THE PHOSPHATE CYCLE IS NOT CLOSED

Supplies will run

The Netherlands is leading the way in research on reusing phosphate. The main motives for this are to spare the environment and to comply with legislation on manure. But within a few decades, phosphate recycling could be a matter of urgent necessity. 'Europe has hardly any phosphate mines.'

TEXT ARNO VAN 'T HOOG **PHOTO** ALAMY **INFOGRAPHIC** STEFFIE PADMOS

out

‘Europe is dependent on Morocco, China and the United States’

‘The latest estimate is that there is enough easily mined phosphate ore available for making artificial fertilizer for roughly another 300 years. That sounds like a long time but it’s not if you want to take care of future generations,’ says Oscar Schoumans, who works at Wageningen Environmental Research. He has been doing research on the manure problem and phosphate in the soil on farmland since 1984.

In the west nowadays we see phosphate as a problem because of our manure surplus, says Schoumans, but in future it will be a strategic mineral resource. Phosphate is not rare but it is only present in concentrations that make extraction viable in a few places. Morocco is the biggest supplier of phosphate ore, much of which gets shipped to the United States, the main producer of phosphate-based fertilizer.

Schoumans comments: ‘Europe has hardly any phosphate mines and we are dependent on supplies from countries such as Morocco, China and the United States. If phosphate ore or artificial fertilizer became scarce in the ground or on the market, due to geopolitical developments, these countries could opt to protect their own agriculture and food supplies. The moment they turn the export tap off, we’ve got a big problem.’

That problem would be one of falling agricultural productivity. Plants, animals and humans cannot do without phosphate: it is in our bones and DNA in the form of phosphorus, and it is an important source of energy at cell level. Phosphate fertilizer makes crops grow better. Since the 1950s, along with nitrogen fertilizer, phosphate has made a massive contribution to global food production. So it is not for nothing that global consumption of phosphate increased by a factor of five between 1960 and 2013. Arable farming is the biggest customer, but livestock farming uses a lot of phosphate worldwide too: an estimated one third of phosphate fertilizer is used for feed crops and grassland.

The idea behind the use of phosphate fertilizer is actually very simple: you replace the phosphate that the crop has used for its growth, and that the farmer has removed from the land in the form of crops, milk or meat. But in reality, the balance is not so easily restored. Much phosphate from fertilizer becomes fixed in the soil and is only available to plants in limited quantities. In areas with intensive agriculture and livestock farming, a surplus of phosphate builds up over the year. The soil acts a bit like a sponge, absorbing phosphate until it is saturated. If even more phosphate is then added, plants can absorb it more easily, but it can also be washed away faster.

Additionally, millions of tons of phosphate get washed into rivers and the sea all around the world, due to erosion and run-off. Charts which depict worldwide phosphate flows show more being lost than used. Less than one quarter of the phosphate from the mines reaches its intended destination: our plates.

SATURATION

Heavy over-fertilization in the past and phosphate’s tendency to stay in the soil have led to saturation in north-western Europe, says Schoumans: ‘In the top 50 centimetres of Dutch farmland soil, there is an average of 5000 kilos of phosphate per hectare. If you assume that arable land consumes about 50 kilos of phosphate per hectare in one growing season, and grassland 100 kilos, then you can see that the bulk of it stays in the soil. One quarter of that – more than 1000 kilos – is readily available to the plant, but that also means it runs off into ground and surface water. We’re talking about one to two kilos of phosphate per hectare per year. That stimulates the growth of algae in ponds and ditches, and causes problems with swimming water. So efforts are being make to reduce runoff by temporarily applying less phosphate fertilizer than the crop needs on land where there is a higher risk of phosphate runoff.’

A lot of land has become so enriched that the use of phosphate fertilizer in Europe has gone down – in the Netherlands from 75 million kilos in 1990 to 5 million kilos in 2015. Some farmers still give their crops a ‘kick start’ which they can absorb easily at the start of the growing season. But animal manure has largely replaced artificial fertilizer as a source of phosphate. This is because artificial fertilizer imports are not the only route by which phosphate enters the country: it also arrives in imported livestock feed. Soya for livestock feed accounted for 30 million kilos of phosphate in 2010, and much of this ends up in the manure.

The Netherlands produces more manure containing phosphate than may be dumped on Dutch agricultural land according to the fertilizer legislation, says Schoumans. ‘That means we have about 45 million kilos of phosphate left over every year, in the form of animal manure that we cannot dispose of on Dutch farmland.’ This is why it is compulsory to process manure, and why manure from pig and chicken farms is exported to Germany and France, while dairy farmers can largely dispose of their relatively low-phosphate cattle manure on their own land (see inset).

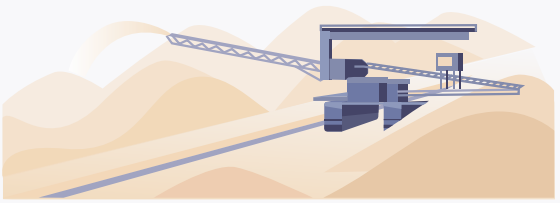
A LOT OF MONEY

Schoumans: ‘By contrast, pig farms do not have much land and produce a lot of phosphate-rich manure. They spend a lot of money on processing and disposing of it. Their manure consists of 90 percent water so exporting it entails high transport costs: about 20 to 25 euros per ton.’

As coordinator of the European project SYSTEMIC and the Dutch top sector project on the added value of manure and minerals, Schoumans is involved in the construction of the new ‘Green Minerals Plant’, where phosphate, potassium and nitrogen will be extracted from pig manure. Schoumans: ‘If you get phosphate out of the manure, you can use the organic matter on farmland, because that is good for the soil life, the soil structure and moisture levels. Since the low-phosphate organic matter no longer >

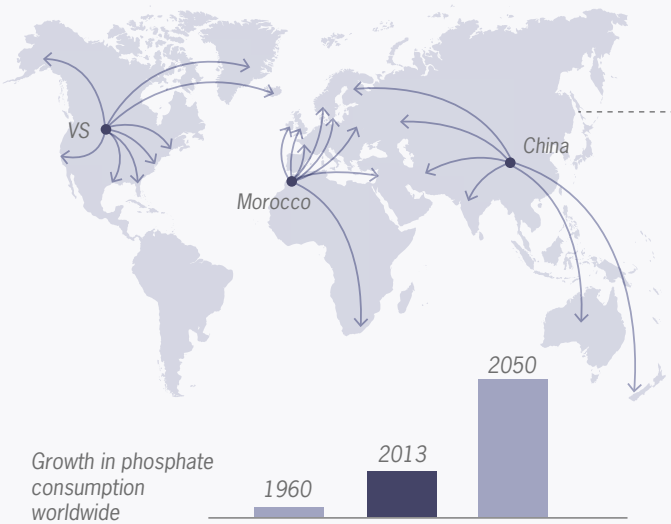
DWINDLING PHOSPHATE SUPPLIES

Worldwide we have created a massive flow of phosphate, mainly for the production of artificial fertilizer. Phosphate from the mines reaches farmland all around the world, and our plates through meat and vegetables. A huge proportion of it is lost, however.



Sources of phosphate

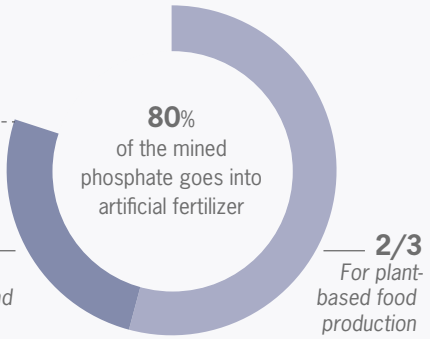
40 million tons of phosphate is mined every year. The total world supply is estimated at **3600-8000** million tons.



Growth in phosphate consumption worldwide

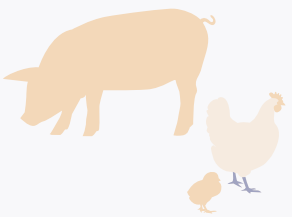
Main consumer: agriculture

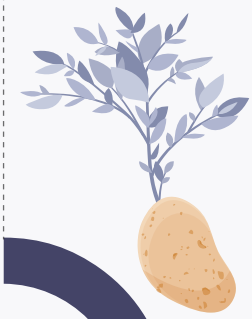
Worldwide, western agriculture is the biggest consumer of phosphate due to the use of artificial fertilizer.



1/3 *For livestock: fodder crops and grasslands*

2/3 *For plant-based food production*

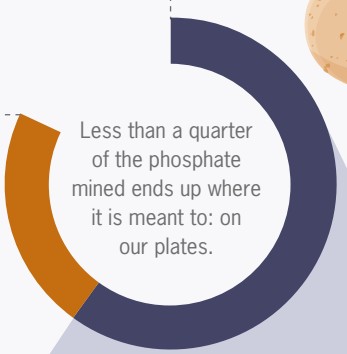




What is phosphate needed for?

Plants, animals and humans cannot do without the mineral phosphorus (P): it is in bones, DNA, enzymes and ATP, a crucial source of energy.

Dutch people consume about **1.2** kilos of phosphorus a year in their bread, vegetables, meat and dairy produce.



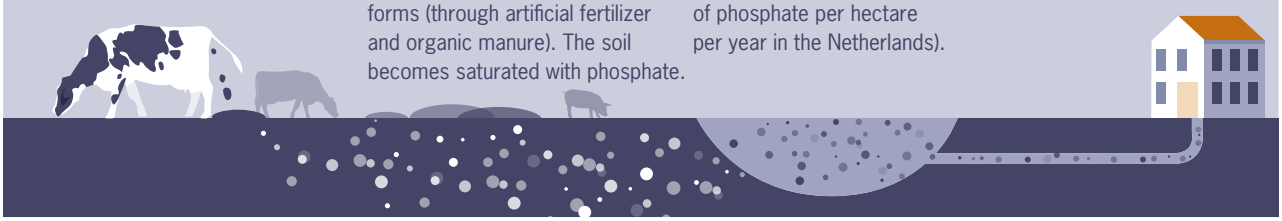
Losses

Manure
A large proportion of the phosphate in livestock feeds and grass ends up in the manure.

Soil
A lot of the phosphate from fertilizer gets fixed in the soil. In areas with intensive crop and livestock farming, a surplus forms (through artificial fertilizer and organic manure). The soil becomes saturated with phosphate.

Water
Some of the phosphate from the soil dissolves in water and washes away into ground and surface water (about **2** kilos of phosphate per hectare per year in the Netherlands).

Sewage
Much of the phosphate eaten by humans goes down the toilet and ends up in surface water via the sewage system.



> ‘The Netherlands has an annual surplus of 45 million kilos’

has to be taken across the border, and you are allowed to dump the decontaminated water, you also reduce transport costs considerably.’
The technology for extracting phosphate, which was developed in Wageningen, is called Re-P-Eat: Recovery of P to Eat. When an acid is added to it, the phosphate separates from the thick manure slurry, after which it is extracted as calcium phosphate, a highly soluble mineral which is also an ingredient of artificial fertilizer.
The Green Minerals Plant should be up and running in November 2018 on the premises of a big manure processing company in the Achterhoek region in the eastern Netherlands, which already produces biogas from about 100,000 tons of pig slurry. With about 25 of these kinds of salvaging plants across the country, 100 million kilos of phosphate from the surplus manure from pig farms could be processed into reusable fertilizer. ‘The task of the Green Minerals Plant is to demonstrate that the technology works on a large scale, and make clear what the quality of the mineral products is. And whether the process is economically viable. It has got to be both doable and affordable.’
This technology helps pig farmers with a manure problem as well as providing a way to further reduce the country’s dependence on artificial fertilizer, says Schoumans. ‘In the Achterhoek region several parties are busy starting up a project with the aim of finding out to what extent we can close the manure cycle in an area of 30 kilometres around the digester plant. We are looking at the kinds of nutrients that are brought to the digester. And identifying the needs of arable farms in the area: which organic and mineral fertilizer types they require. When you know that, you can try to put together a tailor-made product.’

DOWN THE TOILET

Humans in the Netherlands are at the top of the food chain. The Dutch consume about 1.2 kilos of phosphorus per year in their bread, vegetables, meat and dairy products, which is equivalent to 2.7 kilos of phosphate. Most of it disappears down the toilet, so there lies a second opportunity for recycling.
Dutch sewage treatment companies have been working on extracting phosphate for years. Phosphate can crystalize as struvite, or magnesium ammonium phosphate. The main reason for sewerage treatment companies to extract phosphate is to save on maintenance: struvite can form crusty deposits that clog up pipes and pumps. The sewage treatment plant in Apeldoorn already produces tens of thousands of kilos of struvite per year. The installation in Amsterdam West harvests as much as 2500 kilos of struvite per day from the wastewater of hundreds of thousands of residents.
The dried struvite crystals are a rich mineral, containing phosphate and nitrogen, but there is no market for it yet – not in the Netherlands, anyway. ‘Struvite is not popular among farmers here,’ says agronomist Sander de Vries, who does research at Wageningen Plant Research on improving the productivity of agricultural regions around the world. ‘Struvite is not a balanced fertilizer: it contains a high proportion of phosphate, not much nitrogen and no potassium. And it also dissolves quite slowly over the years, whereas farmers want to see fast results. Dutch farmers also usually have a glut of phosphate. So it is difficult to find a market here for a substance which is also less handy to use than conventional phosphate fertilizer.’

TO AFRICA

Other regions often do have land lacking in all sorts of nutrients, such as phosphate, nitrogen and potassium. ‘In some regions of Africa there is plenty of scope for increasing agricultural yields considerably, much more than in Europe. One of the things you could do in Africa is to improve local phosphate fertilization, and for that you could use struvite from Dutch sewage plants,’ says De

THE PHOSPHATE CEILING AND MANURE PROCESSING

Pig farmers have very little land to spread their muck on. And there is very little demand for it in the Netherlands, so these farmers incur high costs to get their manure processed and transported to other countries. Poultry farmers do not have much land, either, but the market for chicken manure is a bit more favourable. Chicken manure contains little water and high levels of phosphate. It can be dried and exported to other European countries. The BMC Moerdijk power station processes chicken manure by burning it as fuel for generating power. This way one third of Dutch poultry manure is processed into 60,000 tons of phosphate-rich ash.
Cattle manure contains relatively low levels of phosphate and dairy farmers have their own grasslands and fields for fodder crops, on which they can use their manure. After the European milk quotas were abolished in 2015, Dutch dairy cattle numbers shot up. Countrywide phosphate production therefore exceeded the European ceiling of 172.9 million kilos and as a consequence, dairy herd sizes were cut back again. In the first half of 2017, phosphate production in the dairy industry fell by 8.3 million kilos, so the Netherlands has ended the year just below the European phosphate ceiling.

PHOTO GETTY

A worker walks through a PhosAgro warehouse full of artificial fertilizer granules in Cheropovets, Russia.

Vries, who has calculated the feasibility of exporting Dutch struvite.
On paper it looks viable compared with the production and transport of traditional artificial fertilizer, both in terms of costs and in terms of greenhouse gas emissions. 'But that is not the end of the story,' says De Vries. 'In practice there are obstacles posed by the export process, customs regulations, and local processing and distribution. To get struvite from the harbour to small farmers, you need transport, and the cost price goes up with every kilometre. And then the farmers don't know yet how to apply this kind of fertilizer efficiently in combination with potassium and extra nitrogen. In other words, if you want to do something with struvite you've got to set up a whole new system. Local recycling of struvite in Africa and Asia is of interest, too, except for the lack of well-functioning sewerage and water purification in many big cities.'

MORE PHOSPHATE IS NEEDED

Recycling and more efficient use is increasingly important in view of the projected growth in the world population and increasing wealth. A western diet with more meat, dairy and eggs will become more common, increasing the demand for phosphate for animal feeds and grassland. The expectation is that worldwide grass production for meat and milk will have to increase by 80 percent by 2015 to cater for the increased demand. If the prognoses are correct, global agriculture will be consuming twice as much phosphate fertilizer in 2050.
Besides extracting phosphate from manure and sewage, another promising strategy in the face of growing scarcity is to make smarter use of phosphate in agriculture. 'If the supply of phosphate goes down, a dairy farm will have to become more efficient to keep up the same output,' says PhD candidate Mart Ros. 'Better use needs to be made of phosphate that is already present in the fertilizer and the soil.' Ros did his research on phosphate cycles in the dairy industry, supervised by Oene Oenema of the Department of Soil Quality at Wageningen University. The 'No food without phosphates' project is supported financially by the University Fund Wageningen through a donation from livestock feed company De Heus and several individuals.
On a dairy farm the phosphate cycle goes from raw feed and grass to the cow, to manure, and then via the soil back to grass and maize fodder crops. But that cycle does not function optimally because phosphate is bound to the soil. Ros: 'In most soils the concentrations of free phosphate in the soil are less than one percent of what a plant needs over the growing season. So the rest has to come from the solid phase of the soil. That could happen when phosphate is gradually released by soil particles, or from the breakdown of organic matter. How available this phosphate is depends on processes in the soil which convert that fixed phosphate into a form those plants are able to absorb.'

WORM FAECES

Ros noticed that the root structure of grass plays a role in the absorption of phosphate. It became clear from greenhouse trials that grass species with a lot of root biomass and long roots grow better and produce bigger yields. Secondly, earthworms play a useful role in the release of phosphate: the availability of phosphate in their faeces goes up by a factor of between 30 and 1000. So grasses grow better in worm-rich soils. 'Under low-phosphate conditions we see a rise of 10 percent in the grass yield due to the impact of earthworms. Field trials are needed to see whether the results we get in the greenhouse are achieved out of doors. But I am convinced that this is a first step towards measures that can help to optimize phosphate application in agriculture.'

TACKLING WASTE

'By using artificial fertilizer we are actually redistributing and diluting phosphate,' says agronomist De Vries. 'You extract it from mines where it is present in high concentrations and spread it over farmland all around the world in the form of artificial fertilizer. You can reclaim phosphate, but recycling gets more and more difficult at lower concentrations of phosphate.'
And yet phosphate recycling is badly needed for the sake of reducing waste. De Vries; 'Many articles have been written about scarcity and rising fertilizer prices. It might become a pressing problem in about 50 years' time, but it is hard to predict precisely. New sources of phosphate get discovered, but we are also starting to use more phosphate. And yet we are still not doing certain obvious things on a large scale. Extracting struvite from sewage water is a start, and the Netherlands is in the lead on that. We are also working on manure processing, and phosphate recycling and export. None of it is particularly complicated but it does take time and money to develop the technology and the market.' ■

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