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THE DISAPPEARING NUTRIENT

Phosphate-based fertilizers have helped spur agricultural gains in the past century, but the world may soon run out of them. **Natasha Gilbert** investigates the potential phosphate crisis.

Ten years ago, Don Mavinic was working on a way to get rid of a pesky precipitate that plugs up the works of waste-water treatment plants. Known as struvite, the solid crud forms in pipes and pumps when bacteria are used to clean up sewerage sludge.

Mavinic, a civil engineer at the University of British Columbia in Vancouver, Canada, realized that struvite was more than just rubbish. A combination of phosphate, magnesium and ammonium, struvite contains many of the essential nutrients that plants need. Mavinic has developed a way to remove the precipitate during the water-treatment process and he is now selling it as a 'green' fertilizer. His technology was first used commercially in 2007 in a treatment plant in Edmonton, Alberta, Canada. It has since been exported to a plant in Portland, Oregon, which began using it this year. A sewage works in Derby, UK, successfully tested the technology in September.

Aside from finding a use for a troublesome by-product, the recycling of struvite could also help solve a much bigger problem: the dwindling supply of phosphate rock. All life forms require phosphorus in the form of phosphate, which has an essential role in RNA and DNA and in cellular metabolism. Every year, China, the United States, Morocco and other countries mine millions of tonnes of phosphate from the ground (pictured above), the bulk of which is turned into fertilizer for food crops. But such deposits are a finite resource and could disappear within the century.

Experts disagree on how much phosphate is left and how quickly it will be exhausted. But many argue that a shortage is coming and that it will leave the world's future food supply hanging in the balance.

"I am starting to think phosphate rock is becoming a strategic material for many countries. In the future it's going to become more and more valuable," says Steven Van Kauwenbergh of the IFDC, an International Center for Soil Fertility & Agricultural Development based in Muscle Shoals, Alabama. Indeed, as political and social tensions build over the reserves of phosphate rock, the world could move from an oil-based to a phosphate-based economy, say some scientists and industry representatives.

"It is a very curious thing that something so important is so poorly understood and so little talked about in the larger political arena," says Arno Rosemarin, a water-resources specialist at the Stockholm Environment Institute who has researched global phosphate use. Although international leaders have not tended to focus on the potential for phosphate shortages, the issue has been proposed for discussion next month at a United Nations meeting on global food security — an indication that it is starting to attract the attention of the international community.

Y. ARTHUS-BERTRAND/CORBIS

Just decades left?

In many countries, phosphorus is a limiting plant nutrient in short supply in the soil. So farmers add phosphate-based fertilizers to increase agricultural yields. That has spawned a global phosphate-mining industry with sales totalling in the tens of billions of dollars.

The US Geological Survey (USGS) in Reston, Virginia, estimates that around 62 billion tonnes of phosphate remain in the ground (see graphic). This includes 15 billion tonnes of deposits that are mineable at present and others

that are not being exploited. The latter are left in the ground mainly because they contain too many impurities — such as cadmium and other toxic metals — or because they are offshore in difficult-to-reach places.

In 2008, 161 million tonnes of phosphate was mined around the world, according to the latest, as yet unpublished, figures from the US Geological Survey. Stephen Jasinski, phosphate-rock commodities expert at the survey, says that demand for fertilizers is predicted to grow by 2.5-3% per year for the next 5 years. If that rate continues, the world's reserves should last for around 125 years.

That is a relatively optimistic timescale, but it is echoed by the International Fertilizer Industry Association in Paris, whose members include 90% of the world's fertilizer producers. Michel Prud'homme, executive secretary of the association's Production and International Trade Committee, says that the industry anticipates that demand for fertilizers will grow at a "fairly moderate rate", slowing by the middle of the century. That would enable reserves to last for at least another 100 years.

But others predict a faster growth in demand for fertilizers, which would deplete phosphate reserves even quicker. The increased use will be driven in part by the rising global population, which will require food production to at least double by 2050, according to the Food and Agricultural Organization of the United Nations (FAO).

Rosemarin and others say that nations should not rely on the reserves laden with impurities or located offshore because of the costs — both environmental and economic — of extracting usable phosphate. The remaining accessible reserves of clean phosphate rock would run out in 50 years, if growth stays at 3% per year, says Rosemarin.

But the estimates all suffer from a lack of reliable data. Most of the world's phosphate-mining companies are integrated with fertilizer firms and the mines are either owned by the companies or are under state control, says Prud'homme. As a result, it is difficult to get accurate, independent information on phosphate reserves.

"I am starting to think phosphate rock is becoming a strategic material for many countries." — Steven Van Kauwenbergh

Eric Kueneman, deputy director of the FAO's plant production and protection division says, "the reality is we as a public institution don't really know what the industry knows and nor do they know among themselves. To give a reliable answer to the question, 'will phosphates run out?', we need a crystal ball."

The International Fertilizer Industry Association collects data from its members on their existing reserves and on potential upcoming capacity. But some experts question the accuracy of these data because they are supplied by producers who might be disinclined to provide proprietary information that could harm their commercial positions.

No agreement

There is also a lot of uncertainty over the data supplied by governments, which is the case with China and Morocco, says Dana Cordell, who has just completed her doctoral thesis on the effect of phosphate reserves on food security at the University of Technology Sydney in Australia. For example, when China joined the World Trade Organization in 2001, its reported reserves of phosphate rock instantly jumped from just over 2 billion tonnes to nearly 8 billion tonnes[1].

Cordell and Kueneman call for independent data collection on phosphate rock reserves. "Unlike for energy, water or nitrogen, there is no single international organization responsible for phosphate resources. That is very concerning," Cordell says.

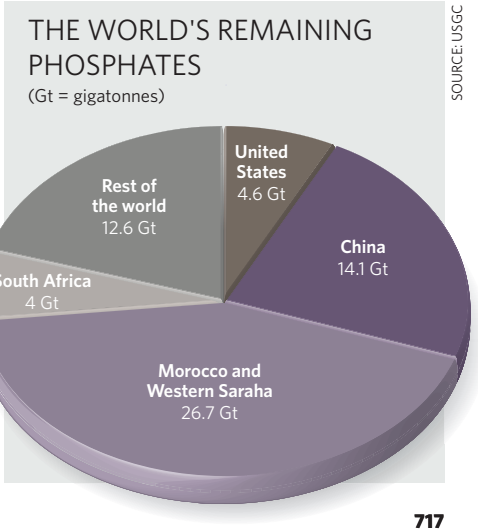
The IFDC hopes to generate more solid data about the extent of the world's phosphate resources and reserves. It will soon launch a project that will query phosphate producers, academics and other minerals specialists to collect extensive data on how much phosphate there is, how pure it is, what might be available in the future and the useful life of existing mines. Van Kauwenbergh, who is leading the project, expects to publish the first round of data in May next year. If the centre secures more funding, he hopes to continue the research for another 5 years.

The USGS figures on phosphate reserves are the most-quoted publicly available information. But there are problems with them because the agency gets its information from foreign governments, not directly from producers, and it is not independently verified. "We just don't know how good the USGS data are because they are based on second and third-hand information. The figures change all the time," says Van Kauwenbergh.

Some people who track the phosphate industry say that there is no cause for concern about phosphate running out. "I don't think this is an immediate crisis, but it is something we should be paying attention to," says Jasinski.

Prud'homme is sanguine about prospects for the future. If demand rises, then so will prices, he says, allowing companies to explore for new reserves and mine those that are harder to reach or from a lower grade of rock. "We feel there are enough reserves to meet food and material needs," he says.

For example, companies have recently begun to investigate deposits in Peru, Australia and off the coast of Namibia that were not previously considered financially viable, says Prud'homme. These resources are not fully taken into account in the most recent USGS figures on world phosphate reserves, he says. And as some existing mines are tapped out, others are opening up in places such as Saudi



Arabia. "I am convinced there are other sources we have not yet found, but it is difficult to say how much impact these will have," he says.

Others are sceptical that further exploration will uncover large new deposits or that they will solve the longer-term problem. "We are not going to find another Morocco," says Jasinski, referring to the country with the biggest remaining reserves.

In the meantime, companies have started to invest in new technologies to exploit the lower-grade and offshore deposits. The impetus for this move into more costly production was the hike in phosphate rock prices in 2008, when the value temporarily spiked at US$500 per tonne, more than five times the average price in 2007 (ref. 2). Prices had remained comparatively flat for the previous five years. The price hike was due to tight supplies of the rock caused by increased demand for phosphate-based fertilizers in India and China as well as record energy prices. Phosphate prices have since dropped back to their pre-spike levels.

Few alternatives

Despite the investments in unconventional reserves, those deposits may not be viable in the long term. Jan-Olof Drangert, an expert in water and land resources at Linköping University in Sweden, says that lower-grade reserves are "not a solution" if the world wants a sustainable system. Not only will extracting lower-grade phosphates be very expensive, it will also pollute the soils with cadmium, which is highly toxic to plant and animal life even in low doses, he says. "And then there is still the problem of exhausting these lower-grade reserves," he adds.

The increase in demand for fertilizer in 2008 may have been a taste of things to come, especially if demand for food rises as fast as some estimates suggest. The price hike last year "was a huge shock to farmers", says Cordell. Fertilizers had to be rationed in some cases.

"The bottom line is that it will just cost more to eat," says Rosemarin. "There will be no cheap lunches any more."

CLEAN WATER SERVICES

Struvite build-up in water-treatment pipes could be a valuable source of phosphate.

Making fertilizers go further

No matter how much phosphate is left to be extracted from the ground, cutting down on the use of phosphate-based fertilizers and improving their efficiency could make a significant improvement, says Alan Townsend, a biogeochemist at the University of Colorado in Boulder. "Fertilizer is seen as a cheap insurance policy. Farmers tend to overuse it because they don't want to be caught out," he says.

In the past two decades, the United States and Europe have reduced the widespread over-application of fertilizers, but that strategy continues to be a problem in other parts of the world, says Townsend. One of the biggest culprits is China[5], where farmers are applying nearly twice as much fertilizer as is needed in the production of wheat.

Experts disagree, however, on whether excess fertilizer application is actually unwarranted. Tony Vyn, an agronomist at Purdue University in West Lafayette, Indiana, says that the overuse of fertilizers in the European Union and United States has built up phosphate reserves in the soil. Farmers are now taking advantage of that by applying less phosphate than the crops actually need each year. So the strategy of China's farmers may not be unreasonable, he says.

Other gains toward preserving phosphate resources could come through improved industrial practices. Between 40% and 60% of phosphate is lost when its host rock is converted to fertilizer. Researchers are now looking to reduce that wastage. **N.G.**

The uncertainty over the world's phosphate reserves is compounded by the fact that supply is concentrated is just a few hands. China, Morocco, the United States and Russia together hold more than 70% of the global phosphate deposits[3], presenting the possibility of "market manipulation", says Amit Roy, president of the IFDC.

Evidence of strategic manoeuvring can already be seen. In March 2004, the United States and Morocco signed a free-trade agreement that covered phosphate rock, among other commodities. In 2008, Morocco exported $65-million worth of fertilizer to the United States[4]. Although the United States has one of the world's largest phosphate rock reserves, the nation will see a significant drop in production in 25 years when it is estimated that production will peak at its key mines in Florida. The deal with Morocco, says Rosemarin, is aimed at securing the United State's future fertilizer and food supply.

> **"There is no single international organization responsible for phosphate resources."**
> — Dana Cordell

In the case of some finite resources, such as oil, alternatives can be found. But there are currently no substitutes for phosphates. Cutting usage will help to make reserves last longer (see 'Making fertilizers go further').

But most agree that some of the biggest gains will probably be made from the recovery and recycling of phosphates, such as Mavinic's work mining the phosphate deposits inside water-treatment plants. In a back-of-the-envelope calculation, he estimates that if all domestic wastewater facilities in Canada were converted into biological treatment systems using his technology, the country could produce enough fertilizer to meet about 30% of its current needs.

That pales, however, when compared with a much richer — and more pungent — source of phosphate: the manure generated by dairy and pig farming. Livestock waste contains around five times more phosphate than human waste. And the global livestock population is around 65 billion, more than ten times the human population. There is "enormous potential" for recovering phosphates from livestock waste, says Mavinic, who has turned his attention to doing just that.

The problem his research team is trying to solve is that phosphates in livestock waste are not in a dissolved form, which is necessary to make struvite. If programmes to recover phosphates from livestock waste succeed, "the sky is the limit", says Mavinic. "We would probably not have to import any fertilizer into this country."

But all this takes time. Decades may pass before recycling technologies gear up and new supplies of phosphate come on line. At present, nations have expressed little concern over the finite phosphate resource and are eagerly consuming reserves. When solutions do eventually emerge, the world could already be in the grip of a fertilizer and food shortage. ■

Natasha Gilbert is a reporter based in *Nature*'s London office.

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2. USGS *Mineral Commodity Summaries: Phosphate Rock* (USGS, 2009).
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Transgenic aubergine put on ice

Stiff opposition from activists has persuaded the Indian government to put off commercial release of the country's first genetically modified (GM) food crop, despite clearance from the nation's top biotechnology regulator.

The 14 October ruling by the Genetic Engineering Approval Committee (GEAC) granted permission for Indian farmers to grow a transgenic version of aubergine, or brinjal, that is insect-resistant. But barely 24 hours later, Jairam Ramesh, India's minister of environment and forests, said that permission for its cultivation will be given only after consulting "all stakeholders".

Ramesh says that the ministry will seek public comments until the end of the year and that he "will have a series of consultations with scientists, agriculture experts, farmers' organizations, consumer groups and NGOs" in January and February 2010 before deciding whether to go forward.

P. PARANJPE/REUTERS/CORBIS

India is mooting commercial use of GM aubergines.

The GM brinjal variety was developed by Mahyco Monsanto Biotech, a joint venture between Jalna-based Maharashtra Hybrid Seed Company and US seed giant Monsanto.

The decision to seek further input has angered some crop scientists. "The minister has set a bad precedent by ignoring the recommendation of the GEAC — a statutory body consisting of scientists," says Chavali Kameswara Rao, secretary of the Foundation for Biotechnology Awareness and Education in Bangalore. "The biosafety issue of *Bt* brinjal has been studied by more than 150 scientists, and nothing new will come from fresh consultations."

But GEAC member Pushpa Bhargava, who was founding director of the Centre for Cellular and Molecular Biology in Hyderabad, says Ramesh has made the right choice. "The government need not accept every recommendation made by the GEAC," he says. Bhargava was one of the three members of the GEAC, out of a total of 20-odd members, who opposed the introduction of *Bt* brinjal — citing what they called inadequate safety data provided by Mahyco.

Mahyco says that at least 25 environmental-safety and food-safety studies on animals carried out since 2002 show that *Bt* brinjal is "absolutely safe" to eat. But Bhargava and activist groups argue that the GEAC did not get the company data independently analysed. The only other study, by French scientist Gilles-Eric Seralini of the Committee for Independent Research and Information on Genetic Engineering, branded *Bt* brinjal "potentially unsafe for human consumption".

According to Seralini, eating *Bt* brinjal reduced appetite in goats, increased prothrombin time (the time it takes blood to clot) in goats and rabbits, and caused the plants to produce a protein inducing resistance to the antibiotic kanamycin. However, an expert committee dismissed these concerns, saying that the crop "has been extensively tested for its biosafety, and no additional studies/review are necessary". That expert report formed the basis for the GEAC's ruling.

The Coalition for a GM-Free India called the approval a "shame" and alleged that "regulators have put the interests of corporations over that of ordinary citizens". But Rao says the anti-GM lobby is nervous. "They have already lost the battle over *Bt* cotton — the only GM crop grown in India — and they know if they lose over *Bt* brinjal they lose the war," he says. ■

K. S. Jayaraman

Corrections

The News story 'Where the US stimulus money is going' (*Nature* **461,** 856–857; 2009) gave the wrong location for the National Synchrotron Light Source II. It is at the Brookhaven National Laboratory in New York. And in the News Feature 'The disappearing nutrient' (*Nature* **461,** 716–718; 2009), the estimate for the amount of phosphate that could be extracted from the ground should have been 47 billion tonnes not 62 billion. This means that the figures in the pie chart should have read: United States (3.4 Gt), China (10 Gt), Morocco and Western Sahara (21 Gt), South Africa (2.5 Gt) and Rest of the world (10.1 Gt).

Mexico's transgenic maize under fire

Experimental planting scheme has insufficient controls to prevent gene flow to native crops, critcs say.

Mexico doesn't have an adequate system to monitor or protect natural maize (corn) varieties from transgenes, say prominent scientists concerned about the experimental planting of genetically modified crops.

In the past month, Monsanto and Dow AgriSciences have received government permission to plant transgenic maize across 24 plots, covering a total of nearly 13 hectares, in the northern states of Sonora, Sinaloa, Chihuahua, Coahuila and Tamaulipas. The planting of transgenic maize had been prohibited for 11 years in Mexico, where maize was first domesticated.

The experiments are meant to test hardier varieties of the crop, and federal officials say that they are implementing controls to prevent gene flow.

Ariel Álvarez Morales, executive secretary of the Mexican Inter-Secretarial Commission on Biosafety of Genetically Modified Organisms, described the experimental planting as a compliance trial to see how the companies and the plants perform. "We want to see how the planting will work in these conditions," he says. Plots will be less than half a hectare in area, seed-planting will occur at different times from that of natural varieties, and farmers will be surveyed about the effect on native maize.

In Sonora, where Monsanto has begun planting, transgenic maize is kept 500 metres away from conventional maize fields, says Eduardo Perez Pico, the firm's chief of research and regulatory affairs for the Latin American region.

However, nearly 2,000 scientists have signed a petition to block the experiments. "There is no way to stop gene flow to the native crops," says signatory Montgomery Slatkin, a geneticist at the University of California, Berkeley. Greenpeace and other groups filed a legal challenge, which the government has rejected.

M. TOVAR/AP PHOTO

Activists question Mexico's transgenic maize.

"If Mexico experimentally plants transgenic maize, it should be done with ideal experiments and a great capacity to monitor them — but we don't have either," adds José Sarukhán Kermez, a Mexican biologist who has served in top ministerial posts and is a former rector of the Autonomous National University of Mexico (UNAM) in Mexico City.

One facet of the debate surrounds the US firm being used by the Mexican government to train and equip staff at two reference labs for transgene testing in Mexico City. The firm, Genetic ID, is a spin-off by John Fagan of the Maharishi University of Management in Fairfield, Iowa, which favours organic crops and transcendental meditation.

Álvarez Morales says the firm was chosen because of its widely known analytical techniques. But geneticist Elena Alvarez-Buylla, of UNAM's Institute of Ecology in Mexico City, questions whether the company's methods are sensitive enough to detect transgenes after several generations of plant growth. Earlier this year, her group reported that Genetic ID failed to detect transgenes in blinded samples[1]. Genetic ID responded that Alvarez-Buylla's results were due to sample contamination[2], which she challenged[3].

Jay Reichman, an authority on transgenic testing with the US Environmental Protection Agency in Corvallis, Oregon, says that "overall the combined evidence suggests" that at least two transgenes "were present within the plant tissues" in question. In particular, Reichman noted that Alvarez-Buylla showed newly grown test plants believed to harbour transgenes were resistant to herbicide, indicating that they bore transgenes just like commercial seeds modified to be herbicide resistant.

Fagan disputes the criticism. Still, he too is against transgenic planting, citing the potential contamination of native maize: "It is very, very unacceptable." ■

Rex Dalton

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2. Schoel, B. & Fagan, J. *Mol. Ecol.* **18,** 4143–4144 (2009).
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Maize genome sequenced

Geneticists have sequenced the genome of maize (corn), one of the world's most widely grown grains, a feat that should accelerate efforts to develop improved crop varieties to meet the world's growing hunger for food, animal feed and fuel.

The genome "is really a tremendous resource", says John Doebley, a maize geneticist at the University of Wisconsin–Madison. "It gives us a tool for mapping genes that we didn't have."

The four-year, US$31-million project to sequence maize (*Zea mays*) was led by a US-based consortium of researchers who decoded the genome of an inbred line of maize called B73, an important commercial crop variety. The 2.3-billion-base sequence — the largest genetic blueprint yet worked out for any plant species — includes more than 32,000 protein-coding genes spread across maize's 10 chromosomes. Sections of DNA called transposable elements, which can move around the genome and cause mutations, are the most abundant parts of the sequence.

"What we have here is a crucial part of the instruction manual for how you breed a better corn plant," says project leader Richard Wilson, director of the Genome Center at Washington University in St Louis, Missouri.

The genome was published last week in *Science* (P. S. Schnable *et al. Science* **326,** 1112–1115; 2009), together with 14 companion analyses in *Science* and other journals. **Elie Dolgin**

For more, see go.nature.com/UXHHw4

Correction

In the News Feature 'The Disappearing Nutrient' (*Nature* **461,** 716–718; 2009), Amit Roy was misquoted as saying there was a possibility of "market manipulation" with phosphates. His full quote was: "The biggest challenge is that concentration of supply is only in a few hands and there is the possibility of manipulation of supply, demand and prices." Roy did not mean to imply that there is a possibility of market collusion.