PHOSPHORUS: How much is enough?

Phosphorus, crucial to agriculture and life, is at present derived from non-renewable sources. Demand will eventually outstrip supply, but when this will happen is a matter of debate. **Ninad Bondre** takes stock.

Can science feed the world?, asked the cover of *Nature* earlier this year. Sustainability and global-change researchers have long had this question on their minds. The *Nature* issue highlighted the key concerns – limited land and water, for example – we must address if we are to provide adequate nutrition to an anticipated human population of nine billion by the year 2050. It emphasised too the need for higher crop yields with less fertiliser and water inputs. But it did not explicitly mention phosphorus. This omission, some researchers would say, points to a failure to recognise the extent to which the availability of this element could limit agricultural productivity in the future. The global markets, on the other hand, seem to have been quite alert to this possibility: the price of phosphorus spiked by almost 800 percent in 2008. Although it declined rapidly, it remains much higher than in the preceding decade or so.

Phosphorus is indispensable to many life processes, and its role cannot be performed by any other element. Plants take up phosphorus in large quantities, along with other macronutrients such as nitrogen and potassium. Healthy and robust plant growth requires an assured supply of these elements, so it is no surprise that the green revolution of the last century relied on substantial inputs of fertilisers.

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We need to urgently tackle widespread malnourishment in some parts of the world while also bearing in mind the nutritional needs of a growing world population. Minimising wastage and maximising equitable distribution will help, but we will also need to produce more food. Simply expanding the currently available land for agriculture will probably come with its own set of problems – land grabs (*see* MBow 2010) and large-scale deforestation, for example. If we want to enhance the production potential of existing agricultural land, we will need to apply fertilisers, even with newer crop varieties and altered management practices.

Producing nitrogen fertilisers is not a problem. We know how to artificially "fix" it to generate forms that can be used by plants. It is so abundant in the atmosphere that we will never run out of it. Phosphate-rich rocks formed slowly over geologic time and are not renewable on human timescales. Potassium is also mined from non-renewable sources. Eventually, we will begin running out of sources that are economically (and environmentally) viable to mine and to process (*see also* Gilbert 2009).

Soils contain a pool of phosphorus that is available for absorption by plants. For any given soil and farming system, there is a critical value at which plants (and hence farmers) benefit the most and the risk of leaching into surface waters is minimal (Syers *et al*. 2008). Before large-scale mining of phosphate rock for use in fertilisers began, agriculture had relied largely on this natural soil reservoir of phosphorus, which was replenished by inputs of human and animal waste, leaf-litter and organic manure. As human populations began to surge and sanitation habits changed, such replenishment was no longer sufficient to keep up with the growing demand for crops and meat. First, societies turned to guano, the phosphorus-rich droppings of birds. Then, as guano stocks ran out, mining for phosphate rock began in earnest (see figure on facing page).

Farmers in the developed world have applied phosphorus fertilisers extensively during the past century or so, which has resulted in soils that have adequate, if not excessive, levels of phosphorus (for example, Tiessen 1995). In contrast, soils in large parts of Africa and

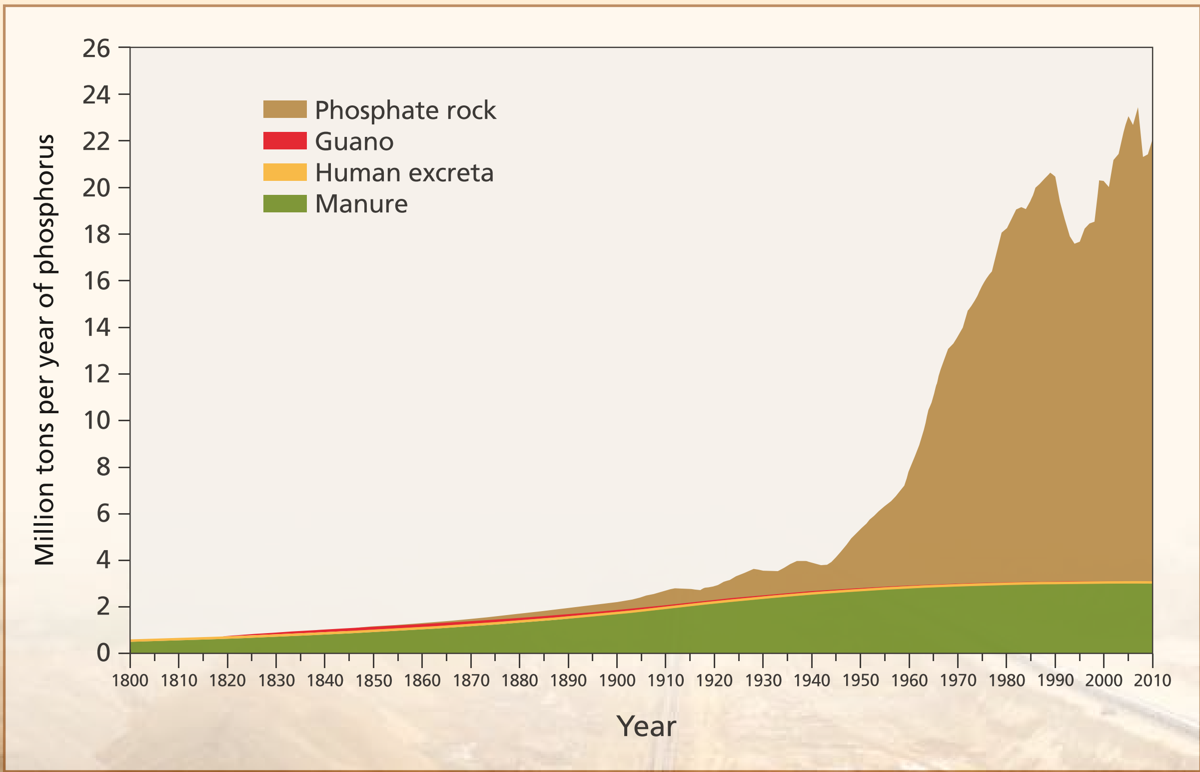

Figure courtesy Dana Cordell. Modified after Cordell *et al.* (2009).

Phosphate mining in Togo.

many parts of Asia are deficient in phosphorus. These are also the regions of the world where we expect most population growth to occur during the coming decades. Economic and socio-political considerations permitting, fertiliser use in these parts of the world is expected to increase in the foreseeable future. Tiessen (1995) reports that phosphorus use may have to double in Asia and quadruple in Africa. In an analysis published this year, Van Vuuren and colleagues conclude that the global demand for phosphorus will likely increase, but how much depends on the path that society chooses to follow during the coming decades. For example, the continued increase in meat consumption will trigger increased phosphorus demand.

How much phosphorus?

Just how much phosphorus is available for human use? The answer, it turns out, depends on whom you ask. Phosphate-rock reserves – proven and quantified material that is currently economic to mine – are on the order of 16 billion tons according to a compilation by the United States Geological Survey (USGS 2010). In addition to this is material that has not been fully quantified and is currently costly or uneconomical to mine; in principle this material could be used in the future. Such material amounts to another 35 billion tons or so according to the USGS. However, as with other strategic commodities, such as oil and important trace elements, figures pertaining to phosphate are to be taken with a pinch of salt. Mining companies often treat such data as a closely guarded secret, and so do nations. The availability of phosphorus is not independent of the demand, the quality of its sources, the technical constraints on mining and recovering the element, and the economic and environmental costs involved. Not surprising, then, that the outlook on future availability of phosphorus varies.

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Concerns about how much phosphorus is available are not new; in fact, the discussion about phosphorus sources began in earnest in the early 1970s. Studies highlighting depleting reserves were quickly countered by other studies that presented more optimistic estimates. What is happening in the field during the past few years is not too different.

Dana Cordell and the Global Phosphorus Research Initiative that she co-founded have been at the forefront of recent discussions about phosphorus availability and its implications. Cordell has recently completed her doctoral research on phosphorus and food security (Cordell 2010), which she undertook jointly at Linköping University and the University of Technology in Sydney. She conducted an exhaustive review of published and unpublished material pertaining to phosphorus sources, and supplemented it with interviews with a variety of stakeholders. Her analysis, in agreement with some earlier studies, suggests that the production of phosphate rock will peak before the middle of this century. This means that we could run out of the high quality and easy-to-mine reserves within a century. The situation is complicated by the fact that only a handful of countries – Morocco and China, for example – hold most of the phosphate-rock reserves. Geopolitics will therefore always be in the equation.

Stephen Jasinksi, USGS's mineral commodity specialist, agrees that reserves are geographically restricted and that production will likely peak around the year 2050 based on current estimates. But he is more optimistic about future prospects, and he estimates that there may be enough to last for at least another 175 years. Weighing into this estimate is the fact that several new mines are being opened this year, for example in Australia and Saudi Arabia. Technological improvements may facilitate extraction of phosphorus from material that is currently not economic to mine. Jasinski adds that although US production of phosphorus peaked in the late 1900s and was expected to decline, it has stayed much higher than predicted. Better use of resources and changing global supply patterns played an important part.

The latest twist in the tale is a report commissioned by the International Fertilizer Development Center (IFDC): this report analysed publicly available information to come up with an estimate of reserves that is about four times that of the USGS. The report authored by geologist Steven Van Kauwenbergh, while mentioning that the estimate is preliminary, dismisses the possibility of a production peak by the middle of the century. It suggests that at current rates of production, phosphate rock reserves should last for the coming three to four centuries.

Responding to this report, Dana Cordell points out that the upward revision in estimates is almost entirely because of revised figures for Morocco – reserves she says are based on uncertain and preliminary data. Moreover, the new estimates raise further concerns about the geopolitical implications of Morocco and China controlling over 90 percent of the reserves. She emphasises that production rates are likely to increase in the future and that processing remaining reserves will cost more, need more energy and will generate more waste.

The future

How long viable phosphorus sources will last is clearly open to debate: we can resolve this debate only after substantial additional work and access to proprietary data. If the recent IFDC report is correct and if geopolitical and technical considerations are favourable, the world would probably have enough phosphorus to last several centuries. But there might just be much less phosphorus than we thought. And technical issues or costs might preclude mining the poorer quality and difficult-to-access sources. Van Vuuren and colleagues, in spite of a detailed analysis of demand and supply, can only come up with three scenarios that range from the relatively optimistic to the relatively problematic because of the uncertainties. Clearly the number of "ifs" and "buts" suggests that more substantive effort is needed to collect/make available data on phosphorus sources.

A complex range of factors was responsible for the phosphorus price spike of 2008, one of which was the real or perceived increase in demand for fertilisers. The same year, China imposed an export tariff of 135 percent on phosphate rock perceiving the need to secure reserves for domestic crops; this tariff was subsequently removed. Mining companies and nations are highly attuned to the possible scarcity in similar commodities arising from future demand from agriculture and perhaps the biofuel sector. The Australian mining company BHP Billiton recently launched a hostile bid to take over Potash Corporation, the Canadian fertiliser producer. Writing for the *New York Times*, Cyrus Sanati mentions that this move can be interpreted as BHP's recognition that the demand for potash – the ore of potassium – is bound to increase in concert with the demand for food by a growing population. At the time of writing this article, there is a possibility that Sinochem, a Chinese company, may be seeking government support to launch a counter bid by making the argument that securing potash supplies is critical to ensuring food security for China's large population.

Whether we have a little or a lot of phosphorus remaining, the majority of mined phosphorus is wasted throughout the production and supply chain, from fertiliser production to crop harvest to food retailing. Some of this makes its way to water bodies, causing eutrophication, a process that leads to oxygen depletion, which has been flagged as a serious global environmental problem. Cordell points out that in spite of these sorts of links, those studying the various aspects of phosphorus – economic, social and environmental, for example – seldom work together. As a result, we have tended to treat phosphorus pollution as an issue separate from, say, food security. This is in contrast to carbon or even nitrogen, the multiple facets of which are now studied in a far more integrated fashion. Cordell and her colleagues are now setting up a global network of various stakeholders interested in the sustainable use of phosphorus. One way to achieve greater sustainability in phosphorus use would be to minimise losses and substitute chemical fertilisers with composted crop residues, and human and animal wastes.

Some argue that technological change and market forces will solve resource problems, such as those caused by finite supplies of oil. This argument is a well-entrenched one, and indeed, it is borne out to an extent by human history: animal-driven carriages were replaced by cars running on petrol, and these cars in turn may well be replaced by electric and solar-powered vehicles. But even new technologies can themselves rely on rare, non-renewable material – highly efficient solar panels, for example, require indium and gallium, which are rare metals that are likely to get rarer (Ragnarsdottir 2008). And although some resources can have substitutes, there is none for phosphorus: it cannot be replaced by, say, cadmium as fossil fuels can be by other substances. The renewed discussion of phosphate rock reserves raises the more general issue of our dependence on non-renewable materials. This is an issue we will inevitably need to confront while planning for a future socio-economic system based on more sustainable principles. ■

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