 846-860.

Cordell, D., White, S., Drangert, J.-O., and Neset, T.S.S. (2009), 'Preferred future phosphorus scenarios: A framework for meeting long-term phosphorus needs for global food demand' in Mavinic, Don, Ken Ashley and Fred Koch (eds), *International Conference on Nutrient Recovery from Wastewater Streams*, *Vancouver, 10-13th May, 2009*. London, UK: IWA Publishing, pp 23-44.

Dockhorn, T. (2009), 'About the economy of phosphorus recovery', in Mavinic, Don, Ken Ashley and Fred Koch (eds), *International Conference on Nutrient Recovery from Wastewater Streams*, *Vancouver, 10-13th May, 2009*. London, UK: IWA Publishing, pp 145-158.

Larsen, T.A., Alder, A.C., Eggen, R.I.L., Maurer, M., and Lienert, J. (2009), 'Source separation: Will we see a paradigm shift in wastewater handling', *Environmental Science and Technology*, 16, 6121-6125.

Metcalf and Eddy, (2003), *Wastewater Engineering: Treatment, Disposal and Reuse*, New York: McGraw-Hill.

Ronteltap, M., Maurer, M., Hausherr, R., Gujer, W. (2010), ‘Struvite precipitation from urine - Influencing factors on particle size’, *Water Research,* 44(6), 2038-2046.

Schuen, R. and Parkinson, J. (2009). *Study for financial and economic analysis of ecological sanitation in Sub-Saharan Africa*. Nairobi, Kenya, Water and Sanitation Program-Africa.

Tilley, E., Gantenbein, B., Khadka, R., Zurbrügg, C. and Udert, K.M. (2009), ‘Social and economic feasibility of struvite recovery from urine at the community level in Nepal’, in Mavinic, Don, Ken Ashley and Fred Koch (eds), *International Conference on Nutrient Recovery from Wastewater Streams*, *Vancouver, 10-13th May, 2009*. London, UK: IWA Publishing, pp 169-178.

Udert, K.M., Larsen, T.A., and Gujer, W. (2005), ‘Chemical nitrite oxidation in acid solution as a consequence of microbial ammonium oxidation’, *Environmental Science and Technology*, 39(11), 4066-4075.

World Health Organization and UNICEF (2010), *Progress on Sanitation and Drinking-water: 2010 Update*, Geneva: WHO/UNICEF Joint Monitoring Programme for Water Supply and Sanitation.

Zurbrügg, C., Bufardi, A., Tilley, E., Maurer, M., Truffer, B. (2009), ‘Decision making for sanitation systems’, *Sandec News*, 20-21.

Sustainable Sanitation and Nutrient Recovery

Jan-Olof Drangert, Department of Water and Environmental Studies,
Linköping University

This presentation focuses on how to formulate the challenge of phosphorus and food security in order to make an impact on decision-makers and laymen.

We are all part of the globe and contribute with our footprints. This may sound rather non-threatening, however, it has far-reaching implications. We tend to think as if we were still only one billion people on the globe. An important information task is to adjust our thinking to being 9 billion people shortly!

A common way to dodge the personal responsibility for pollution is to claim '*What I do can not possibly effect the globe*'. A powerful illustration of the global environmental impacts of human activities, is to view the earth from a satellite in the day- and night-time. The impression in daytime is a blue-green globe which appears beautiful and inviting. However, if seen in the night the impression changes. Large areas are illuminated. This implies that each individual activity to lit houselights, drive a car, street lights etc. adds up to lighting the globe. This, in turn, requires energy and its generation emits large volumes of greenhouse gases that affect the thin layer of atmosphere around the globe.

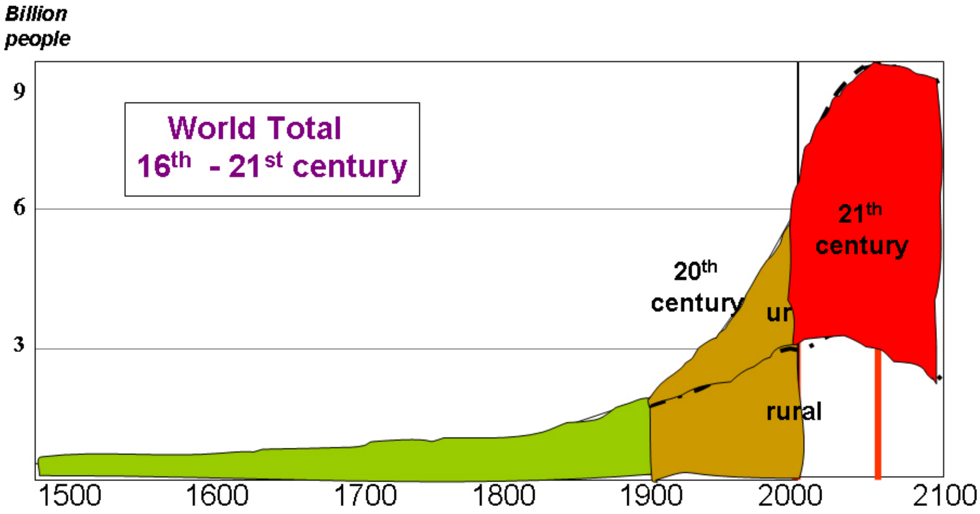
The speed of population growth is difficult to comprehend - in just a generation the global population has doubled. The growth of production is even faster. Therefore, introduction of more sustainable lifestyles are urgently needed.

The rapid growth provides a golden opportunity to develop and implement innovative ways of saving resources. As many urban houses and buildings are to be built in the next 40 years as the number of houses we occupy today. Thus, new housing on virgin land in new cities provides excellent opportunities for new sanitation options to fulfil the Millennium Development Goals for sanitation. China contributed 50% of the built area in the world in 2009 which shows that the innovations need to start there! (Straight Times in Singapore Dec 7, 2009). If we do not act now, we will delay the progress till the time when these new houses have aged and need to be retrofitted.

We could also initiate awareness building at the level of the human body. In principle a short loop could supply the required fertiliser for the person's food production. The 'Urine Equation' tells that urine itself could contribute more than half of the nutrients to produce 250 kg of cereals which the person needs in a year (Drangert, 1998). Dense urban living requires new approaches to bring the urine to farm land, but the distance is typically very short – certainly compared to sending fertilisers over the globe from phosphate mines to fields.

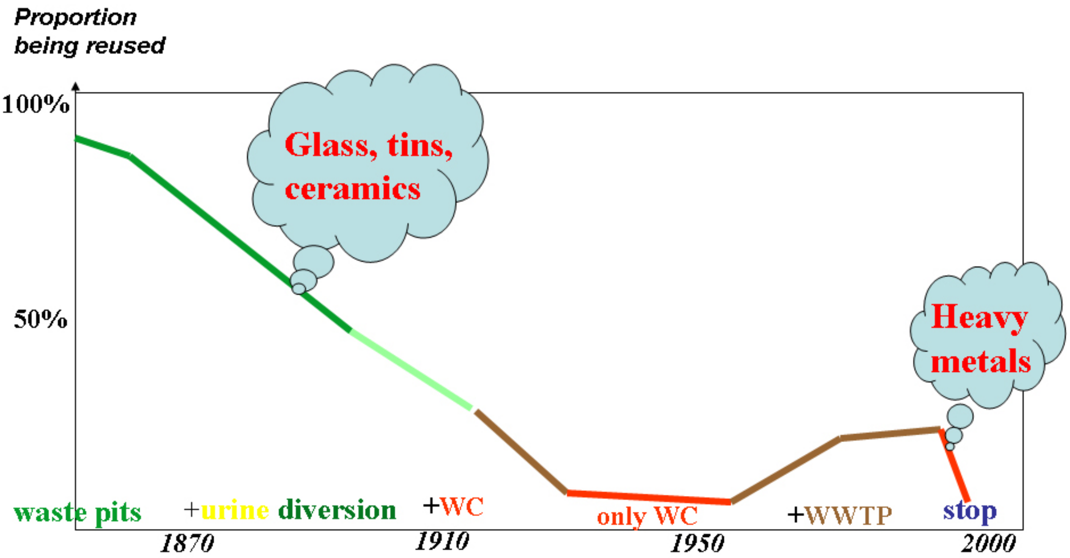
Many urban areas today discharge the valuable urine and faeces to water bodies, often with no prior treatment. In the 20th century as much excreta was produced as in the previous four centuries (see Figure 1). In the 21st century urban areas will discharge 10 times more human excreta compared to the previous century. We have only seen a fragment of the coming volumes of excreta from urban populations, and will have to manage these through recirculation if we are not to be drowned in our own waste.

Figure 1: Production of human urine and faecal matter over time



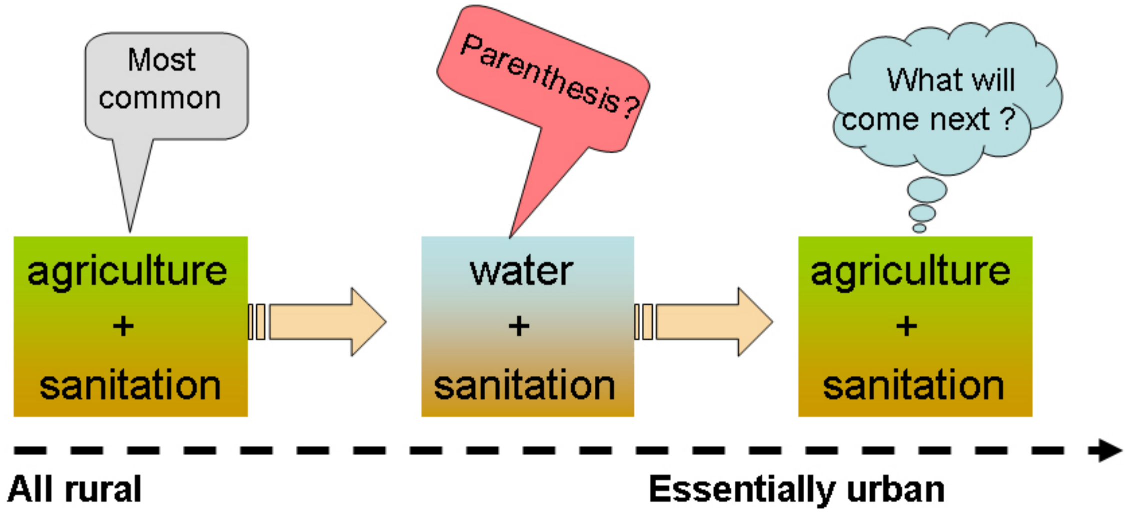
A look in the back mirror tells us how recirculation has changed in the last hundred years (Figure 2). A representative city in Sweden managed to recirculate almost all organic waste including excreta to farmland. This figure gradually dropped to zero during the following 80 years. The main reason was the introduction of flush toilets with no treatment of the blackwater. In order to combat deterioration of rivers and water bodies city councils had to invest in wastewater treatment plants. Initially the capacity to remove nutrients was poor, but the sludge was spread on the farms. The recirculation rate rose to some 30% (1980s). The emerging chemical society produced more and more contaminated wastewater, and eventually the farmers refused to take the cadmium-loaded sludge to their farms. Recirculation went down to almost zero, and only later was some of the sludge used to fertilise energy forests (Schmid-Neset et al., 2010).

Figure 2. Actual reuse of nutrients in urban areas (the case of Sweden 1850-2000)



The future sanitation systems have to return the so called wastes to productive use through total recirculation. This will likely include reconnecting the sanitation sector to the agricultural sector, and divorce it from the present connection to water (Figure 3).

Figure 3: Long-term sector connections



To address the challenge posed by a more sustainable society where food is secured, we need to recycle used resources. It will only be possible if norms and attitudes are adjusted to a new global world order of recycling, endorsed by most societies. Also, we cannot isolate the discussion of P recovery but need to consider energy and water usages simultaneously and coordinate the approaches to all three resources.

Biography

Jan-Olof Drangert, Associate professor at the Department of Water and Environmental Studies, Linköping University is engaged in linking sanitation arrangements to food security and energy conservation through alternative management approaches.

References

Drangert, J-O., Schönning, C. and Vinnerås, B. 2010. Sustainable Sanitation for the 21st Century. www.sustainablesanitation.info

Drangert, J-O. 2004. *Norms and Attitudes Towards Ecosan and Other Sanitation Systems*. Report 2004-5. EcoSanRes Publications Series. Stockholm Environment Institute. 30 p

Drangert, J-O. 1998. Fighting the urine blindness to provide more sanitation options. *Water SA* Vol 24, No 2. 157-164.

Schmid-Neset, T.-S. Drangert, J-O., Bader, H-P., Scheidegger, R. 2010. Recycling of phosphorus in urban Sweden. A historical overview to guide a strategy for the future. *Water Policy* 12 (2010) 611–624.

Recycling of Phosphorus from Wastewater – Why It Makes Sense and How It Could Work

Christian Sartorius and Jana von Horn, Fraunhofer ISI, Karlsruhe, Germany

The Challenge of Closing P Cycles in Wastewater

While the world-wide reserves of phosphorus (P) are not considered to be scarce in the short run, the raw material crisis of 2007/2008 showed that temporary supply shortages can occur at any time (von Horn and Sartorius 2009). In contrast to this supply situation, P as non-substitutable plant nutrient is in increasing demand from agriculture, which has to supply an increasing global population with food, provide forage for increasing herds of livestock and produce biomass as renewable energy and material source. In order to nevertheless preserve the existing reserves, scientists have been looking at opportunities for recovering and reusing P.

In the competence centre Sustainability and Infrastructures of the Fraunhofer Institute for Systems and Innovation Research (ISI) we are looking at P from two directions. From the infrastructure perspective P is a component of wastewater and accumulates during wastewater treatment. Especially if phosphate precipitation is carried out to reduce phosphate concentrations in the run-off, most of the P ends up in the sewage sludge, which needs to be disposed of. From the sustainability perspective, P is a valuable resource especially for biomass production. If the sludge could be used directly as fertilizer in agriculture, the cycle was closed and the gap between both perspectives bridged. However, owing to the contamination of much of the sewage sludge with heavy metals and organic halogen compounds, a controversy about the damage caused by the sludge use in agricultural sites is going on especially in Germany. As a consequence, a variety of technology approaches to recover P from sewage sludge was developed in the past decade. We compare these approaches on the basis of a variety of criteria. From the ecological perspective, it is important that possible contaminants are removed and the P is sufficiently available to the plants. Economically, the process should be applicable broadly, not too expensive and show a certain maturity to reduce uncertainty.

Comparison of Approaches

If sludge use in agriculture is to be avoided, the question arises how the P cycle can still be closed. Three basic flows of P can be tapped in a sewage plant (Von Horn 2007):

The run-off is free of organic matter and other contaminants. However, it only contains a small fraction of the P contained in the wastewater (20 percent or less, if P elimination takes place) and the P is fairly diluted.

40 percent of P is accessible in the sludge liquor. The recovery requires a precipitation of P after the dewatering of the sludge. If phosphate is precipitated in the sludge liquor separation of the precipitated P from the accompanying organic matter is possible but difficult and expensive.

Up to 80 percent of P is accessible in the total sludge. For recovery P has to be leached from the sludge and afterwards it has to be subjected to a fractionated re-precipitation to eliminate heavy metals. This again is an elaborate and costly procedure. If the sludge is incinerated (which is a prerequisite for disposing any sludge in landfills in Germany), leaching and re-precipitation can also be done with the ash. Up to 90 percent of the P is (in principle) accessible by this procedure, but it is an even more costly approach. By contrast, removing heavy metals from the ash metallurgically, appears to be much less costly. However, this process is not yet performing sufficiently well, limitíng the application of its output for agriculture.

So far, no clear favorite procedure appears to exist. Even in the most economical approaches the produced P fertilizers are at least twice as expensive as P from rock phosphate – despite restrictions in plant availability.

P Separation at the Source

Human excreta is the major flow of P leaving the households. Instead of dissipating this P in large quantities of wastewater it could alternatively be collected before it enters the central sewerage. Especially urine, which contains about 60 percent of the excreted P, is easily converted into fertilizer by precipitation of struvite. However, the main problem is the logistics needed to collect the urine. In industrialized countries it may not make economic and ecological sense to collect urine from any single household by truck or pipe. Instead collection could be focused on larger, preferentially public and administration buildings, which are already equipped with urinals and where collected the quantities would be large enough to render the collection economical. In developing countries, inexpensive labor and the possibility to operate low-tech variants of the precipitation approach could basically render urine separation more attractive on a broader scale (see Tilley 2010). At the moment, however, the approach seems to suffer from low public acceptance and economic disincentives raised by subsidized industrial fertilizers, for instance in India.

Conclusions

A variety of approaches to the recycling of P from the sewage of households seems to exist. At the moment, all of them are hampered by ecological, economic or agronomic short-comings. But some appear to be quite promising and once the fossil P reserves will be in short supply over longer time periods, P recycling will become feasible rather rapidly. In the meantime, two more general recommendations could be given. P precipitation from wastewater is usually done with ferric chloride, which results in technical difficulties in some of the procedures and generally hampers the efficacy of the fertilizer. Aluminum sulfate could be a favorable substitute which is only slightly more expensive, but opens up larger potentials with respect to the future use of the recycled material. Moreover, as long as P recycling cannot be done economically, sewage sludge should be disposed off in mono-landfills (containing sludge only) – possibly as ash after mono-incineration. In this case, the P is not dissipated further and can be used once the natural reserves become sufficiently scarce and expensive.

Biography

Christian Sartorius studied biology and economics at the Universities of Saarbrücken and Freiburg and received doctorates in biochemistry (Dr. rer. nat.) and economics (Dr. rer. pol.).

After research work at the Max-Planck-Institute for economics in Jena and the Technical University in Berlin he is working in the Competence Center for Sustainability and Infrastructure Systems at the Fraunhofer Institute for Systems and Innovation Research ISI since 2004. His research focuses on (the promotion of) technical and organizational innovations giving rise to the more efficient use of resources especially in the context of water and energy.

After studying civil engineering at the Leibniz University in Hanover **Jana von Horn** worked as a researcher at the Bauhaus University in Weimar where she received a doctorate (Dr.-Ing.) for her work on phosphate recovery from excess sludge of sewage treatment plants in 2007. Since then she has been working at the Fraunhofer Institute for Systems and Innovation Research ISI in the Competence Center Sustainability and Infrastructure Systems.

References

Tilley, E., Gantenbein, B.; Khadka, R.; Zurbrügg, C.; Udert, K.M. (2009): Social and economic feasibility of struvite recovery from urine at the community level in Nepal. In: Ashley, K.; Mavinic, D.; Koch, F. (Ed): International Conference on Nutrient Recovery from Wastewater Streams, London: IWA Publ.

Von Horn, J. (2007): Untersuchungen zur Rückgewinnung von Phosphat aus Überschussschlamm von Kläranlagen mit vermehrt biologischer Phosphatelimination. Dissertation at the Bauhaus University Weimar (Germany)

Von Horn, J.; Sartorius, C. (2009): Impact of supply and demand on the price development of phosphate (fertilizer). In: Ashley, K.; Mavinic, D.; Koch, F. (Ed): International Conference on Nutrient Recovery from Wastewater Streams, London: IWA Publ.

Towards a System of Closed-Loop Phosphorus Management for The UK

Dr Cynthia Carliell-Marquet, School of Civil Engineering,
College of Engineering and Physical Sciences, University of Birmingham, UK,
c.m.carliell@bham.ac.uk

Key Challenges and Opportunities

One of the greatest global challenges of the next five years (and beyond 2015) will be improving food security in the world's most vulnerable regions. Small-scale farming families represent about half of the hungry worldwide and about three quarters of the hungry in Africa. Improving *their* crop productivity by restoring and improving soil health is a major priority, which requires application of both organic and mineral fertilisers, of which phosphorus (P) is an essential ingredient; *"Making mineral fertilisers available at affordable prices and using them efficiently remain major challenges [to ensuring food security]"* (UN Millennium Project, 2005).

A key challenge, therefore, is to manage the dwindling economic reserves of phosphate rock so that mineral fertilisers remain available and affordable for the developing world, where they are needed to attain food security. The challenge for all countries, but particularly the developed world, is to start immediately to manage the phosphorus already within their terrestrial system so as to minimise losses to the environment and maximise recovery and reuse, hence reducing their demand on the remaining mineral phosphorus reserves.

The UK has no mineral phosphorus reserves. Phosphorus is imported as animal feed, agricultural fertiliser and food and most of what is imported is rapidly lost to waste streams – largely in a recoverable form. A third of all food bought in the UK is thrown away, producing an estimated 8.3 million tonnes of household food waste per year (WRAP, 2010). Combined with industrial sector food waste, this totals 20 million tonnes per year (DEFRA, 2009). Approximately 98% of the phosphorus consumed by humans and animals is excreted (Smil, 2000), with an estimated 40,000 tonnes of phosphorus flowing through sewage treatment works (STW) in the UK every year (UKWIR, 2010) and 80-90 million tonnes of slurry-like agricultural waste being produced per year (DEFRA, 2009). The phosphorus held in these organic waste streams is going to be increasingly valuable as global reserves dwindle.

Current and Future Research Contribution

For the UK to move towards a closed-loop system of phosphorus management, it is going to require more than just standard phosphorus removal or recovery from wastewater. Even if all the phosphorus was recovered from wastewater, this would represent about 30% of the phosphorus used in the UK per year (UKWIR, 2010). A high proportion of the UK's imported phosphorus is in the 80 to 90 million tonnes of agricultural slurry[1] produced each year, as well as the 20 million tonnes of food waste. While a high proportion of animal manure is returned to agricultural land in the UK, the bulky nature of manure limits application to a small radius around the area of production. Hence, phosphorus in animal manure actually supplies a much smaller portion of the overall agricultural phosphorus requirement than the available mass would imply. Similar constraints apply to phosphorus contained in digested sludge applied to land.

Researchers at the University of Birmingham are investigating potential scenarios for closing the loop in terms of phosphorus management in the UK. One of the options being explored is the idea that STW could be operated as green phosphorus refineries, importing regional phosphorus-rich waste streams (e.g. industrial, agricultural or food wastes) to increase phosphorus concentrations in the wastewater, so maximising the potential for phosphorus recovery as struvite or calcium phosphate. Another potential scenario is to combine decentralised bioenergy recovery with phosphorus recovery from organic wastes, based on the 1,000 anaerobic digesters planned to treat 100 million tonnes of agricultural and food wastes in the UK by 2020 (DEFRA, 2009).

Although there are technical challenges to overcome in terms of proving existing phosphorus recovery technologies under UK conditions, the immediate challenge to closing the phosphorus loop lies in the lack of acknowledgement of phosphorus as a resource security issue either in the UK or the EU. Without being able to see the entire picture of phosphorus as a resource, both at a global and national level, and particularly, how this is going to unfold over the coming years, it is difficult for decision-makers to motivate for major investment into phosphorus recovery. A principle aim of our current research is, therefore, to roadmap political, economic, environmental and technological variables key to phosphorus management scenarios for the UK. These key variables are critically evaluated at a global and national level so that the impact of global phosphorus trends (which ultimately dictate the economic viability of phosphorus recovery schemes) are integrated into local phosphorus management scenarios, to be used for decision making at a national or regional level.

Key Future Research and Policy Priorities

Key research priorities to ensure global phosphorus security have at the core the need to understand future trends of global phosphorus prices, because more confidence in projected price trends will be necessary to encourage investment in phosphorus recovery. There is also a continuing need to understand country- and regional- scale phosphorus flows and to improve the data on which these are based, so phosphorus management scenarios can be targeted at the points of greatest potential recovery with minimum environmental and economic cost. From a technical viewpoint, there is a need for more research into optimising recovery of multiple resources, e.g. biomethane and phosphorus, in a single flowsheet and also for technologies suitable for recovering phosphorus from smaller, decentralised organic waste treatment facilities.

1 At a dry solids content of 10% and P content of 1%, this gives an estimated 100,000 tonnes of P per year.

Biography

Dr Cynthia Carliell-Marquet is a lecturer in the School of Civil Engineering at the University of Birmingham. Her interest in phosphorus stems from her PhD research into the fate of phosphorus in sludge treatment, which was followed by research into chemical P removal systems and digestion of phosphorus-rich sludges. Dr Carliell-Marquet's current research is focused on developing future scenarios for sustainable phosphorus recovery by the UK water industry.

References

DEFRA UK (2009). *Anaerobic Digestion – Shared Goals*, February 2009.

Smil, V (2000). Phosphorus in the Environment: Natural Flows and Human Interferences, *Annual Review of Energy and the Environment*, 25, 53–88.

UKWIR (2010). *Phosphorus Life Cycle Management*, UK Water Industry Research Briefing Note, January 2010.

UN Millennium Project (2005). *Halving Hunger: It Can Be Done. Summary version of the report of the Task Force on Hunger*. The Earth Institute at Columbia University, New York, USA.

WRAP UK (2010) *Food waste*. http://www.wrap.org.uk/retail/food_waste/index.html , accessed 16 March 201.

Mobilizing China to Act on the Coming Phosphate Rock Depletion Crisis

Scott Chen, General Manager of China Erdos Eco-tech Consultancy Ltd,
scottchentrier@gmail.com

Abstract

The 3-year operation of the China-Sweden Erdos Eco-town has demonstrated the feasibility of large scale Ecosan projects to the world. China has the potential to take quick action on the coming phosphate rocks depletion endangering food security around the world, provided appropriate information could be communicated to: Chinese policy makers, entrepreneurs as well as the younger generations as an issue of politics, new economy development pattern and recovering Chinese ancient ecological culture.

Part I The Lessons Learned in Erdos

China has the largest population in the world and food security is the foundation of sovereignty and state security. Therefore, the Ecosan program is actually a matter of politics for China.

Chinese could accept the urine diverting toilet (UDT) generally and UDT can be used in the multi-storey buildings technically, proved by the China-Sweden Erdos Eco-town. Investigations between Oct 11-15th 2008, shows 111 of the 141 households were using the UDT exactly as instructed adding sawdust and toilet paper into the faeces bins in the basement.

But, both the local decision makers and some households were careless about the ground water scarcity as well as the food security issue, and the UDTs were ordered to be replaced with normal water flush toilets from May 2009, marking the close of the largest scale Ecosan program in multi-storey buildings in China.

If Chinese policy makers were assured that the phosphorus depletion is a possible threat to the long-term food and state security, they may establish a quick policy on recovering the phosphorus from the human waste and animal manure.

The strict implementation of One Family One Child policy has shown us that China government can take the quickest actions on the sustainability issue.

Part II SOHO CHINA Tian Shui School Ecosan Toilet Project

Even without the support from the Chinese government, the ambitious Chinese entrepreneurs, the major driving force of the economy should be involved in the Ecosan programs aiming at creating a new economy development pattern as well as meeting the Target 10 of MDG 7 halving the proportion of people without sustainable access to sanitation.

In early 2009, collaboration with Soho China led not only to a blog[1] about phosphorus depletion written by Mr. Panshiyi, Soho China Director, read by over one million (inspired by

Arno Rosemarin and myself), but also to the construction of ten toilets with squatting UDT for 10 schools in Tianshui city of Gansu province. Another 20 toilets are under construction to be used by over 30, 000 students and teachers at the end of this year.

The case of SOHO Tianshui Ecosan toilet program reminds us that the international phosphorus research organizations should encourage and support the successful Chinese businessmen to use their charity money for dealing with the phosphorus depletion crisis while most of them still have the horrible memory of the famine in 1970 during which Mr. Pan Shi Yi's two younger sisters had to be given up for adoption and one of his grandfathers starved to death.

"Without a clear target, we often donated money to some areas hit by natural disasters or some schools here and there at the early stage. Only four years ago, did we start to focus on the virtue education where the government money can not be easily seen. Any improvement to the society must start from changing the human heart…", quoted Zhangxin, the SOHO China CEO, as saying, on June 27th , 2010.

Part III Attitudes of Chinese University Students to Human Waste Reuse in Agriculture

As embodied in two Chinese characters, home 家(a pig under a house) and manure**糞**(food excreting to the arable land), using animal manure and human waste as the fertilizer has been a long tradition. It is the most important element of Chinese culture which should be inherited, studied, improved and spread to the world.

Inspired by a research questionnaire[2], 203 students of Guangdong Medicine University were surveyed on Nov 1st, 2007. The results, as shown in the following table, indicate that around 50% of the well-educated university students have the same attitude towards handling human waste as Nigerian and Mali farmers who are almost illiterate.

1. Do you have any knowledge about human waste reuse in Agriculture?		Yes	No	Declined to answer
	China	99.5%	0.5%	0
	Nigeria	52%	39%	9%
	Mali	58%	42%	0
2. Is the use of human waste in agriculture acceptable to you?		Yes	No	Declined to answer
	China	95%	5%	0
	Nigeria	52%	39%	9%
	Mali	48%	40%	12%
3. Would you buy and eat food if you knew it was grown using human waste as manure?		Yes	No	Declined to answer
	China	90%	8%	2%
	Nigeria	51%	41%	8%
	Mali	46%	54%	0
4. What do you think about touching or handling human waste?		unacceptable	acceptable	Declined to answer
	China	52%	30%	18%
	Nigeria	48%	47%	5%
	Mali	58%	30%	12%

For establishing a good culture image, China has financed around 300 Confucius Institutions, USD 150,000 each, in 90 countries since 2004. If Chinese ecological culture is to be included in the teaching activities, they would potentially become more popular to westerners who often regard it as political propaganda.

References

GTZ, Mercy Akerelolu, Ibiyemi Ilesanmi, Ralf Ottepohl,(2006), 'the Attitudes of rural people in Mali and Nigeria to human waste reuse in Agriculture', http://www2.gtz.de/Dokumente/oe44/ecosan/en-attitudes-rural-people-2006.pdf, accessed August 2, 2010.

Pan Shiyi, (2009), 'The Largest Crisis in the World is Phosphorus Depletion', http://blog.sina.com.cn/s/blog_4679dbbf0100cves.html, accessed August 2, 2010.

Managing Phosphorus Pollution – the Case of The Baltic Sea

Åsa Danielsson, Water and Environmental Studies,
Linköping University; Linköping, Sweden.
asa.danielsson@liu.se

Eutrophication is one of the most well-known anthropogenically driven environmental problems of today. It is a world wide phenomenon found in coastal zone all over the globe. The process of eutrophication affects the ecosystem in a number of ways – changes in the constitution of flora and fauna, decreased water transparency, increased oxygen consumption causing hypoxic/anoxic sediments. One of the most studied water bodies affected by eutrophication is the Baltic Sea, where the primary production today is 3-4 times higher than at the end of the 19th century (Savchuk *et al*., 2008). This process is caused by a higher load of nutrients – mainly nitrogen (N) and phosphorus (P), which have increased by 4 respectively 8 times during the 20th century (Larsson *et al.,* 1985). During the latter years, the loads seem to have levelled off (Papush and Danielsson, 2006), but the affects have not, *e.g*. have the extent of cyanobacteria blooms increased due to an excess of PO_4 and nitrogen shortage in the surface waters. To combat these toxic blooms the P concentrations must decrease even further. Further efforts including both external and internal loads are needed in order to reduce eutrophication.

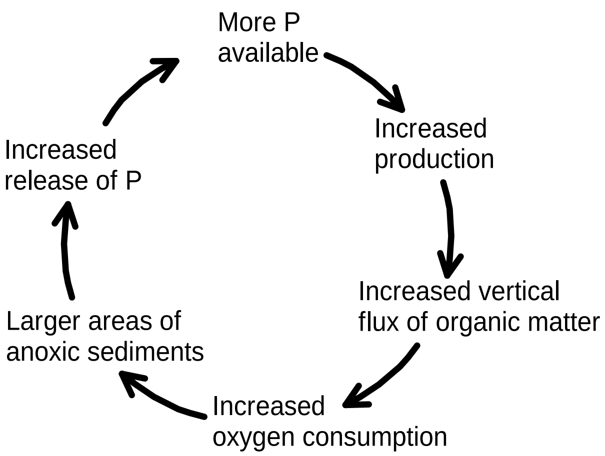
Key Challenges and Opportunities – External Loads

To decrease the load from the drainage area remedy actions must be put forward, both for point sources and more diffuse ones. According to HELCOM (2005) the major P load comes via agriculture (45%), waste water treatment plants (20%), industries (17%), and single outlets (12%). Wulff *et al.* (2007) tested different scenarios of remedy actions to evaluate the response of the Baltic Sea to different changes in load. According to their study, improving sewage treatment (90% P removal) in all countries led to a decrease in P load by 33 % with large improvements for the cyanobacteria blooms and the spread low oxygen sediments decrease. Also P free detergents had a major affect, while improved manure handling and reduction of livestock did not significantly contribute. However, it is probably not cost effective to use the same remedy actions in each country. Geographically, Poland represents the single largest contributor (39%), followed by Russia, Sweden, Finland and Lithuania (10-13% respectively; HELCOM, 2005). The other countries only contribute with 2-5% each. The greatest potential for P reduction is found in the eastern states (Humborg *et al.,* 2007; Wulff *et al*., 2007). To be able to run large-scale scenarios, with the possibility to change input data, is an opportunity not only to evaluate future situations but also to involve stakeholders to participate in the process.

Key Challenges and Opportunities – Internal Loads

During the last few years the internal P source, *i.e.* P in the sediments and the bottom waters, has been discussed more frequently. The amount of inorganic P is coupled to the oxygen concentration in the deepwater (Conley *et al*., 2002). When the bottom waters are oxygenated the sediments may bind more inorganic P. Changed conditions to a hypoxic/anoxic environment will result in mobilisation of the iron-bound phosphate (Figure 1). The deep water sediments can almost instantly bind/release ~3 g P m^{-2} when becoming oxic/ anoxic (Stigebrandt and Gustavsson, 2007).

Figure 1. The vicious circle of phosphorus in aquatic ecosystems



During the 90's the phosphorus content decreased by one third, which coincided with an inflow of saline water, lowering the halocline (a drastic change in the vertical salinity profile separating less saline from more saline water volumes) with an oxygenation of deep waters that allowed P to bind to Fe in the sediments. After a few years, the halocline raised once more, the oxygen content decreased and the environment went back to a state with high P content and extensive cyanobacteria blooms. This event, however, triggered the idea that it should be possible to counteract hypoxia and return the system into a less eutrophic state using artificial oxygenation of the deep water by enforced mixing. This is the starting point of BOX – a pilot study to evaluate effects of possible Baltic deep water oxygenation, where the efficiency of phosphorus retention under various conditions, with and without artificial oxygenation, will be studied. This will be performed by laboratory studies, field measurements, the installation of a wind driven pump, budget calculations and modelling. This is a key research large-scale study to find ways to control the increasingly essential internal load.

Biography

Åsa Danielsson is an associate professor in Water and Environmental Studies (Linköping University, Sweden). She is working with modelling of biogeochemistry in aquatic environments and especially of nutrients and heavy metals. Her address: D. of Thematic Studies – Water and Environmental Studies; Linköping University; SE-581 83 Linköping, Sweden. E-mail: asa.danielsson@liu.se

References

Conley, D., C. Humborg, L. Rahm, O. Savchuk and F. Wulff (2002), 'Hypoxia in the Baltic Sea and basin-scale changes in phosphorus biogeochemistry', *EST* 36, 5315.

HELCOM (2005), 'Nutrient pollution to the Baltic Sea in 2000', *Baltic Sea Env. Proc*. 100.

Mörth, M., Humborg, C., Eriksson, H., Danielsson, Å., Rodriguez Medina, M., Löfgren, S.,
Swaney, D. and Rahm, L. (2007), 'Modelling nutrient transport to the Baltic Sea: A large-scale approach', *Ambio* 36(2-3): 124-133.

Larsson, U., Elmgren, R., Wulff, F. (1985), 'Eutrophication and the Baltic Sea', *Ambio* 14, 9-14.

Papush, L., Danielsson, Å. (2006), 'Silicon in the marine environment: dissolved silica trends in the Baltic Sea', *Estuarine, Coastal and Shelf Science* 67, 53-66.

Rosenberg, R & Diaz, JD (1993), 'Beggiatoa (spp.) mats indicate hypoxic conditions in the inner Stockholm Archipelago', *Ambio* 22(1), 32-36.

Savchuk, O., Wulff, F., Hille, S., Humborg, C. and Pollehne, F. (2008), 'The Baltic Sea a century ago - a reconstruction from model simulations, verified by observations', *Journal of Marine Systems* 74(1-2), 485-494.

Stigebrandt, A. and Gustavsson, B. (2007), 'Improvement of Baltic proper water quality using large-scale ecological engineering', *Ambio* 36, 280-286.

Wulff, F., Savchuk, O., Sokolov, A., Humborg, C and Mörth C.-M. (2007), 'Management options and effects on marine ecosystem: assessing the future of the Baltic', *Ambio* 36(2-3): 124-133.

The Material Flow Analysis as a Tool for Planning

David A. Vaccari, Ph.D., P.E., BCEE
Stevens Institute of Technology, Hoboken, NJ USA
dvaccari@stevens.edu

Key Challenges and Opportunities

One of the challenges that was discussed at the Linköping workshop regarded how to map out a future for phosphorus production and consumption. Part of the discussion revolved around Figure 11 from (Cordell et al, 2009a). This Figure shows “Long-term historical and future sources of phosphorus fertilizers for global food demand, based on aggregated preferred future scenarios.” Current phosphorus sources for food are shown to be primarily from phosphate rock, secondarily from animal waste, and the third-largest source is from crop residue. Current trends indicate that phosphate rock production may peak as early as 2033 (Cordell, et al., 2009). In the long term, if we implement conservation by dietary changes and increased efficiency in the food chain and in agriculture, most fertilizer may come from animal waste.

During the workshop discussion, the question was raised as to whether animal wastes could be considered a “source.” A similar question was raised regarding the effect that dietary changes resulting in reduced meat consumption would have on phosphorus production. In response, it was pointed out that decreased meat consumption and increased manure recycling both would reduce demand for phosphate rock by reducing the area of cultivated land. Fertilizer use would be reduced accordingly, along with losses along the usage chain, such as from erosion.

Questions such as these would best be addressed in terms of the material flow analysis (MFA), such as shown in Figure 3 in Cordell et al. (2009b). An MFA can be described as a set of stocks (or reservoirs) and flows connecting one reservoir to another or to external sources or sinks. The stocks are quantified as mass of material and the flows as mass per unit time moving from one stock to another, or between a stock and an external source or sink. The MFA is diagrammed as a network of boxes representing the reservoirs, connected by arrows representing the flows. Projections for planning purposes should show how the values of the flows should or would change. Expressing changes in terms of the MFA would help ensure that interactions among the flows are accounted for, such as the effect of manure recycling on fertilizer use.

The utility of the MFA as a planning tool could be further improved by formulating it as a predictive model. Ideally, the model would be a dynamic material flow analysis (DMFA), which can predict rates of changes of the flows. In an MFA or DMFA model, each flow would be expressed as a function. The independent variables for an MFA model would include: the other flows, the stocks, exogenous variables. A DMFA could also include previous values of the independent variables. Exogenous variables include, for example, the price of phosphate rock on the spot market, climatic events (e.g. droughts or floods), government interventions, or factors governing export demands. The first steps in developing DMFA models have been taken by Chen, et al. (2008) and by Neset, et al. (2008). Their models are based mostly on exogenous variables. Neset, et al. interpolated the independent variables at 30 to 50 year intervals, allowing them to interpolate their predictions for intermediate time periods.

Current Contributions

My research group has focused on stochastic empirical modeling, including linear autoregressive models with exogenous variables and artificial neural networks. This led to the development of multivariate polynomial regression, which combines advantages of both approaches. The robustness of MPR was shown by its ability to reproduce the dynamics of chaotic processes (Vaccari and Wang, 2007).

We have applied these techniques for modeling and optimization of complex systems for NASA research on advanced life support systems (ALS). ALS involves the use of plant growth chambers, food production, and waste recycling for long-term space missions such as a three-year Mars mission. This work is directly applicable to the development of models such as are proposed above. The work included research in waste treatment and in nutrient recycling (Levri et al. 1998), as well as modeling and optimization of the ALS system (Vaccari and Levri 1999). This work has recently culminated with a mechanistic dynamic material flow model of the ALS system tracking fourteen compounds and consisting of over 600 individual material flows in forty-five modules within six subsystems (Levri, 2010).

Research and Policy Priorities

I suggest that we need to learn how to empirically fit models of the flows to periodic data on the independent variable set explicitly, deriving a data-driven dynamic model as described above. These models could be used to evaluate interventions aimed at conserving the phosphorus resource while minimizing environmental and economic harm.

Further research directions for this area could include developing integrated models to link MFA models of a variety of resources necessary to sustain the population, such as for nutrients, water, and energy, along with modeling of population and economic factors. This is a long-term goal that could lend more precision to the discussion of global sustainability.

Biography

Dr. Vaccari has a B.S., M.S. and Ph.D. degree in environmental science and a M.S. in chemical engineering, all from Rutgers University. He has been professor of environmental engineering at Stevens for twenty-five years. His areas of specialty include wastewater treatment and nonlinear empirical modeling. More recently he has been involved in modeling advanced life support systems for long-term space travel, which led to his interest in modeling biogeochemical cycles.

Contact

David A. Vaccari, Ph.D., P.E., BCEE, Professor, Department Director, Civil, Environmental and Ocean Engineering, Stevens Institute of Technology, Castle Point-on-the-Hudson, Hoboken, NJ 07030, PH: 201/216-5570; FAX: 201/216-8739, Email: dvaccari@stevens.edu; URL: http://personal.stevens.edu/~dvaccari/.

References

Chen, M., J. Chen and F. Sun, (2008) *Science of the Total Environment*, 405(1-3), 140-152.

Cordell, D., T. Schmid-Neset, S. White, J.-O. Drangert, (2009a) “Preferred future phosphorus scenarios: A framework for meeting long-term phosphorus needs for global food demand," International Conference on Nutrient Recovery from Wastewater Streams. Edited by Ken Ashley, Don Mavinic and Fred Koch. ISBN: 9781843392323, IWA Publishing, London, UK.

Cordell, D., J.-O. Drangert, S. White, (2009b) "The story of phosphorus: Global food security and food for thought," *Global Environmental Change* 19, 292–305.

Levri, J., K. Davies, D.A. Vaccari, C. Christodoulatos, T.-L. Su, (1998) "Modeling Long-Term Biodegradation of Inedible Plant Material", *SAE Technical Paper Series* 981819.

Levri, J., Ph.D. Thesis, (2010) "Global Modeling and Optimization of an Advanced Life Support System" (expected).

Neset, T., H.-P. Bader, R. Scheidegger, U. Lohm, (2008) "The flow of phosphorus in food production and consumption — Linköping, Sweden, 1870–2000," *Science of the Total Envir*. 396, 111 – 120.

Vaccari, D. A., Levri, J. (1999). "Multivariable empirical modeling of ALS systems using polynomials." *Life Support and Biosphere Science*, 6, 265-271.

Vaccari D. A., and H.K. Wang, (2007). "Multivariate polynomial regression for identification of chaotic time series." *Mathematical and Computer Modeling of Dynamic Systems*, 13 (4), 319-325.

On the Criticality of Integrating Social Science, Humanities and Existing Knowledge in Phosphorus Sustainability Research

Andrea E. Ulrich[2]
Natural and Social Science Interface (NSSI), Institute for Environmental Decisions,
ETH Zurich, Universitaetsstrasse 22, CHN J70.1, 8092 Zurich, Switzerland
andrea.ulrich@env.ethz.ch

The discourse currently developing on phosphorus (P) and global food security presented during the Linköping workshop raises a number of questions that need to be dealt with in order to establish a P mitigation strategy. Indeed, one of the most apparent issues concerns the kind of research and development required to appropriately assess and deal with the phosphorus challenge. The following is a call to use existing knowledge in a much more integrated fashion and enhance the involvement of social sciences and humanities in P sustainability research.

An Integrative Natural-Social Science Link

The introduction of declining phosphorus reserves into the global food security discourse opens a wide variety of P research opportunities in many different fields, including economics, resources management, security studies, law, governance and environmental history. Nevertheless in phosphorus research, efforts have traditionally orbited around natural sciences, ranging from plant nutrition to soil science and geochemical flow assessment. With the phosphorus sustainability debate emerging and quickly moving to a here-to-stay status, so too are calls for a more comprehensive understanding of production costs and related resources use, such as for energy and water; environmental and human health risks, including eutrophication; and broader societal impacts associated with changing supply and demand patterns, among other issues. While we know much about natural aspects of the P cycle, understanding of its human influence remains less understood. To conduct P sustainability research in a meaningful way, various science domains such as natural and engineering sciences together with humanities and social sciences should cooperate. To apply social sciences and humanities can add substance as Prof. Mauch from the Rachel Carson Center in Munich points out: "Humanities imply creativity and stimulations – a potential beyond the calculation of statistics and statisticians, engineering and economic studies. Their strength is in reflecting the deficits and defects of science, technology and economy" (MUM, 2009). Integrating and encouraging these research fields to contribute offers possibilities that go hand-in-hand with the process of finding solutions, to make holistically-informed choices among alternative actions.

2 I thank Diane Malley for her helpful remarks in reviewing this article.

While new funds are required for research and development in this field, it is also important to expand current programs. Much can be learned from integrating what is already known in various areas of research. A great deal of the information we are using today is derived from sources available on the web, yet going beyond current cyberspace data and modern literature available in languages other than English might provide crucial insights. To find such information, reassess it under given circumstances and include it into the emerging P sustainability research appears to be another important task for the future. Nonetheless, any endeavor to solve the phosphorus challenge needs to include solutions outside the technological toolbox. The belief that we, as western societies, can continue current lifestyles and consumption pattern leads to false expectations (Ekardt et al., 2010). This required different perspective needs to be examined by humanities and social sciences, not only by natural sciences and engineering to which environmental issues have traditionally been left (Daschkeit & Schröder, 1998).

Interdisciplinarity and Transdisciplinarity as Sustainable Coping Strategies

Similarly to the case of climate change, strategies to holistically assess and compile necessary information for crucial change in P resource understanding, use and reuse require an interdisciplinary approach. There are many good reasons to engage in interdisciplinary research and perspectives in respect to sustainable resources management challenges. Each discipline has aspects that are being addressed in a more progressive fashion than in others, yet as a whole these various disciplinary constraints can be overcome. To engage different disciplines can be a way to promote innovative exchange on both challenges and opportunities in establishing P security, a common concern of those attending the workshop. Yet, while it is essential to “think collectively about complex problems” in a horizontal way, the issue also needs to be addressed from a vertical perspective (Klein, 2004). By this, Klein refers to transdisciplinarity, engaging stakeholders and society by conducting research in action (Lewin, 1942). This, in essence, refers to focusing on the interface between science and society, integrating practice and research from the outset. Such an approach, namely to foster exchange between both researchers and practitioners working in different disciplines on various scales, is likely to result in better understanding of the complexities and allows the formulation of entry points for improving current practices (Scholz, in prep.; Ulrich, 2010). To engage in inter-and transdisciplinary research can help to further facilitate networking, dialogue and growing awareness. And it can help to expand our disciplinary “silo and Mikado mentalities” to combine the many separate existing initiatives towards comprehensive research and action so that the human-nature relationship is reflected centrally in a more systemic way.

P Scarcity Associated with Social Process

While scientific discourse is growing, the potential P scarcity has yet to make its way onto the political agendas of the world. Moreover, considerations on how to include the issue into social discourse for discussion and consideration are of critical importance. Clearly, to broadly include society in this process will be demanding. Especially so since the social process needs to be made culturally relevant, hence including a North-South dimension assessing P availability, accessibility, and distributive justice. This should be done as an outset, not as an attempted add-on. While there is no substitute for expert knowledge or innovative technical solutions, there is a need for the quintessence of sustainability. That is, to develop within societies the ability to sustain. This makes P sustainability less top-down than bottom-up. Any efforts in developing sustainability in P use and reuse are likely to fail if they stay detached from civil society. Our current "window of opportunity" hands a unique possibility to all stakeholders, including the public to develop sustainability oriented around the five pillars of sufficiency, efficiency, consistency, responsibility and capacity (resilience). In this respect, transdisciplinarity and participation are social shaping tools for sustainable transformative processes. These cannot be created within science alone but require the social context to discuss and pinpoint crucial processes. Moreover, political will and an open and free media are required as necessary components of societal response. Such a process through participation is required as one of the four pillars constituting sustainability on the operative level, in order to identify and list problems as well as to categorize priority areas within which more detailed investigation and action must be carried out.

P Research and the Human-Nature Interface

Climate change and water security are two of the mega issues of the 21st century. Declining phosphorus reserves is likely to become another one. Therefore, evolution towards holistic views and actions on both the regional, national and global scale are required. Studies combining the human-nature interface as well as social-environmental studies, in general, are likely to play a central role in the future. Research questions focusing on human-nature systems management, values, needs and preferences of stakeholders and the larger public, personal relationships and experiences, governance and stewardship aspects can be very interesting. These outcomes could then become indicators for further investigation and basis for action. This can potentially complement and provide direction in terms of securing ecologically sound, efficient and socially effective resource use. Given the challenges we are facing in the 21st century, the role of human-nature systems management and the role of social sciences and humanities cannot be overlooked. Therefore, the unrealized potential for research, linkages and information sharing not only among stakeholders but also within academia itself need to be addressed. To take advantage of the considerable interest and solid opportunities in such linkages as e.g. proposed with establishing a Phosphorus Research Network seems to be a promising first step towards sustainable P futures.

Biography

Andrea E. Ulrich studied American Cultural History, Geography and Law at LMU Munich, Germany. She received a M.Sc. in Sustainable Resource Management from TUM Munich and is currently conducting phosphorus sustainability research at ETH Zurich. Grounded in a human-environment system perspective, her work focuses on phosphorus management and stewardship options.

References

Daschkeit, A. & Schröder, W. (Eds.) (1998). Umweltforschung quergedacht. Perspektiven integrativer Umweltforschung und –lehre. Berlin: Springer.

Ekardt, F., Holzapfel, N. & Ulrich, A. E. (2010). Nachhaltigkeit im Bodenschutz - Landnutzung und Ressourcenschonung. Phosphor-Düngung und Bodenbiodiversität als Rechtsproblem. UPR Umwelt-und Planungsrecht. Forthcoming.

Klein, J. T. (2004). Prospects for transdisciplinarity. Futures 36, 512–526.

Lewin, K. (1948). Action research and minority problems. In G. W. Lewin (Ed.). Resolving social conflicts (pp. 201-216). New York: Harper & Row.

MUM. (2009). Rachel Carson Center, Munich. Internationales Kolleg für Umweltforschung. Globale

Geistesblitze. Retrieved October 28, 2009, from http://www.rachelcarsoncenter.de/html/media/mum_02_2009.pdf

Scholz, R. W. (2011) Environmental Literacy in Science and Society: From Knowledge to Decisions. Cambridge: Cambridge University Press.

Ulrich, A.E. (2010). Slowing the Flow. Food and Water Security in the Lake Winnipeg Basin. An Action Research Approach for Sustainable Phosphorus and Water Resources Management. Master`s thesis, TUM Munich.

Workshop Synthesis

Professor Stuart White

The workshop was organized around the four thematic areas of:

1. Food security and current sustainability challenges (Session hosts Prof. Stuart White and Prof. Björn-Ola Linnér).
2. Sustainable Phosphorus use in agriculture (Session hosts Dr. Jaap Schröder and Dr Bert Smit).
3. Sustainable sanitation and nutrient recovery (Session hosts Elizabeth Tilley and Dr Jan-Olof Drangert).
4. Managing phosphorus pollution and waste from mine to field to fork (Session hosts Dr Åsa Danielsson and Dr Arno Rosemarin).

The following synthesis is based on presentations, discussion and the outcomes of the World Café[3] table discussions during the workshop, and our gratitude goes to the session hosts for contributing with a summary of their specific thematic area.

Food security and current sustainability challenges

The discussions about food security and the most current sustainability challenges including climate change and global resource use and resource scarcity identified some particular research gaps including the evident need to study the footprint of embodied phosphorus (the 'P-Food-print') in order to cover phosphorus flows and losses through the entire food production and consumption chain. A particular emphasis lies in the call for an integrated approach, which includes water, land use, and other crucial resources for food production.

One of the important future research challenges discussed during the workshop is the development of future scenarios for phosphorus supply and demand, which specifically needs to address the role of future diets. Interactive scenarios that allow the creation and exploration of the scenarios in, for example, stakeholder workshops are an option that should be further explored. This would also contribute to identifying the linkages and synergies between future phosphorus use and other sustainability challenges and measurements that need to be taken.

The issue of data scarcity on phosphorus flows was a recurring issue and the need to expand data access and availability on some areas such as waste and losses throughout the food chain etc. was discussed.

3 World Café is a facilitated workshop method for creating collaborative dialogue, sharing mutual knowledge and discovering new opportunities for action. The process (based on the theory of systems thinking), creates dynamic conversations that can catalyze a group's collective intelligence around the questions and issues that matter most to the group as a whole. This method has been used in many international and national forums and workshops, including the World Resources Forum in Davos, 2009.
For more information see: http://www.theworldcafe.com/articles/cafetogo.pdf

However, we also need to increase the consideration of ethical issues and human rights issues in our studies on global phosphorus scarcity and food security.

In terms of policy issues, the discussions focused on two areas:

- Would a sustainable use of phosphorus be encouraged by using the price mechanism or taxation system, and what efficiency could such a system provide?
- The need for further analysis of the relative cost-effectiveness of options to reduce phosphorus use and wastage, in effect the development of a comprehensive 'supply curve' to illustrate the most cost-effective options.

Sustainable Phosphorus Use in Agriculture

In relation to the question of what new knowledge is needed regarding phosphorus use in agriculture, some of the participating researchers considered that there is no specific need for new knowledge, but instead a need for integrated actions. It was also pointed out that there is a large difference between regions in terms of whether the problem of lack of phosphorus use efficiency stops at harvest or continues along the entire food chain.

Would it in general terms be necessary to reconsider our spatial planning to bring production (e.g. from human waste) and consumption of phosphorus closer together again to increase efficiency in agricultural phosphorus use? Also in this section, we identified a need for scenario studies, for example, some of the identified studies were whether the EU could be self-reliant and what that would imply for requirements on phosphorus use and re-use. Most attendees concluded that there is little need for much additional knowledge before action can be taken to improve phosphorus use, although a number of areas were identified where additional research and knowledge would support this, and these are listed below. There is a good knowledge based on:

- the phosphorus value of organic inputs;
- soil phosphorus chemistry;
- short and long term recovery of soil phosphorus;
- technology to use phosphorus inputs more efficiently.

The challenge relates to the application of knowledge, rather than its generation and transfer.

The specific areas or issues that were identified where there is still a need for additional knowledge include:

- How much phosphorus is unnecessarily lost between farm and market ('South') and between market and mouth ('North')?
- To what extent does spatially separated production (farms), processing (industries) and consumption (urban regions) make phosphorus recycling more difficult? Is 'small beautiful' or should we go for clustering in larger units?
- To what extent would self-reliance of Europe in terms of phosphorus, affect Europe's food export position and, hence, food security elsewhere?
- As extensive use of phosphorus in agriculture is partly inspired by risk aversion, there is scope for more research into the underlying motivations and alternative institutions to compensate those exposed to risks.

- It is still difficult to say whether efficient use of phosphorus is best stimulated with fees or premiums, i.e. the use of a price mechanism on specific inputs, on balance surpluses, or on output/input ratios. This needs further investigation.

Further discussion on the areas of communication and knowledge focused on how we can cope with the cultural barriers to using phosphorus from urine and faeces in food production, and how we can achieve a better understanding of strategies for sustainable use of phosphorus resources in agriculture through greater communication and knowledge generation. In particular, some participants highlighted the lack of interaction between the waste producers (such as the wastewater treatment industry) and the farmers who are meant to use the phosphorus in sludge and organic waste. Discussion also pointed to the need for improved communication on the implications of regional biofuel production and use, since biofuel production is likely associated with an additional need for phosphorus (unlike other renewable energy sources such as photovoltaic cells).

The trend to privatise agricultural extension services was also highlighted as a barrier. In almost all countries, state-supported extension services have been replaced by extension services that are paid for by firms selling phosphorus. This transition is not necessarily conducive to an efficient use of phosphorus fertilisers, and there is a need to rethink how information is transferred to farmers.

Recycling of human urine and faeces is, among many other measures, needed for the sustainable use of phosphorus. Recycling of this resource may, however, be undermined by cultural barriers. This will require an extensive communication program in many parts of the world. If it is important for industrial and urban residues to be recycled for agricultural use, the industry representatives producing these residues should interact with farmers regarding appropriate composition and contaminant levels. Without such interaction, residues will continue to be seen as waste products that are of no value. Although the general public may be hardly concerned about the environmental implications of phosphorus use, it is certainly interested in food security, even in developed countries. This basic interest should be used to put phosphorus on the political agenda.

One of the improvements and changes within the policy area that was discussed was the suggestion to come up with a system similar to the idea of a ‘fee-bate’ or hypothecated tax revenue that can be used to improve the efficiency of phosphorus use. Capacity building by itself will only contribute to sustainable use of phosphorus in those circumstances where lack of action has been caused by lack of awareness among stakeholders. Unfortunately, unsustainable use of phosphorus is often a direct result of a lack of appropriate pricing signals, since the price does not reflect the many externalities of the mining, manufacture and distribution of phosphorus fertilizer, including the limitations of the resource. Future policy initiatives affecting the use of phosphorus seem inevitable, and these initiatives should ideally consist of smart combinations of ‘sticks and carrots’, that is, rewarding those that use phosphorus sustainably and charging those that do not. Some participants pointed out that there should be less emphasis on penalty to farmers – that is, there should be more carrots rather than sticks.

Sustainable Sanitation and Nutrient Recovery

With regard to the issues of sustainable sanitation and nutrient recovery the research gaps discussed ranged from questions regarding whether urine diversion is an option, to the need to determine reasons as to why urine separation is not currently a widely applied solution. Is this due to technical or perception issues, or is it the users or the people installing and operating these systems? The need for more analysis from the initial implementation of urine separating systems was highlighted, along with analysis of the social aspects of aversion to certain characteristics of urine-separation (e.g. names, colours and concepts).

To identify future sustainable pathways, we need to be looking at the best technologies for the best situations (e.g. optimizing socio-technical systems), provide cost benefit analysis for different technologies, taking into account environmental and health benefits, and compile the experiences from the ecological sanitation community - keeping in mind that the adoption of the standard flush toilet was also slow to make progress.

Further, the value of reuse and recycling of phosphorus needs to be communicated, and we might need to be changing the lexicon, as vocabulary changes the perception – e.g. from 'waste' to 'resource stream'.

What policy measures and institutional frameworks would be needed then to achieve a sustainable future? Economic incentives given to products was one means discussed, e.g. to put a price on the value of sludge, but also to provide for the possibility of selling nutrients back to agriculture and food production. A possible way would be to enable farmers buying phosphorus from waste - the same way that the power companies can buy power from private generators. Especially in developing countries where processes are often at a smaller scale – sewer-mining opportunities might have the potential to spur innovation. Other incentives for returning nutrients, e.g. organic waste, might be orchestrated in a similar way to the way we recycle cans. However all this needs to be coordinated by a central body – located in agricultural or environmental ministry- or, as suggested, why not a future Ministry of Food?

Managing Phosphorus Pollution and Waste from Mine to Field to Fork

In the session a number of priorities and key steps were identified. The basic precondition for the discussion is the evident need to reduce external phosphorus loads, and we need to find ways to reduce internal sources. Phosphorus reuse was pointed out as a crucial strategy to decrease pollution and reduce losses.

The research gaps and needs that were discussed ranged from the mapping of regional phosphorus flows (for example Stockholm phosphorus stocks and flows), to the extension of research on mapping regional and global flows. Further, there is a need for more studies based on both static and dynamic substance flow analysis from the local to the global level. Research challenges also lie in studying the opportunities of phosphorus reuse, e.g. through pricing of phosphorus use and phosphate rock use. Synergies with bioenergy production also need to be studied for instance with focus on the extraction of algae, and regarding acceptable levels of metal concentrations and other contaminants in organic waste. The idea of a cap on phosphorus flows was discussed.

Policy recommendations were strongly linked to current environmental goals, such as the 2030 scenario of zero discharge, or the Baltic Sea Region 1988 goal to cut phosphorus emissions by 50%. There is also a need for policies that focus on both biophysical and geographical linkages – e.g. the EU Water Framework Directive is already based on runoff areas and research projects need to be linked up on a joint platform. There are intergovernmental examples of eutrophication governance, as the example of the Great Lakes and the Baltic Sea shows. The question remains however, regarding the opportunities for the reducing the flows, and there is a clear demand to create incentives for reuse and composting. The challenge is clearly focused on improving the efficiency of the system. A key tool is to involve the stakeholders from industry, research, government, financial, media and civil society, to identify sustainable pathways. However, the question remains regarding who are the main stakeholders and how do we get them involved and how do we create a platform for interaction between these stakeholders?

Priorities and Next Steps

An objective of the Workshop was to create the platform for research and decision-making, as identified in the different workshop sessions as well as to provide an analysis of synergies and linkages. The initial steps that were discussed at the workshop were to create a research programme, to provide a White Paper with an analysis of the problem and its complexity. Similarly, the Declaration on Phosphorus Security (available in the Appendix of these Proceedings) represents a communication of the Global Phosphorus Research Initiative (GPRI), and the development of the Global Phosphorus Network are important steps in research communication and stakeholder interaction. The question of how to secure research and network funding was obviously an important part of the Workshop discussions.

In almost all groups the essential need to collect more data was highlighted, including questions of who collects, manages, controls the data and how we ensure transparency?

National stakeholder workshop(s) should be considered as part of future research endeavours, similar to the Australian stakeholder workshop held in Sydney in November 2008[4]. This provides us with the possibility to bring together the key stakeholders at the regional or international level. Important stakeholders and research collaborations were discussed, such as with the UN's FAO, and the inclusion of national farming organisations which could be connected on a multi-national level, for example through conferences or workshops. Other current activities that were discussed included: the existing phosphorus cost action, with a focus on eutrophication (Wageningen University); the example of regional round tables in Canada, the Alliance for a Green Revolution in Africa, and phosphorus flow analysis studies in Stockholm, with a focus on the Baltic Sea Region. The GPRI aims to set up a joint email list and a connected discussion group with the potential participants of the Global Phosphorus Network.

So, What Are Our Next Steps…?

We aim for participants to continue to promote a sustainable phosphorus future in the framework of international conferences and international policy and industry meetings, for example at the International Phosphate Conference that was held March 2010 in Brussels and the International conference on phosphorus at Arizona State University in February 2011 (Sustainable Phosphorus Summit) and other national and regional conferences. Further, the Global Phosphorus Network and website will be launched in late 2010, hosted by members of the Global Phosphorus Research Initiative, and with support from participants of this workshop.

4 See http://phosphorusfutures.net/news#Future_of_Phosphorus_workshop.

Appendix

Workshop Program

Thursday Feb 25th

14.30 – 15.30, Open Public Lecture:
An environmentally sustainable diet: good for our health and good for the planet
Dr. Rosemary Stanton, Nutritionist and Visiting Fellow, School of Medical Sciences, University of New South Wales

Friday Feb 26th

8:30 – 9:00	Registration and coffee	
9:00 – 9:15	Welcome note	*Åsa Danielsson* (Head of Department, Department of Thematic Studies - Water and Environmental Studies, Linköping University)
9:15 – 9:30	Workshop introduction, objectives and overview	*Tina Schmid Neset* (Department of Thematic Studies - Water and Environmental Studies, Linköping University) *Dana Cordell* (Department of Thematic Studies - Water and Environmental Studies, Linköping University and Institute for Sustainable Futures, University of Technology, Sydney)
9:30 –10:30	**SESSION 1**: Food security and current sustainability challenges (presentation and group discussion)	*Stuart White* (Institute for Sustainable Futures, University of Technology, Sydney) *Björn-Ola Linnér* (Centre for Climate Science and Policy Research /Department of Thematic Studies – Water and Environmental Studies)
	Coffee break	
10:45-11:45	**SESSION 2**: Sustainable Phosphorus use in Agriculture	Jaap Schröder (Wageningen University) Bert Smit (Wageningen University)
11:45– 12:45	**SESSION 3**: Sustainable sanitation and nutrient recovery	Jan-Olof Drangert (Department of Thematic Studies - Water and Environmental Studies, Linköping University). To be announced
	- Lunch -	
14:15 – 15:15	**SESSION 4**: Managing phosphorus pollution and waste from mine to field to fork	*Åsa Danielsson* (Department of Thematic Studies - Water and Environmental Studies, Linköping University) Arno Rosemarin (Stockholm Environment Institute)

15:15 – 16:15	WORLD CAFÉ	Session hosts, Tina Schmid Neset and Dana Cordell
16:30 – 17:30	SYNTHESIS – PRIORITIES & NEXT STEPS	*Stuart White* (Institute for Sustainable Futures, University of Technology, Sydney)
17:30–18:30	Drinks and mingle	
19:00	Workshop dinner	

List of Participants

Name	Affiliation
Dr Tina Neset	Department of Thematic Studies - Water and Environmental Studies, Linköping University
Dr Dana Cordell	Department of Thematic Studies - Water and Environmental Studies, Linköping University and Institute for Sustainable Futures, University of Technology Sydney
Dr Stuart White	Institute for Sustainable Futures, University of Technology Sydney
Dr Jan-Olof Drangert	Department of Thematic Studies - Water and Environmental Studies, Linköping University
Dr Bert Smit	Plant Research International Agrosystems Research, Wageningen, Netherlands
Dr Jaap Schröder	Plant Research International Agrosystems Research ,Wageningen, Netherlands
Dr Arno Rosemarin	Stockholm Environment Institute, Sweden
Dr Dan Childers	Arizona State University, USA
Michelle McCrackin	Arizona State University, USA
Dr Rosemary Stanton	Nutritionist and Visiting Fellow, School of Medical Sciences, University of New South Wales
Dr David Vaccari	Civil, Environmental and Ocean Engineering, Stevens Institute of Technology, USA
Dr Christian Sartorius	Fraunhofer ISI, Karlsruhe, Germany
Dr Zsofia Ganrot	Melica, Göteborg, Sweden
Andrea Ulrich	ETH Zürich, Institute for Environmental Decisions, Switzerland
Elizabeth Tilley	EAWAG, Zürich, Switzerland
Kimo van Dijk	University of Amsterdam, Netherlands
Dr Cynthia Carliell-Marquet	School of Civil Engineering, College of Engineering and Physical Sciences, University of Birmingham; UK
Dr Mats Johansson	Ecoloop, Stockholm, Sweden
Dr Håkan Jönsson	Swedish University of Agricultural Sciences, Sweden
Dr Jan Lundqvist	Stockholm International Water Institute, Sweden
Dr Åsa Danielsson	Department of Thematic Studies - Water and Environmental Studies, Linköping University, Sweden
Dr Björn-Ola Linnér	Department of Thematic Studies - Water and Environmental Studies/Centre for Climate Science and Policy Research, Linköping University, Sweden
Dr Julie Wilk	Department of Thematic Studies - Water and Environmental Studies/Centre for Climate Science and Policy Research, Linköping University, Sweden