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POSTNOTE

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Phosphate Resources

World food security is dependent on phosphate fertilisers manufactured from finite deposits of phosphate ore. The majority of remaining reserves are restricted to a limited number of countries raising geopolitical risks. This POSTnote describes the uses of phosphate and summarises ways in which dependence on mineral reserves could be reduced.

Overview

- Phosphorus is a vital nutrient for all living organisms and is essential for maintaining high yields in agriculture.
- There are differing estimates of primary (mined) global phosphate resources.
- Elevated phosphate concentrations in surface waters can cause algal blooms and reduce biodiversity.
- More efficient use of fertiliser and manures could reduce phosphate demand and environmental damage.
- Phosphate in waste water is a source of pollution. It is increasingly being recovered from waste water and used as a fertiliser.
- Efficient management of phosphate to minimise losses and develop recycling would enhance the resilience of supply.

Background

The element phosphorus is vital to all life and cannot be substituted. It plays a critical role in maintaining growth in all agricultural systems, especially those with high yields.[1] Phosphorus does not exist as a free element because it is very reactive; it is typically found in combination with other elements, for example as phosphate (PO_4). Bone meal was used for centuries as a source of phosphate. The use of imported phosphate fertilisers intensified in the mid to late 19th century with the importation of guano (mined bird and bat droppings) from islands in the Pacific.[2] Since the early 20th Century, the primary source of phosphate for fertiliser and animal feed supplements has been phosphorus extracted from phosphate-rich rocks.[3]

This has quadrupled the flow of phosphorus into plants, soils and water ways, while providing sufficient food to sustain high levels of population growth.[4] However, the supply of phosphate from mined deposits is limited. There is disagreement in estimates of the loss of primary (mined) phosphate to the environment with figures ranging from 80% to 95%[3,5] throughout the various stages of phosphorus production and use.[6] Much of this loss is avoidable. Phosphate lost from land is ultimately deposited in the oceans, where the diluted concentrations are insufficient to enable recovery that is economic.[7]

Phosphate rock was added onto the EU list of critical materials in May 2014. Phosphate resources need to be carefully managed because of a limited supply of high grade phosphate, a risk of political unrest in some of the supplying countries and environmental problems caused by an excess of phosphorus in waterways.

The EU Water Framework Directive aims to protect the environmental quality of all water bodies and requires limits to be set for a number of pollutants including reactive phosphorus (the amount of phosphorus potentially available for plants) in rivers and total phosphorus (all the dissolved and particulate forms) in lakes.[8, 9] There is currently no EU or UK policy to address security of supply, such as by increasing efficiency or recycling.

Security of Supply

The price of phosphate is determined by global supply and demand (Box 1).[10] The majority of the known remaining phosphate deposits are located in North Africa (64%), the USA (15%) and China (6%).[11] The concentration of production in a limited number of countries, and the location of some of these deposits in areas of geopolitical tension, has the potential to disrupt supply. Aside from some small phosphate mines in Finland, the EU contains no phosphate deposits and is heavily reliant on imports from Russia (where 1% of deposits are located), countries in the Middle East (where 3% of deposits are situated) and North Africa.[10]

Box 1. Economics of Phosphate Rock

In 2008, the price of phosphate rock increased by 800% in one year.[12] Although the price fell sharply in late 2008, the phosphate rock price has still not returned to pre-event values. A combination of factors caused the prices to rise sharply in 2008:

- Elevated oil prices made it more expensive to move and process the rock.
- Increased global demand for meat, dairy and biofuels increased demand for fertilisers. [13]
- The supply chain was unable to respond rapidly to the increased demand. A new phosphate mine can take between 5 and 20 years to become fully operational.
- There was an increase in demand and prices for sulphur to produce sulphuric acid, which is essential for phosphate rock processing.[12]
- China imposed a 135% export tax on fertiliser in order to protect domestic markets, although some countries were exempt.

In 2008, many farmers were unable to afford phosphate fertilisers. This led to a decrease in demand and then resource prices.[14] The beginning of the financial crisis also decreased phosphate demand.[15]

Estimates of Phosphate Deposits

Mineral 'resources' are defined as minerals concentrations that are, or may become, of potential economic interest; 'reserves' are the part of a mineral resource that has been fully evaluated and is deemed commercially viable. Some studies have suggested that phosphate production will reach a peak and slow down, as the reserves become increasingly expensive and energy intensive to extract. Pre-2010 estimates of the remaining deposits led some to conclude that peak production would occur in the next 20 to 30 years.[3,16] A reappraisal of the remaining phosphate resources has resulted in a substantial increase in the estimates of resources located in Morocco,[11] although this new figure has been subject to recent debate.[17] Estimates of the year of peak production based on the updated reserve/resource estimates vary from 2051 to 2092.[18]

The recyclable nature of phosphate and the reliance of the calculation on static reserve has brought into question the validity of these estimates.[19] A more widely accepted approach is focused on the longevity of supply. This is calculated by dividing the total reserves and resources by the current yearly demand.[11] Although the potential resources are much bigger, based on this approach, current reserves should last 300-400 years.[11] However, this is an oversimplification as demand in the future is expected to rise because of population growth and rapidly increasing demand for meat from developing countries, which requires animal feed with high phosphorus content.[20] Additional influencing factors include: more efficient or new agricultural technologies, mining and processing capabilities, rate of recycling, further exploration and rises in market price. Commentators suggest that there is a need for more reliable and transparent information concerning world phosphate reserves and resources.[1]

Phosphorus in the Environment

The major reservoirs of phosphorus in the environment are seawater and ocean sediments, rocks, plants, animals and soils. The cycling between these different components occurs at different speeds, with the slowest part of the cycle – the return of phosphorus from ocean sediments to the surface via rock formation and uplift – taking millions of years. Human intervention has changed the partitioning of phosphorus between the different parts of the cycle by releasing phosphate bound up in rock and using it as a fertiliser, increasing the concentration in soils, plants and water bodies.

Phosphorus in Water

An excess of phosphorus in water bodies, particularly freshwaters (rivers, lakes and reservoirs), can lead to accelerated algal growth and adverse effects on the ecology and quality of the water. This is the process known as eutrophication (see PN478). Reactive phosphorus is the reason for failure to achieve EU Water Framework Directive objectives in 45% of river water bodies and total phosphorus causes 74% of lake water bodies to fail in England. [21] Consequently the Environment Agency (EA) has identified phosphorus and the risks of eutrophication as a nationally significant water management issue.[22]

The main sources of phosphorus pollution are discharges from waste water treatment plants and losses from agriculture.[23] While loss of phosphorus to water bodies, as a percentage of the total applied on agricultural land, is very small (1-10%),[24] the EA estimates that it still accounts for 20-30% of the phosphorus in rivers.[23] Waste water discharge from sewage treatment plants (STPs) contributes 60-80% of the phosphorus in rivers.[23] Other minor sources of phosphorus include diffuse urban pollution (3%) and septic tanks and small containerised sewage treatment plants (3%). The exact proportions of phosphorus that comes from these various sources varies between regions.[25,26]

Analysis of cost-effectiveness suggests that to reach Water Framework Directive targets a combination of a reduction in the quantity of phosphorus used and a decrease in the amount discharged in waste water and lost from agricultural land are required.[23,27]

Phosphorus in the Soil

Only 10-15% of applied fertiliser is taken up by crops; the majority remains as a reserve in the soil.[28] Although the soil reservoir is not sufficient to provide the required phosphorus for maximum yields, taking this source into account when determining the amount of fertiliser required can result in reduced application rates.[29] Aside from chemical fertiliser, phosphorus is also added to soil in animal manure and the solids from STPs (biosolids). In the UK, 75% of biosolids are routinely returned to agricultural land. However, STPs are typically concentrated in urban areas. In agriculture, arable land that typically needs fertiliser input and livestock farming that produces manure, are rarely situated in the same regions.[30] The high transportation costs means manure and biosolids use is generally concentrated in areas close to the source rather than returned to arable land. [31] The resulting high soil phosphorus levels can increase the risk of losses to rivers and lakes resulting in eutrophication. From the end of 2014, the efficient use of biosolids will be guaranteed by the ‘Biosolids Assurance Scheme’ which will set minimum standards for biosolids production and use.[32]

Reducing Demand

Efficient Agricultural Use of Phosphate Fertilisers

Following World War Two, soils were phosphorus deficient, caused in part by fertiliser shortages during the war.[33] This caused a drive to increase yields with the increased use of phosphate fertiliser. By 1980-90, the average concentration in the soil was optimal for high yielding crop production. Since the mid-1990s phosphate application rates have decreased in the UK due to cost saving, a greater awareness of crop nutrition and eutrophication risks,[29] and the continued use of soil analysis to test for adequate levels of plant-available phosphorus in soil.[34,35] Application rates could be further reduced by increasing the specificity of the fertiliser application recommendations.[28]

Phosphate transfer from agricultural land to surface waters can be managed at three different stages:

- Managing sources: Applying the correct amount of inorganic fertilisers, animal manures and biosolids in the right place at the right time.[36]
- Controlling mobilisation and delivery pathways: Managing surface water runoff over farm tracks and winter tramlines, establishing cover crops in autumn.[37]
- Protecting the receptor: Building artificial wetlands, silt traps and embankments, managing riverbank zones with woodland and vegetated buffer strips.

There are several mechanisms for encouraging farmers to manage phosphate more efficiently in areas at risk from phosphorus pollution (Box 2). Both national initiatives – for example, Catchment Sensitive Farming (CSF, see PN478) and Tried and Tested Nutrient Management – and local schemes – for example, SWARM Knowledge Hub in South West England[38] – exist to aid farmers in reducing phosphorus pollution from agriculture. Based on modelling of current CSF, a recent analysis estimates that between 2006 and 2014 the scheme reduced agricultural phosphorus losses on average by 9% (total phosphorus) and 7% (reactive phosphorus).[39] In autumn 2014, Defra intends to set out the tools it will use to tackle agricultural diffuse pollution, including phosphorus.[40]

Phosphate in Meat Production

Only a fraction of the naturally-occurring organic phosphorus in the plant component of the feed can be utilised by the animal, so inorganic phosphate supplements are added. Of the global phosphorus supply, 5% is added to animal feed.[41] A high proportion of the total phosphorus ends up in the manure.[42] Adding an enzyme ‘phytase’ to animal feed can break down the phosphorus compounds into a form that monogastric animals such as pigs can absorb,[43] reducing the need for phosphate supplements.[44] Meat requires a significant input of phosphate. Producing the food consumed by meat-eaters requires approximately three times as much phosphate per person annually compared to a vegetarian diet, although much of the phosphate consumed by the animal remains on the farm as manure. Approximately 55% of phosphorus in food for all diets is lost between ‘farm and fork’ including waste in processing, transportation and storage.[3]

Box 2. Regulation of Phosphate Use in Agriculture

England and Wales

There are no direct regulatory controls on agricultural phosphorus input that limits the accumulation of surplus phosphorus in soils and prevents phosphorus losses to water from agricultural activities.[45] Manure nitrogen restriction in the Nitrates Directive can limit phosphate applications indirectly.[46]

Scotland

The Water Environment (Controlled Activities) (Scotland) Regulations 2011, Amendment Regulations 2013 state that fertilisers must not be applied to land in excess of the nutrient needs of the crop. However, there is no reporting system or mandatory soil analysis, which makes enforcement of this regulation difficult.[46]

Northern Ireland

The application of chemical phosphorus fertiliser is restricted by the Northern Ireland Phosphorus (Use in Agriculture) Regulations 2006. The use of chemical phosphorus is only allowed if a farmer can demonstrate that the applied amount is not above the crop requirement as determined by the RB209 fertiliser manual, and then there are additional controls on where and when the fertiliser can be used.[47] The Northern Ireland Environment Agency carries out compliance checks for phosphorus when conducting farm inspections for the Nitrates Action Programme. Phosphorus fertiliser use has decreased to 3.3 kg phosphorus/ha in 2011 compared to 6.1 kg phosphorus/ha in 2006. The increasing phosphorus prices and the influence of legalisation covering nitrogen makes it difficult to assess the effectiveness of the phosphorus regulation in isolation.[48]

Phosphate in Food Additives

Food additives comprise 5-10% of the phosphorus in domestic waste water. [49] Phosphate additives are used in a wide range of food products, but are most commonly found in processed meat, biscuits, cakes and cola drinks where they have a range of functions including moisture retention, leavening and as an acidifier.[49] There are few alternatives to phosphate additives available that are permitted for use. The EA is leading a working group on finding potential alternatives.

Phosphate in Detergents Products

Phosphate compounds used to be a core component of laundry and dishwasher detergents.[50] Since June 2013, an amendment to the EU Regulation 648/2004 on Detergents has meant that the phosphate content of laundry detergents is limited.[51] Similar restrictions will apply to dishwasher detergent from January 2017. These restrictions only apply to domestic cleaning products; they do not include industrial detergents.[51]

Phosphate in Drinking Water

New EU regulations on lead in drinking water have resulted in the addition of phosphate in water supplies to remove lead that dissolves from the piping.[52] This source accounts for 5% of the total phosphorus in domestic waste water.[53] Alternatives exist, including lining the pipe with a polymer or replacing the lead pipes with an alternative.[54]

Efficient Management of Phosphorus

Recycling of Phosphate from Sewage Treatment

Waste water discharge from sewage treatment plants contributes the largest proportion of the phosphorus in rivers.[55] The amount of phosphorus water companies are allowed to discharge to the environment is controlled by a number of directives including the EU Urban Waste Water Treatment Directive (UWWTD) and the Water Framework Directive. Between 1995 and 2010, there has been a 50% reduction in phosphorus discharge from STPs under the UWWTD.[56] The reduction has mainly been achieved by the chemical dosing of waste water with iron and aluminium salts in order to precipitate the phosphate, which is then returned to land in biosolids.[57] However, the resultant compound is not in a form readily available to plants.[58] The phosphorus restrictions (0.5-2 mg/l)[59] so far have been limited mainly to medium and large waste water treatment plants except in areas of particular environmental sensitivity. However, these measures are not sufficient to ensure compliance with the WFD objectives and consequently trials are currently underway at a number of UK water companies to reduce the minimum output limit to 0.1 mg/l.

Innovation in Phosphate Removal from Waste Water

There are over 30 processes for recovering phosphate from waste water.[60] One method that both removes phosphate from waste water and ensures it remains in a form that plants can utilise is biological phosphate removal followed by struvite recovery (Box 3). There are no financial incentives in the UK to encourage water companies to recover the phosphate in a form that agriculture can use. However, in other European countries legislative and regulatory support is encouraging collaboration between those involved in phosphate removal from waste streams and it's recycling to land. ICL Fertilizers in Amsterdam and Germany is using some of the excess phosphate that is currently a problem in the Netherlands and Germany in fertiliser manufacture. The Amsterdam fertiliser plant has made a legal covenant with the Dutch government to use 15% recycled phosphate in the manufacture of fertilisers by 2015 and will aim to use 100% by 2025.[61,62]

More Efficient Production of Phosphate

Higher phosphate rock prices and an increasing concern for sustainability has led to innovation in the phosphate mining industry and further exploration. Globally, there is a trend towards improved recovery rates in the mining of lower grade phosphate rock. Previously, phosphate ore grades, measured in units of bone phosphate of lime (BPL), were sought at levels of 70 or higher.[6] Now BPL grades of 50 or even lower are being mined, which means that estimates of phosphate reserves continue to increase. However, the usability of lower grade rock may be limited by the impurity content of the phosphate.[30]

Increasing the Longevity of Phosphate Resources

Sustainable use of phosphate in the future would require phosphate in waste streams to be returned to land.[6,63] The global nature of food production means that international efforts would be needed in order to manage phosphate to ensure food security. However, management of phosphate does not currently fall under the remit of any international group.[66]

Box 3. Struvite Recovery

Struvite is produced by the addition of magnesium to waste water in order to remove phosphate, along with some ammonium, in a form that is available to plants and can be used as a fertiliser.[64] While the current price of phosphate fertilisers means that phosphate recovery is not profitable purely to sell into the fertiliser industry, the recovery of struvite can reduce the costs associated with the uncontrolled precipitation of phosphate salts. There are some concerns with struvite recovery, including concern over the incorporation of other materials[65] (e.g. drugs, medicines, viruses) and high magnesium concentrations, which may cause soil contamination.

Case Study 1: Thames Water

The Thames Water struvite recovery plant at Slough was opened in November 2013 and is currently undergoing monitoring to assess the applicability of the technology to other sites. It recovers phosphate as a slow release fertiliser.

Case Study 2: Severn Trent Water

The first struvite recovery plant in the Severn-Trent Water catchment is at Stoke Bardolph, Nottingham where 500 tonnes/year of phosphate contained in struvite will be produced from Summer 2014.[57] Severn Trent has come to an agreement with a liquid suspension fertiliser company who will blend the precipitate with nitrogen to produce the required nutrient balance.

European Union Management

In Europe, a recent Consultative Communication,[67,68] due to be published in July 2014, asked EU member states and the public how best to manage phosphate resources. Currently, any phosphate management is because of European water regulation and is focused on reducing environmental emissions of phosphate rather than recycling because of limitations in supply. Within Europe, awareness of the need to tackle phosphate problems in a number of ways is being raised by the European Sustainability Phosphorus Platform (ESPP). [69] ESPP is working to engage all relevant parties including the mining companies located in northern Africa.

Endnotes

1 UNEP Yearbook 2011
2 Ashley *et al*., 2011, *Chemosphere*, 84(6): 737‑746
3 Cordell *et al*., 2009, Global Environmental Change, **19**: 292‑305
4 Falkowski *et al*., 2000, *Science*, ***290***: 291-296
5 Hilton and Stana, 2011, *Joint Meeting of the Jordan Atomic Energy Commission and the International Atomic Energy Agency*
6 Dawson and Hilton, 2011, *Food Policy*, **36**: 14–22
7 Schröder *et al*., 2010, *Sustainable Use of Phosphorus*, Plant Res.Int.
8 WFD-UKTAG, 2014, *UKTAG River Assessment Method: Phosphorus- River Phosphorus Standards*
9 WFD-UKTAG, 2008, *UK Environmental Standards and Conditions (Phase 1)*
10 De Ridder *et al*., 2012, *Risks and Opportunities in the Global Phosphate Rock Market*, The Hague Centre for Strategic Studies (HCSS)
11 IFDC report, 2010, *World Phosphate Rock Reserves and Resources*
12 U.S. Geological Survey, 2009, *Mineral Commodity Summaries*
13 Gilbert, 2009. *Nature*, **461**: 716–718
14 C. Dawson, Pers. Comms.
15 IFA, 2009, *Short-Term Fertilizer Outlook 2009-2010*
16 Elser and Bennett, 2011, *Nature*, **478**: 29-31
17 Edixhoven *et al*., 2013, *Earth Syst. Dynam. Discuss.*, **4**: 1005–1034
18 Cordell *et al*., 2013, *Peak phosphorus: the crunch time for humanity?*
19 Scholz and Wellmer, 2013, *Global Environmental Change*, **23**: 11–27
20 The Government Office for Science, 2011, *Foresight. The Future of Food and Farming-Final Project Report.*

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21 Environment Agency, 2013, *Water Framework Directive Classification 2013 progress update*
22 Environment Agency, 2013, *Water for Life and Livelihoods- England's waters: challenges and choices- Summary of significant water management issues*
23 Environment Agency, 2012, *Freshwater Eutrophication Briefing Note*
24 Ulén *et al.*, 2007, *Soil Use Manage*. **23**: 5-15 .
25 Withers *et al.*, 2014, *Front Ecol Environ*; **12(2)**: 123–130
26 Smith *et al.*, 2005, *Journal of Hydrology*, **304**: 193–202
27 Whitehead *et al.* 2013 Phil. Trans. R. Soc. A, 371(2002), 20120413
28 Johnston *et al.*, 2014, *Advances in Agronomy*, **123**: 127-228
29 Sattari *et al.*, 2012, *PNAS*, **109(16)**: 6348-6353
30 Tirado & Allsopp 2012, *Phosphorus in agriculture Problems and solutions Greenpeace Research Laboratories Technical Report (Review)*
31 James and Carliell-Marquet, 2013, *Resources, Conservation and Recycling*. **74**: 82– 100
32 Water UK, 2013, *Press release, Working towards an assurance scheme for biosolids recycling*
33 Potash Development Association 2012
34 Defra, 2013, *The British Survey of Fertiliser Practice 2012*
35 SWARM Hub, 2013, *A report summarising the findings from soil samples collected by farmers in the South West and analysed through the S4P Project*
36 Defra, 2009, *Protecting our Water, Soil and Air A Code of Good Agricultural Practice for farmers, growers and land managers*
37 Andrew *et al.*, 2001, *Communications in Soil Science and Plant Analysis*, **32(7-8)**: 1071-1100
38 SWARM Knowledge Hub http://www.swarmhub.co.uk/
39 Environment Agency, 2014, *Catchment Sensitive Farming Evaluation Report Phases 1 to 3 (2006 – 2014).*
40 Almond, S, Pers. Comm.
41 Smit *et al.*, 2009, *Phosphorus in agriculture: global resources, trends and developments.* Report to the Steering Committee Technology Assessment of the Ministry of Agriculture, Nature and Food Quality, The Netherlands
42 Schröder *et al.*, 2011, *Chemosphere* 84(6): 822‑831
43 Jacela *et al.*, 2010, *J Swine Health Prod.*; **18(2)**:87‑91.
44 Afinah *et al.*, 2010, *Int. Food Res. J.*, **17**: 13‑21
45 Environment Agency and NFU, 2012, *Review of phosphorus pollution in Anglian River Basin District*
46 Amery, F. and O.F. Schoumans, 2014, *Agricultural phosphorus legislation in Europe*. Merelbeke, ILVO, 45 p
47 DARDNI, 2014, *Nitrates Action Programme 2011-2014 and Phosphorus Regulations Guidance Booklet (updated November 2012)*
48 Doody D, Pers. Comm.
49 Environment Agency, 2013, *Phosphorus in Food Additives*
50 Defra, 2008, *Summary of Responses to the Consultation on Options for Controls on Phosphates in Domestic Laundry*
51 EC Detergent legalisation 2012 (Amendment) Consolidated version of Regulation (EC) No 648/2004
52 Scher, 2011, *Lead Standard in Drinking Water*
53 Comber *et al.*, 2013, *Environmental Technology*, **34(10)**: 1349–1358
54 UKWIR, 2011, *Alternatives to phosphate for plumbosolvency control*
55 White and Hammond, 2007, *Updating the Estimate of the Sources of Phosphorus in UK Waters.*
56 Environment Agency, 2011, *Sustainable Business Report*
57 Vale, P, Pers comms
58 Defra, 2012, *Review of the feasibility of recycling phosphate at sewage treatment plants in the UK*
59 Davis, K, Pers Comm.
60 Sartorius *et al.*, 2011, *Nutrient Recovery and Management: Inside and Outside the Fence*
61 ICL Fertilisers Environmental Policy
62 Langeveld, K Pers Comm.
63 Childers *et al.*, 2011, *BioScience,* **61**: 117–124
64 Gell *et al.*, 2011, *Journal of Agricultural Science*, **3(3)**: 67-80
65 Kemacheevakul *et al.*, 2012, *Water Sci Technol.*, **66(10)**: 2194-2201
66 3rd Sustainable Phosphorus Summit 2012, *Blueprint for Global P Security*
67 EC DG Environment, 2013, *Consultative Communication on the Sustainable Use of Phosphorus*
68 UK Government, 2013, *Response to the Consultative Communication on the Sustainable Use of Phosphorus*
69 ESPP