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LOOMING SCARCITY OF PHOSPHATE ROCK AND INTENSIFICATION OF SOIL PHOSPHORUS RESEARCH

Philippe C. Baveye[1, 2]*

[1] Rensselaer Polytechnic Institute, Department of Civil and Environmental Engineering, Soil and Water Laboratory, New York, USA.
[2] Université Paris-Saclay, Unité EcoSys, AgroParisTech, Thiverval-Grignon, France.
* Corresponding author.
E-mail: Baveye.RPI@gmail.com

ABSTRACT

In recent years, many researchers have claimed that world reserves of rock phosphate were getting depleted at an alarming rate, putting us on the path to scarcity of that essential resource within the next few decades. Others have claimed that such alarmist forecasts were frequent in the past and have always been proven unfounded, making it likely that the same will be true in the future. Both viewpoints are directly relevant to the level of funding devoted to research on the use of phosphate fertilizers. In this short essay, it is argued that information about future reserves of P or any other resource are impossible to predict, and therefore that the threat of a possible depletion of P reserves should not be used as a key motivation for an intensification of research on soil P. However, there are other, more compelling reasons, both geopolitical and environmental, to urgently step up our collective efforts to devise agricultural practices that make better use of P than is the case at the moment.

Keywords: phosphorus reserves, phosphorus availability, depletion phosphorus, food security.

RESUMO: *A AMEAÇADORA ESCASSEZ DE FOSFATO DE ROCHA E A INTENSIFICAÇÃO DE PESQUISAS COM FÓSFORO NO SOLO*

Nos últimos anos, muitos pesquisadores têm afirmado que as reservas mundiais de fosfato de rocha estão se esgotando a um ritmo alarmante, o que nos coloca no caminho para a escassez desse recurso essencial nas próximas décadas. Outros afirmaram que tais previsões eram frequentes no passado e sempre foi provado que eram infundadas, o que provavelmente será verdade no futuro. Ambos os pontos de vista são diretamente relevantes para o nível de financiamento dedicado à investigação sobre o uso de fertilizantes fosfatados. Nesta breve revisão, argumenta-se que as informações sobre reservas futuras de P,

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ou qualquer outro recurso, são impossíveis de prever e, portanto, que a ameaça de um possível esgotamento das reservas de P não deve ser usada como motivação-chave para uma intensificação das investigações sobre o P no solo. No entanto, há outras razões, mais atraentes, tanto geopolíticas como ambientais, para intensificarmos, urgentemente, os nossos esforços para conceber práticas agrícolas que proporcionem o melhor uso de P do que as atuais.

Palavras-chave: reservas de fósforo, disponibilidade de fósforo, depleção de fósforo, segurança alimentar.

INTRODUCTION

Over the last few years, the question of the availability of P to crops has been the object of significant societal concern, which has translated into sizeable research efforts on all aspects of the question. Kruse et al. (2015), in a very thorough review article published recently, show how extensive efforts have been in the past decade to find novel techniques to analyze the fate of P in soils at ever-finer scales. All this research has translated into a large and steady stream of publications, worldwide. In this journal, for example, articles dealing in one way or another with phosphate fertilizers or P in soils represent a large percentage (roughly 21 %) of all articles published, and cover a wide range of topics, from more fundamental ones all the way to applications (e.g., Freitas et al., 2013; Gatiboni et al., 2013; Schmitt et al., 2013; Vieira et al., 2013; Lourenzi et al., 2014; Oliveira et al., 2014; Sandim et al., 2014; Santos et al., 2014; Souza et al., 2014).

Whenever a justification is provided by authors for this interest in topics related to P, arguments revolve very often around serious concerns about “future global supplies of phophorus (P)” (Kruse et al., 2015). Indeed, some authors are forecasting that, at the current rate of exploitation, P reserves around the world will become depleted, and production of P fertilizers will decrease dramatically after 2033, a year that will correspond to what is referred to as “peak phosphorus” (Clabby, 2010). As a result of this impending shortage of a nutrient that is essential to crop growth, some argue that a significant portion of humanity will starve (Grantham, 2012). Even if threats in this respect were in fact far less than anticipated by these authors, even a partial shortage of P fertilizers worldwide would add further constraints to agricultural practice, already struggling in most countries with limited water and soil resources, at a time when food security requires crop production to double, globally, over the next 35 years.

Not everyone, however, is convinced that access to phosphate fertilizers in adequate quantities is going to be a major problem in years to come, nor considers that steps should be taken to alleviate difficulties before they emerge. In the last few months, in private conversations and in talks at national or international conferences, reference is increasingly made in this context to an overview article published by Ulrich and Frossard (2014), which is more and more often presented as a clear demonstration that we should not worry unduly about P, nor think about modifying agricultural practices too drastically in prevision of a possible scarcity of that nutrient in the future[(3)].

In this general context, the objective of this short essay is to determine which one of the two conflicting perspectives on the risks associated with P scarcity is the more realistic one at this point, i.e., to some extent, whether or not there is urgency in continuing or even intensifying the current research effort devoted to this general topic.

THE PAST, GUIDE TO THE FUTURE?

As an initial step in this analysis, it is useful to assess if allusions to Ulrich and Frossard’s (2014) message really are in line with these authors’ conclusions. In their article, Ulrich and Frossard (2014) describe in detail a large body of evidence available in the literature, suggesting that current concerns about the availability of phosphate fertilizers, and their relevance to food security, are not at all recent or novel, as some authors have tried to portray them, but have a “long, well-documented, and repetitive history.” Moreover, these authors show that past worries about P depletion have been systematically “refuted by means of new resource appraisals, indicating that the supply was substantially larger than previously thought.”

Beyond the clear demonstration that anxiety about the “peak phosphorus” issue is *déjà vu*, it is

(3) Encouragement to write this short article came after a colleague commented on a manuscript I was writing and in which I referred to phosphorus supply as being one of the three main issues facing soil science research in the coming decade. Based on his reading of Ulrich and Frossard (2014), he tried to convince me to drop phosphorus from the list.

unclear what additional "take-home" message(s) Ulrich and Frossard (2014) would like readers to derive from their analysis. They caution that "we cannot blindly transfer past happenings to today's situation" or that "lessons from the past are not necessarily good indicators for the future", which suggests in straight language that history cannot help us determine whether or not a P depletion scenario is at all likely to occur in the foreseeable future. However, at other junctures in their article, for example when they state that "promulgating the notion of depletion is inconsistent with past findings", Ulrich and Frossard (2014) seem to argue exactly the opposite, namely that history *can* serve as a guide for the future.

Some readers could derive from these latter statements a potentially false confidence that, as has been repeatedly the case in the past, there is a high probability that new P-rich deposits will yet again turn up sooner or later somewhere in the world, alleviating qualms one might have about current P reserves running out. From that perspective, there would just be a tiny step, which undoubtedly a number of individuals will make without hesitation, to considering that at the moment there is no particular problem at all associated with P availability, and that measures to curb P consumption are unnecessarily cautious. To some extent, I fear that this latter viewpoint is prevailing at the moment.

INSUFFICIENT INFORMATION

Nevertheless, it does not take a very long analysis of relevant statistics to realize that nothing, other than mere guesses, can be said about the future of phosphate fertilizer production, in part because the quality of the information currently available on phosphate rock reserves around the world leaves much to be desired. There are various reasons for this, associated, e.g., with difficulties commonly met in the quantitative assessment of any underground geological resource, or with the fact that the related data are most often provided by the private sector, for which they have clear financial repercussions, and therefore may not be entirely trustworthy. As a result, there is considerable uncertainty about the present status of phosphate rock reserves. It is also clearly anyone's guess whether any new, economically exploitable resources will or will not be found in the future, in particular in Brazil where there is a significant prospection effort underway.

Under these conditions, we can discuss depletion scenarios *ad nauseam*, and go as far back in history as we want, to find arguments in one sense or another, but unfortunately neither exercise is likely to help us predict with any kind of accuracy what will happen in the next few years or decades. This may be what Ulrich and Frossard (2014) mean when they suggest, in a somewhat cryptic sentence at the very end of their article, that the debate about phosphate reserves should not focus on depletion: "It seems more advisable to shift the main problem representation from geological P availability and comprehend more prominently socio-economic (e.g., the fertilizer access to small-holder farmers), or environmental (e.g., pollution) vulnerabilities that may result from current and future P production and consumption patterns." However, their conclusion does not convey any sense of urgency, as if we had ample time to resolve the "larger systemic issues" to which they very briefly allude. Unfortunately, I do not think that this viewpoint is well-founded. We do not have ample time, for several key reasons. One of these is geopolitical.

GEOPOLITICAL REALITY

The only piece of information on which most industry observers and government officials seem to agree at the moment is that a very significant proportion of the phosphate rock reserves (as reported by producers) appears to be concentrated in one, relatively small, area of the globe, in Morocco and Western Sahara (e.g., Cordell et al., 2009). Estimates of the amount of rock phosphate present in these two countries range from 45 to 85 % of the world's total reserves. The most recent estimate, by the U.S. Geological Survey, places the figure at 75 % (Jasinski, 2014). This picture would not be complete without considering the geographical concentration of the production of another chemical compound that is extremely important to the manufacture of phosphate fertilizers. Indeed, sulfuric acid, which is crucial to the transformation of phosphate rock into superphosphate, is produced predominantly in five countries: China, the US, India, Russia, and (increasingly) Morocco[4]. Not only do these five countries hold, combined, over 80 % of the known reserves of phosphate rock, and produce 76 % of the world's phosphate rock mined annually (Jasinski, 2014), but they also control roughly 70 % of the sulfuric acid market. These different statistics mean that the geographical concentration of

(4) According to Jasinski (2014), Brazil holds only 0.4 % of the known, exploitable world reserves of phosphate rock. Unless new reserves are found in the country, Brazilian agriculture would be potentially very vulnerable to any attempt by producing countries to control exports.

phosphate rock reserves and production, as well as of the capacity to transform the phosphate rock into fertilizers, is far worse than what has been historically the case for petroleum. Indeed, the estimated 75 % of the world's oil reserves controlled by the OPEC cartel, at the time it still unilaterally dictated oil prices, were spread over 12 countries, not a mere five. In other words, even if by chance a new, sizeable deposit of phosphate rock were found somewhere beside in Morocco or Western Sahara in the next few years, phosphate rock reserves would still be remain extremely localized geographically.

Any concern about the creation of a cartel by phosphate rock producers could be tempered by noting that China, India, Russia, and the US are unlikely to agree on a common agenda in this context, for example to limit their production. Yet, prices of phosphate rock and phosphate fertilizers could easily rise for other reasons. There could be political unrest in Western Sahara and Morocco, for example if the POLISARIO (the Front for the Liberation of Saguía el Hamra and Río de Oro) decided to try to put an end to the Moroccan occupation of Western Sahara, or if some extremist faction attempted to invade the territory and caused political unrest in Morocco. All of these events would likely have a very negative impact on the evolution of the phosphate rock market. A price hike could also simply result from a sudden increase in demand for phosphate rock by some of the major players in the fertilizer market. Observers consider this to be the key reason the price per metric ton of phosphate rock on the world market shot from $45.50 to a whopping $430, almost 10 times higher, within a little over a year, between April 2007 and August 2008 (based on data provided at http://www.indexmundi.com/commodities/?commodity=rock-phosphate&months=180). In effect, this increase put phosphate fertilizers completely out of reach for a significant portion of humanity, with potentially dire consequences for hundreds of millions of people in terms of food security. Fortunately, the situation did not last, and phosphate rock prices have since come down somewhat (even though, at about $115.00 per metric ton, they are still appreciably higher than they were in 2007).

Parenthetically, the fact that price-related threats are not taken idly by a number of countries is evinced by the efforts of the European Commission and the US, started a few years ago and continuing to this day, to ensure an uninterrupted supply of phosphate rock from Morocco in the future. Both the EC (in 2000) and the US (in June 2004) signed bilateral free trade agreements with Morocco, which cover many aspects of commercial exchanges between the signing entities, and in particular would guarantee unhindered phosphate rock exports from Morocco, as long of course as Morocco remains politically stable. However, other countries that have not signed similar treaties with Morocco might be vulnerable not only to price fluctuations but also to any decision of the Rabat government to curtail production or to restrict export of phosphate rock, for one reason or another.

Generally, when faced with a situation where the price of an essential raw material is likely to rise at a moment's notice because of scarcity or monopoly, most manufacturing companies endeavor to reduce their dependency in some fashion, as rapidly as possible. Nobody wants to be at the mercy of someone who holds all the cards... For example in the case of lithium, in part because as much as 98 % of worldwide reserves are located in a single country (Bolivia), battery manufacturers are actively looking for suitable substitutes (e.g., Larcher and Tarascon, 2015). The same goes for rare earths, used in electronics and whose trade was increasingly becoming controlled by China (Aston, 2010) until recently, when reserves were found in the Brazilian amazon region. Brazil holds anywhere between 80 and 95 % of the world's niobium (used to manufacture specialty steel), for which substitutes are also actively sought.

NO SUBSTITUTE TO P

Unfortunately, P presents a uniquely daunting challenge, because there are no substitutes for it in the context of plant nutrition. Therefore, options are more limited. One possibility, which is being explored in a number of venues (e.g., Cordell et al., 2009), is to rethink the life cycle of agricultural products, e.g., through composting of household organic wastes, so that P actually gets recycled onto the land, instead of ending up in landfills or in wastewater streams. Another approach is to try by various means to increase the efficiency of phosphate fertilizers applications to agricultural fields (Simpson et al., 2011). Presently, a common estimate in that respect is that only about 15 % of P is used by crops during the year following application. Some of the remaining 85 % either gets sorbed to soil constituents, is taken away through soil erosion, runs off, or is leached, the exact partitioning between these various mechanisms depending on local soil characteristics. Some authors (e.g., Richardson et al., 2011) have suggested that increased phosphate fertilizer efficiency could be obtained by modifying root growth and architecture, through manipulation of root exudates, or by managing associations between plants and microorganisms, such as arbuscular mycorrhizal fungi and microbial inoculants. Specific objectives in the research in this area currently target (1) root-foraging strategies that improve P acquisition by lowering the critical P requirement of plant growth and allowing agriculture to operate at lower levels of soil P, (2) P-mining strategies to enhance the desorption, solubilisation or mineralisation of P from sparingly-available sources in soil using root exudates (organic anions, phosphatases), and (3) improving internal P-utilisation efficiency through the use of plants that yield more per unit of P uptake. Until researchers explore some of these routes more fully and find ways to alleviate the current inefficiency of P fertilizer use for crop production, significant amounts of phosphate will continue to be applied in vain to agricultural fields...

ABUNDANCE OF NEGATIVE ENVIRONMENTAL CONSEQUENCES

And, in the mean time, this inefficiency is causing a wide array of critical problems of a different nature. Since they often contain non-negligible amounts of impurities, e.g., heavy metals (Silva et al., 2014) and radionuclides, the wasteful usage of phosphate fertilizers makes these contaminants accumulate in soils in quantities that, over decades, often become staggering (e.g., Pizzol et al., 2014). A recent estimate in Germany, for example, shows that fertilizer application there from 1951 to 2011 has led, among others, to the cumulative addition of about 14,000 tons of uranium to agricultural land (Schnug and Lottermoser, 2013). Phosphate rock could in principle be treated to remove contaminants, but this process involves a cost, which is likely to be prohibitive for a wide segment of the world population. In the absence of such processing, some of the contaminants not only accumulate in soils, but are also likely to migrate to the underlying groundwater bodies, through direct or facilitated transport, along with the phosphates themselves (e.g., Hendricks et al., 2014).

In this respect, the concentration of phosphates in groundwater in many parts of the world has been increasing over the years, and is associated with a number of different health and technological problems. For example, elevated phosphate levels in drinking water supplies may cause kidney damage and osteoporosis in humans (e.g., Calvo and Uribarri, 2013). The presence of P can also reduce the efficiency of specific remediation strategies, e.g., for the treatment of arsenic-laden groundwater (e.g., Brunsting and McBean, 2014). Over the years, seepage, through streambeds, of groundwater containing phosphates, along with phosphate fertilizer runoff from agricultural fields, and the release in the environment of phosphate-laden treated wastewater, have also caused many lakes and rivers all over the world to become eutrophicated (e.g., Domagalski and Johnson, 2012). Hundreds of hypoxic, so-called "dead zones" have developed in oceans at the mouths of rivers flowing through regions of the world where input-intensive agriculture is practiced, in particular in the US and Europe. The largest of these dead zones, in the Gulf of Mexico close to where the Mississippi river discharges, has an astoundingly extended surface area of about 7,000 km^2, and apparently keeps expanding at an alarming rate, as do many other such dead zones in other parts of the globe.

TAKE-HOME MESSAGE

Perhaps even more so than the geopolitical reasons alluded to earlier, this depressing pot-pourri of environmental problems, in and of itself, should constitute a compelling argument to drastically modify the way phosphate fertilizers are currently used in agriculture, and to do so as rapidly as possible. In this context, it is tempting to think that all those who invoked the specter of phosphate fertilizer scarcity with such obstinance over the past decades, did so out of a genuine belief that it constituted the most effective way to convince anyone to modify traditional attitudes. As a strategy to stimulate change, such a threat might lead to desirable soul-searching and effect change in the short run, but the slightest hint that new phosphate rock reserves may be located in the not-too-distant future would be enough to make all efforts collapse like a house of cards, as they indeed have, historically. In that sense, a historical perspective is useful in pointing out that, based on past evidence, it might be a bad bet to "cry wolf" once more and expect to get away with it. So, the logical conclusion is that to encourage society to adopt a sustainable outlook on phosphate use, a more rational strategy would be to advocate sounder reasons for doing so, which are partly geopolitical (and therefore economic), but especially environmental. Without equivocation, we should state that it is imperative for the preservation of nature and the well being of human populations that we urgently do a far better job of managing the phosphate fertilization of our food crops. This may be on land, as it has been traditionally. Or it may be off it. Indeed, we could decide to go where phosphates have tended to be carried away, unimpeded, over the last few decades and where - added advantage - water is plentiful, i.e., in rivers, lakes, and oceans, and we could attempt to grow crops there, as is currently tried increasingly in a number of areas around the world (e.g., Baveye et al., 2011; Radulovich, 2011), to relieve some of the pressure exerted on soil resources. Whatever avenue one decides to explore, the crucial take-home message here is that time is of the essence, just as much or perhaps even more so than if we were to actually run out of phosphate rock 10 or 20 years down the line.

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