CIWEM Chartered Institution of Water and Environmental Management

Policy Position Statement

Phosphorus: wastewater's potential in stewardship of a vital resource

Purpose

This Policy Position Statement outlines the main issues relating to the world's supply of useable phosphorus[1] and highlights the need for urgent action to achieve its recovery from urban wastewater to improve food security and reduce geopolitical risk.

CIWEM considers that:

1. There is a global issue of phosphorus depletion, the extent and urgency of which is not appreciated sufficiently widely.
2. Action is required now to start to reduce the rate at which this essential, non-substitutable resource is being depleted. There is no time to delay in initiating action.
3. High priority should be given to recovering phosphorus from urban wastewater. All governments should follow the leads given by Sweden and Germany and make phosphorus recovery from urban wastewater a legal requirement.
4. Consideration of the impact on the stewardship of phosphorus should be included in the design of policies and strategies.
5. Land application of suitably treated biosolids (sewage sludge) is the best way to conserve and recycle the phosphorus it contains.
6. To date, attention has focussed on the effects of phosphorus in the wrong place, i.e. eutrophication of waters; in future attention should also focus on capturing phosphorus from waste-streams and recovering it for use.
7. When sewage sludge is burnt, gasified, etc. there should be a requirement to recover the phosphorus or at the very least to store the phosphorus-rich residues (ash) so that in future they can be processed to recover phosphorus.
8. If viewed as a resource, phosphorus recovery can provide more benefits than the conventional paradigm of regarding it merely as a potential pollutant.

[1] In this PPS, the word 'phosphorus' will be used to cover any and all the of forms and compounds of phosphorus.

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Context

Phosphorus is essential for all living cells; it is a part of DNA, cells' energy cycles, bones, etc. It is one of the three major plant nutrients (nitrogen, phosphorus and potassium) but is the least abundant. For phosphorus there can be neither substitute nor replacement. It is scarce and the rate that resources are being depleted is unacceptably rapidly.

Inorganic phosphorus rock is mined for agriculture and industry. Of the mined phosphorus rock, 80% (and increasing) is used as fertiliser; the rest is divided between detergents (12%, and declining), animal feeds (5%) and speciality applications (3%), such as food grade, metal treatment, etc. There would not be an issue if there were abundant supplies, but that is far from the case. At the present rate of extraction, today's phosphorus mines will be exhausted by the end of the 21st century and estimates of future reserves range from 200 to 400 years (at the current rate of extraction).

In 1800 (before chemical fertilisers) the world's population was about 1 billion people. By 1900 it had increased to 1.6 bn; in 1950 it was 2.5 bn. Today the world's population is about 7 bn and by 2050 it is expected to reach around 9 bn and then grow more slowly to 10 bn in 2200 (UN, 2004). Not only has the world's population grown rapidly, for the first time more people now live in urban areas than in rural areas, which means more food, with its embodied phosphorus, moving from rural areas to urban areas. Whilst population growth and dietary changes will increase the demand from agriculture, the area of farmable land is expected to decrease due to climate change (sea level rise, unreliable rainfall, increasing frequency of severe weather, etc.). Those in countries with growing economies (Brazil, Russia, India, China, etc.) desire more animal products, which is more costly in energy and nutrients than grains, vegetables, etc. The cereals to meat conversion ratios in intensive animal husbandry are 3:1 for poultry, 4.5:1 for pork and 6:1 for red meat (Steén, 1998). All of this means that we shall need to grow more food, which with its embodied nutrients, water and carbon will be transferred from rural soils to urban population centres and food processing facilities.

Whilst the future may sound bleak, wastewater treatment could recover 95% of the phosphorus from urban wastewater and concentrate it into the sewage sludge that, after appropriate treatment, can be applied to land as nutrient-rich soil improver (biosolids) and/or into side-stream recovered phosphorus. To date attention has focussed on the effects of phosphorus in the eutrophication of waters; in future attention should also focus on capturing phosphorus from waste-streams and recovering it for use.

Discussion

As regards threats to the human population, phosphorus depletion is on a par with climate change. Life on a hotter planet will be difficult; life without phosphorus would be impossible. Asimov (1974) summarised its importance nicely:

"…life can multiply until all the phosphorus is gone, and then there is an inexorable halt which nothing can prevent…. We may be able to substitute nuclear power for coal, and plastics for wood, and yeast for meat, and friendliness for isolation - but for phosphorus there is neither substitute nor replacement."

In the 19th century, Europe's agricultural potential was limited by phosphorus. Much of the food was imported from the 'newly discovered' continents, especially North America, where it was grown on the fertility accumulated over centuries under natural vegetation. Now there are no new worlds from which we can milk fertility. Mineral fertiliser supplies the gap between crop-offtake and the sum of returns (including biosolids, manure and organic resources), fixation and mineralization.

Limiting nutrients

The major plant nutrients are nitrogen, phosphorus and potassium. Nitrogen is not scarce: 80% of the atmosphere is nitrogen (dinitrogen gas), so it is not in short supply, it just has to be "fixed" as plant-available forms of nitrogen (urea, ammonia, nitrate, etc.), this requires energy. Rainfall in the UK adds about 50 kg N/ha but drainage of water through soil leaches soluble nitrogen, principally nitrate. Legumes are able to fix nitrogen via a symbiotic relationship with Rhizobium bacteria. There is the real possibility of engineering symbiotic N-fixation into wheat and other crop plants eventually but there is a substantial yield penalty because of the metabolic load on the plant of feeding the Rhizobia. Phosphorus (P) is the least abundant of the major plant nutrients (Table 1).

Table 1 Abundance of some elements in the earth's crust (CRC, 2005)

Element	Symbol	% m/m
Oxygen	O	46.50
Silicon	Si	28.20
Aluminium	Al	8.23
Iron	Fe	5.63
Calcium	Ca	4.15
Sodium	Na	2.36
Magnesium	Mg	2.33
Potassium	K	2.09
Hydrogen	H	0.14
Phosphorus	P	0.105
	Sub-total	99.735%

Agricultural development

Agricultural science has served humans magnificently. Fertilisers, plant breeding, improved animal genetics, animal and crop protection, weed control and improved husbandry have all raised yield potentials. J.B. Lawes patented superphosphate in 1842, guano imports started in 1847, Haber invented the Haber Bosch process for fixing N in 1913; it is all relatively recent in the history of humankind.

The unintended consequence of reducing starvation and of improving public health through sanitation is that we have a population crisis.

One tonne of wheat grain contains approximately 20 kg N, 9.2 kg P_2O_5[2] and 6.7 kg K_2O. A respectable/good wheat yield in the UK is about 10 tonnes/ha. When these nutrients are removed from the field, they must be replaced from somewhere. Even more is removed if the straw is taken as well (e.g. for animal bedding or biomass for energy).

Precision farming targets inputs better. In future crops might be developed that are more resistant to disease and drought, can fix nitrogen and use less (or more brackish) water. However, whatever other developments are made, we are expecting soils to work ever harder. Organic matter is one of the key factors of soil fertility. It feeds soil biomass, stabilises soil structure (which improves soil water, temperature and aeration and improves resistance to erosion) and it is a reserve of nutrients. Soil organic matter breakdown is increased by increased soil temperatures and by cultivation. Using biosolids on land helps to conserve soil organic matter, in addition to recycling the phosphorus it contains.

Phosphorus for fertiliser

Farmers do not squander fertiliser, it is too expensive and they are too aware of the potential for environmental pollution and also for criticism. Great advances have been made in understanding nutrient dynamics in soil and in phasing inputs to match the demands that crops have for nutrients. This information has been disseminated to farmers and the fertiliser industry. The Fertiliser Advisors Certification and Training Scheme (FACTS) has improved practice.

Adult humans only retain 2% of the phosphorus in their food because they are replacing cells rather than laying down new ones. Adult humans excrete about 1.2-1.4 g P/capita.day (about 98% of the phosphorus in our diets); to this we can add 1.3-1.8 g P/capita.day from other household and urban sources (Smil, 2000). The combined average is about 2.7 g P/capita.day, i.e.1 kg P/capita.year.

The phosphorus-cycle in agriculture is complex (Figure 1). Plant-available phosphorus is in dynamic equilibrium with "pools" of less available phosphorus, which contain the majority of phosphorus in soil. Generally the largest loss pathway is "particulate-phosphorus" i.e. loss of soil particles (to which phosphorus is sorbed) in runoff water. Loss of dissolved phosphorus in drainage is small because it only lasts a short period of time after soluble phosphorus has been added to soil; it is largely stopped when the soluble phosphorus has equilibrated with

[2] It is a matter of historical convention that analytical data for some purposes are expressed as oxides and for other purposes as elements; 1 g P = 2.3 g P_2O_5

the soil's pools of availability. In areas where mains drainage is limited, the potential contribution of septic tanks to phosphorus in surface waters has been recognised only recently. The effluent from septic tanks is discharged to soil sorption zones and the soluble phosphorus it contains saturates the sorption sites, depending on the soil conditions it can break through to surface waters eventually.

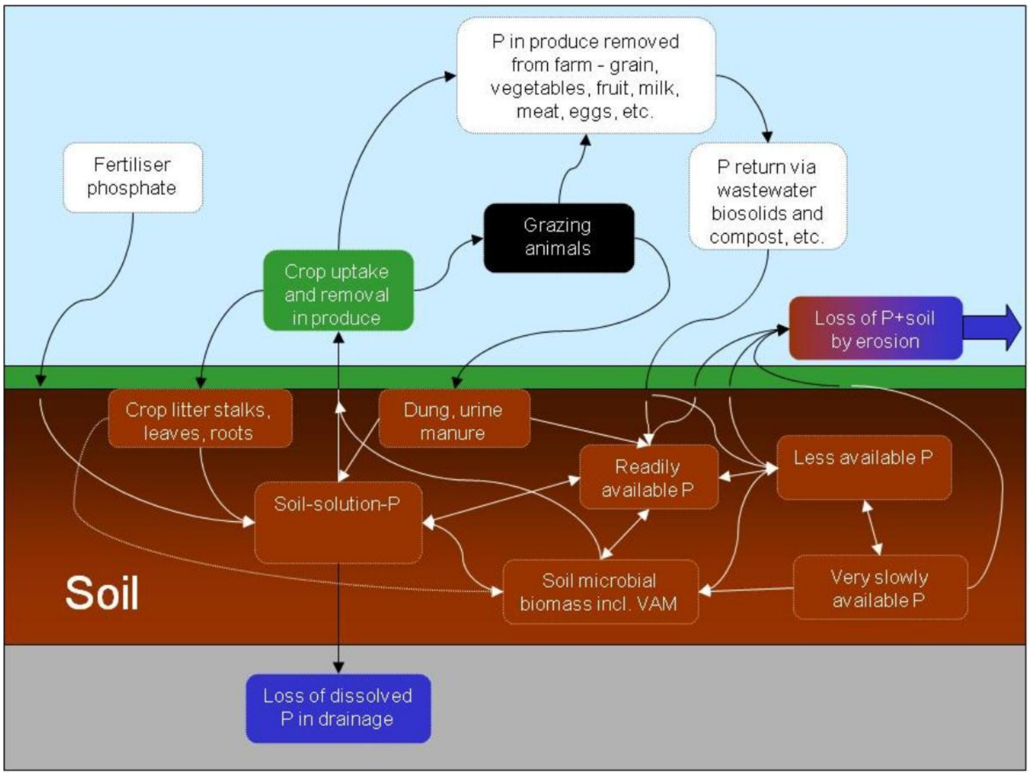

Figure 1 Simplified version of the phosphorus cycle in soil (CIWEM own)

Reserves of phosphorus rock

In 2006, Heffer et al. predicted that today's mined resources will be exhausted in 67 years at the then current rate of exploitation, i.e. 2073. In addition a total of 208 years' supply from reserves was thought to exist, again at the 2005 rates of production (Table 2). Of course, to increase food production by between 70% and 100% (the requirement that has been predicted) will require more phosphorus.

Table 2 World phosphorus rock production and reserves (after Heffer et al., 2006)

Country	Production in 2005 Mt/y	2005's resources Mt	Estimates of future reserves Mt	% of total
Morocco & Western Sahara	28.8	5700	21000	56.7%
USA	35.5	1000	4200	11.0%
South Africa	2.6	1500	2500	8.5%
Jordan	6.4	900	1700	5.5%
China	51.0	500	1200	3.6%
Russia	11.3	150	1000	2.4%
Tunisia	8.2	100	600	1.5%
Brazil	5.5	330	370	1.5%
Israel	2.9	180	180	0.8%
Senegal	1.5	50	160	0.4%
Syria	3.5	60	100	0.3%
Togo	1.0	30	60	0.2%
Other countries	13.1	1000	2500	7.4%
Total	171.3	11500	35570	
Years at 2005 production		67	208	

China and the USA have both implemented measures to reduce exports of phosphorus because they consider phosphorus is too important strategically, however the World Trade Organisation has challenged this restriction of free trade.

The largest deposits of phosphorus are in Morocco and Western Sahara; 56.7% of the world's total. Coincidentally the rock-phosphorus in Morocco and Western Sahara is more contaminated with cadmium than most of today's biosolids. It contains about 80 mg Cd/kg P_2O_5 and modern biosolids contain less than 30 mg Cd/kg P_2O_5. Today the world is beholden to the Middle East for oil; in the future it will be beholden to Morocco and Western Sahara for phosphorus. Some consider this inevitability to be geopolitically undesirable and therefore should be postponed for as long as possible.

Phosphorus in water treatment

The UK is unusual in dosing phosphorus into the public water supply to reduce plumbosolvancy (dissolution of lead from old pipework). Phosphorus dosing ranges from 0.5-1 mg P/L in low alkalinity areas to 1-1.5 mg P/L in high alkalinity areas. Most water is dosed with phosphorus because it is not practicable to target properties with lead supply or internal plumbing. Taking 1 mg P/L as an average and 17395 ML/day into supply equates to about 15,000 t P_2O_5/y. To put this in context, Defra (2011) reports the total phosphorus fertiliser use in UK is [only] about 200,000 t P_2O_5/y. Lining or replacing lead pipes would be more protective of consumer health, eliminate a significant use of phosphorus and reduce the cost of removing phosphorus at WwTWs.

Phosphorus recovery

Until recently we only thought about removing phosphorus from wastewater to prevent eutrophication when the recovered water is returned to the water environment, but in future attention should also focus on capturing phosphorus from wastewater and recovering it for use. Land application of suitably treated biosolids (sewage sludge) is invariably the best way to conserve and recycle the phosphorus that is in biosolids.

Wastewater treatment could recover 95% of the phosphorus from urban wastewater and concentrate it into the sewage sludge that, after appropriate treatment, can be applied to land as nutrient-rich soil improver (biosolids) and/or into side-stream recovered phosphorus. Technologies are being developed for recovering phosphorus from wastewater directly.

The total amount of phosphorus in urban wastewater in EU27 is about 1,145,000 tonnes P_2O_5/y. This is equivalent to 34% of the total 3,400,000 tonnes P_2O_5 per year imported by the EU27 (Rosemarin et al., 2010). About 595,000 tonnes P_2O_5 ends up in biosolids; that is 52% of the phosphorus in wastewater. Overall 37% of the biosolids was recycled to farmland, which is approx. 220,000 tonnes P_2O_5 per year. Thus, only 20% of the phosphorus in urban wastewater in the EU is recycled, the rest is squandered by failing to capture it (48%) or by 'losing' it in landfill or ash, etc. There is considerable potential to improve capture, recovery and conservation of phosphorus.

Sweden has a law that targets recycling 60% of the phosphorus in urban wastewater by 2015. Germany plans similar legislation under its resources programme. Schröder et al. (2010 demonstrated that while the European Union has for many decades seen itself as a food secure region, the EU food system is in fact highly vulnerable to future phosphorus scarcity. The EU is almost entirely dependent on imported phosphorus. It uses 9% of the world's annual phosphorus production. The European Commission's Roadmap to a Resource Efficient Europe (EC 2011) recognises "an additional issue for long term global food security is the sustainable supply of phosphorus, a key resource for soil fertilisation that cannot be substituted"; the Commission plans a Green Paper on phosphorus in 2012. CIWEM believes all governments should follow the examples of Sweden and Germany and make phosphorus recovery from urban wastewater a legal requirement.

If sludges, biosolids and biowastes have to be burnt, the phosphorus should be extracted in advance or the phosphorus-rich ash should be preserved pending the day when it is financially viable to recover that phosphorus. Regulators should consider this as responsible stewardship of a non-substitutable, irreplaceable and essential resource that is being exhausted at an alarming rate.

Conclusions

9. CIWEM considers more attention should be given to phosphorus. The world's population continues to increase. People will require more per-capita agricultural production (food, fibre and fuel) from a declining area of farmable land with greater harvest uncertainty because of weather. The reserves of phosphorus are dwindling rapidly. Climate change has had all the attention but in many ways this phosphorus situation is no less serious. It is essential we complete the nutrient cycle, capture the phosphorus out of urban wastewater and return phosphorus in manure, food waste, biosolids and other organic residuals to the areas where crops are grown.

10. Facilitating stewardship of phosphorus should be a priority for governments and a matter of corporate social responsibility for companies.

11. Policy makers should make legal obligations to capture phosphorus.

12. Stewardship of phosphorus should be factored into biosolids and biowastes treatment strategies so that investment is not stranded by this readily anticipatable policy change. The phosphorus industry is already identifying and conserving its historic phosphogypsum waste heaps pending the day when it is financially and technologically viable to rework them and extract the residual phosphorus. When sewage sludge is burnt, gasified, etc. there should be a requirement to recover the phosphorus or at the very least to store the phosphorus-rich residues (ash) so that in future they can be processed to recover phosphorus.

13. Phosphorus conservation will reduce geopolitical risk, improve food security and reduce the introduction of additional contaminant load into the anthropogenic cycle.

14. Phosphorus is too precious to squander.

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Note: CIWEM Policy Position Statements (PPS) represents the Institution's views on issues at a particular point in time. It is accepted that situations change as research provides new evidence. It should be understood, therefore, that CIWEM PPS's are under constant review and that previously held views may alter and lead to revised PPS's. PPSs are produced as a consensus report and do not represent the view of individual members of CIWEM.

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