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# Phosphorus Famine: The Threat to Our Food Supply

**This underappreciated resource--a key component of fertilizers--is still decades from running out. But we must act now to conserve it, or future agriculture could collapse**

By David A. Vaccari



As complex as the chemistry of life may be, the conditions for the vigorous growth of plants often boil down to three numbers, say, 19-12-5. Those are the percentages of nitrogen, phosphorus and potassium, prominently displayed on every package of fertilizer. In the 20th century the three nutrients enabled agriculture to increase its productivity and the world's population to grow more than sixfold. But what is their source? We obtain nitrogen from the air, but we must mine phosphorus and potassium. The world has enough potassium to last several centuries. But phosphorus is a different story. Readily available global supplies may start running out by the end of this century. By then our population may have reached a peak that some say is beyond what the planet can sustainably feed.

Moreover, trouble may surface much sooner. As last year's oil price swings have shown, markets can tighten long before a given resource is anywhere near its end. And reserves of phosphorus are even less evenly distributed than oil's, raising additional supply concerns. The U.S. is the world's second-largest producer of phosphorus (after China), at 19 percent of the total, but 65 percent of that amount comes from a single source: pit mines near Tampa, Fla., which may not last more than a few decades. Meanwhile nearly 40 percent of global reserves are controlled by a single country, Morocco, sometimes referred to as the "Saudi Arabia of phosphorus." Although Morocco is a stable, friendly nation, the imbalance makes phosphorus a geostrategic ticking time bomb.

In addition, fertilizers take an environmental toll. Modern agricultural practices have tripled the natural rate of phosphorus depletion from the land, and excessive runoff into waterways is feeding uncontrolled algal blooms and throwing aquatic ecosystems off-kilter. While little attention has been paid to it as compared with other elements such as carbon or nitrogen, phosphorus has become one of the most significant sustainability issues of our time.

**Green Revelation**

My interest in phosphorus dates back to the mid-1990s, when I became involved in a NASA program aiming to learn how to grow food in space. The design of such a system requires a careful analysis of the cycles of all elements that go into food and that would need to be recycled within the closed environment of a spaceship. Such know-how may be necessary for a future trip to Mars, which would last almost three years.

Our planet is also a spaceship: it has an essentially fixed total amount of each element. In the natural cycle, weathering releases phosphorus from rocks into soil. Taken up by plants, it enters the food chain and makes its way through every living being. Phosphorus—usually in the form of the phosphate ion $PO_4^{3-}$—is an irreplaceable ingredient of life. It forms the backbone of DNA and of cellular membranes, and it is the crucial component in the molecule adenosine triphosphate, or ATP—the cell's main form of energy storage. An average human body contains about 650 grams of phosphorus, most of it in our bones.

Land ecosystems use and reuse phosphorus in local cycles an average of 46 times. The mineral then, through weathering and runoff, makes its way into the ocean, where marine organisms may recycle it some 800 times before it passes into sediments. Over tens of millions of years tectonic uplift may return it to dry land.

Harvesting breaks up the cycle because it removes phosphorus from the land. In prescientific agriculture, when human and animal waste served as fertilizers, nutrients went back into the soil at roughly the rate they had been withdrawn. But our modern society separates food production and consumption, which limits our ability to return nutrients to the land. Instead we use them once and then flush them away.

Agriculture also accelerates land erosion—because plowing and tilling disturb and expose the soil—so more phosphorus drains away with runoff. And flood control contributes to disrupting the natural phosphorus cycle. Typically river floods would redistribute phosphorus-rich sediment to lower lands where it is again available for ecosystems. Instead dams trap sediment, or levees confine it to the river until it washes out to sea.

So too much phosphorus from eroded soil and from human and animal waste ends up in lakes and oceans, where it spurs massive, uncontrolled blooms of cyanobacteria (also known as blue-green algae) and algae. Once they die and fall to the bottom, their decay starves other organisms of oxygen, creating “dead zones” and contributing to the depletion of fisheries.

**While Supplies Last**

Altogether, phosphorus flows now add up to an estimated 37 million metric tons per year. Of that, about 22 million metric tons come from phosphate mining. The earth holds plenty of phosphorus-rich minerals—those considered economically recoverable—but most are not readily available. The International Geological Correlation Program (IGCP) reckoned in 1987 that there might be some 163,000 million metric tons of phosphate rock worldwide, corresponding to more than 13,000 million metric tons of phosphorus, seemingly enough to last nearly a millennium. These estimates, however, include types of rocks, such as high-carbonate minerals, that are impractical as sources because no economical technology exists to extract the phosphorus from them. The tallies also include deposits that are inaccessible because of their depth or location offshore; moreover, they may exist in underdeveloped or environmentally sensitive land or in the presence of high levels of toxic or radioactive contaminants such as cadmium, chromium, arsenic, lead and uranium.

Estimates of deposits that are economically recoverable with current technology—known as reserves—are at 15,000 million metric tons. That is still enough to last about 90 years at current use rates. Consumption, however, is likely to grow as the population increases and as people in developing countries demand a higher standard of living. Increased meat consumption, in particular, is likely to put more pressure on the land, because animals eat more food than the food they become.

Phosphorus reserves are also concentrated geographically. Just four countries—the U.S., China, South Africa and Morocco, together with its Western Sahara Territory—hold 83 percent of the world’s reserves and account for two thirds of annual production. Most U.S. phosphate comes from mines in Florida’s Bone Valley, a fossil deposit that formed in the Atlantic Ocean 12 million years ago. According to the U.S. Geological Survey, the nation’s reserves amount to 1,200 million metric tons. The U.S. produces about 30 million metric tons of phosphate rock a year, which should last 40 years, assuming today’s rate of production.

Already U.S. mines no longer supply enough phosphorus to satisfy the country’s production of fertilizer, much of which is exported. As a result, the U.S. now imports phosphate rock. China has high-quality reserves, but it does not export; most U.S. imports come from Morocco. Even more than with oil, the U.S. and much of the globe may come to depend on a single country for a critical resource.

Some geologists are skeptical about the existence of a phosphorus crisis and reckon that estimates of resources and their duration are moving targets. The very definition of reserves is dynamic because, when prices increase, deposits that were previously considered too expensive to access reclassify as reserves. Shortages or price swings can stimulate conservation efforts or the development of extraction technologies.

And mining companies have the incentive to do exploration only once a resource’s lifetime falls below a certain number of decades. But the depletion of old mines spurs more exploration, which expands the known resources. For instance, 20 years ago geologist R. P. Sheldon pointed out that the rate of new resource discovery had been consistent over the 20th century. Sheldon also suggested that tropical regions with deep soils had been inadequately explored: these regions occupy 22 percent of the earth’s land surface but contain only 2 percent of the known phosphorus reserves.

Yet most of the phosphorus discovery has occurred in just two places: Morocco/Western Sahara and North Carolina.

And much of North Carolina's resources are restricted because they underlie environmentally sensitive areas. Thus, the findings to date are not enough to allay concerns about future supply. Society should therefore face the reality of an impending phosphorus crisis and begin to make a serious effort at conservation.

**Rock Steady**

The standard approaches to conservation apply to phosphorus as well: reduce, recycle and reuse. We can reduce fertilizer usage through more efficient agricultural practices such as terracing and no-till farming to diminish erosion [see "No-Till: The Quiet Revolution," by David R. Huggins and John P. Reganold; Scientific American, July 2008]. The inedible biomass harvested with crops, such as stalks and stems, should be returned to the soil with its phosphorus, as should animal waste (including bones) from meat and dairy production, less than half of which is now used as fertilizer.

We will also have to treat our wastewater to recover phosphorus from solid waste. This task is difficult because residual biosolids are contaminated with many pollutants, especially heavy metals such as lead and cadmium, which leach from old pipes. Making agriculture sustainable over the long term begins with renewing our efforts to phase out toxic metals from our plumbing.

Half the phosphorus we excrete is in our urine, from which it would be relatively easy to recover. And separating solid and liquid human waste—which can be done in treatment plants or at the source, using specialized toilets—would have an added advantage. Urine is also rich in nitrogen, so recycling it could offset some of the nitrogen that is currently extracted from the atmosphere, at great cost in energy.

Meanwhile new discoveries are likely just to forestall the depletion of reserves, not to prevent it. For truly sustainable agriculture, the delay would have to be indefinite. Such an achievement would be possible only with a world population small enough to be fed using natural and mostly untreated minerals that are low-grade sources of phosphorus. As with other resources, the ultimate question is how many humans the earth can really sustain.

We are running out of phosphorus deposits that are relatively easily and cheaply exploitable. It is possible that the optimists are correct about the relative ease of obtaining new sources and that shortages can be averted. But given the stakes, we should not leave our future to chance.

**Toxic Assets**

Fertilizer runoff and wastewater discharge contribute to eutrophication, uncontrolled blooms of cyanobacteria in lakes and oceans, often large enough to be seen from orbit. Cyanobacteria (also known as blue-green algae) feed on nitrogen and phosphorus from fertilizers. When they die, their decomposition depletes the water of oxygen and slowly chokes aquatic life, producing "dead zones." The largest dead zone in U.S. waters, topping 20,000 square kilometers in July 2008, is off the Mississippi delta; silt from the river is visible in a 2001 satellite image at the right. More than 400 dead zones now exist worldwide, covering a combined area of more than 245,000 square kilometers. Researchers disagree about which element—phosphorus or nitrogen—should be the main focus of cost-effective water treatment to prevent eutrophication. Cyanobacteria living in freshwater can extract nitrogen from the air, so limiting phosphorus runoff is essential, as was confirmed in 2008 by a 37-year-long study in which researchers deliberately added nutrients to a Canadian lake. "There's not a single case in the world where anyone has shown that you can reduce eutrophication by controlling nitrogen alone," says lead author David Schindler of the University of Alberta in Edmonton. Cyanobacteria living in seawater seem unable to take in atmospheric nitrogen but may get enough phosphorus from existing sediment, other researchers point out, urging controls on nitrogen as well. —*Davide Castelvecchi, staff editor*

*Note: This article was originally published with the title, "Phosphorus: A Looming Crisis."*

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