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THE AUSTRALIAN STORY OF PHOSPHORUS

THE AUSTRALIAN STORY OF PHOSPHORUS:

Sustainability implications of global fertilizer scarcity for Australia

Discussion paper prepared for the
National Workshop on the Future of Phosphorus, Institute for Sustainable Futures, University of Technology, Sydney
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Institute for Sustainable Futures

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The National Workshop on the Future of Phosphorus is a one-day workshop bringing together key Australian stakeholders to discuss the implications of global phosphate scarcity (and related sustainability and ethical issues) for Australia's food production and consumption system and vision possible future scenarios.

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Introduction: why phosphorus

All living matter - including plants, animals and humans - require phosphorus to grow. We get phosphorus from the food that we eat, though where the phosphorus in our food comes from and how sustainable it is in the long term is often not widely discussed nor a topic of significant investigation. Additions of phosphorus fertilizer are essential for achieving high crop yields, especially in agricultural systems with naturally phosphorus deficient soils, such as Australia. Mining of phosphate-rich deposits of guano and phosphate rock have played an important part in feeding the world in the past 100 years, and supporting the Australian economy. However, increasing environmental, economic, geopolitical and social concerns about the short and long-term use of phosphate rock in agriculture means there is a need to start a conversation on what a sustainable phosphorus future might look like for Australia, how we might get there and what are the pertinent challenges that need to be addressed.

The current global situation: phosphorus supply, demand & geopolitics

Modern agriculture in Australia and worldwide is today dependent on continual inputs of phosphate fertilizer processed from mined phosphate rock to boost soil fertility and replenish soil with what is taken away by harvested crops. Yet phosphate rock is a non-renewable resource and approximately 50-100 years remain of current known reserves (Steen, 1998; Smil, 2000b; Gunther, 2005). The reserves that do exist are under the control of a handful of countries, including China, the US and Morocco (figure 1). While China has the largest reported reserves, it has recently imposed a 135% export tariff on phosphate, effectively banning any exports in order to secure domestic supply. The US, historically the world's largest producer, consumer, importer and exporter of phosphate rock and phosphate fertilizers, has approximately 25 years left of domestic reserves (Stewart et al., 2005; Jasinski, 2008). US companies import significant quantities of phosphate rock from Morocco to supply their phosphate fertilizer plants (Jasinski, 2008). This is geopolitically sensitive as Morocco currently occupies Western Sahara and its massive phosphate rock reserves, contrary to international law. Trading with Morocco for Western Sahara's phosphate rock has been condemned by the UN, and importing phosphate rock via Morocco has been boycotted by several Scandinavian firms (The Norwegian Support Committee for Western Sahara, 2007; Corell, 2002). Box 1 outlines the key issues.

Box 1: The phosphorus situation

- Phosphorus, like potassium and nitrogen, is an essential nutrient – all living organisms require phosphorus to grow. Without phosphorus, we could not produce food at today's yields.
- Demand for phosphorus fertilizers is expected to increase by 50-100% over the next 50 years due to increased population, increased demand for meat and dairy-based diets and increased demand for non-food crops like biofuel crops.
- Today agriculture today relies on phosphorus fertilizers processed from mined phosphate rock, which is a non-renewable resource, like oil.
- Current global reserves could be depleted in the next 50-100 years. Reserves that remain are of lower quality and cheap fertilizers are likely to be a thing of the past.
- While all farmers need access to phosphorus, remaining phosphate rock reserves are in the control of only a handful of countries, including China, US, and Morocco (which also controls Western Sahara's reserves).
- Phosphorus in effluent and leakage from agriculture can also lead to eutrophication of water bodies, resulting in potentially significant ecological and economic damage.

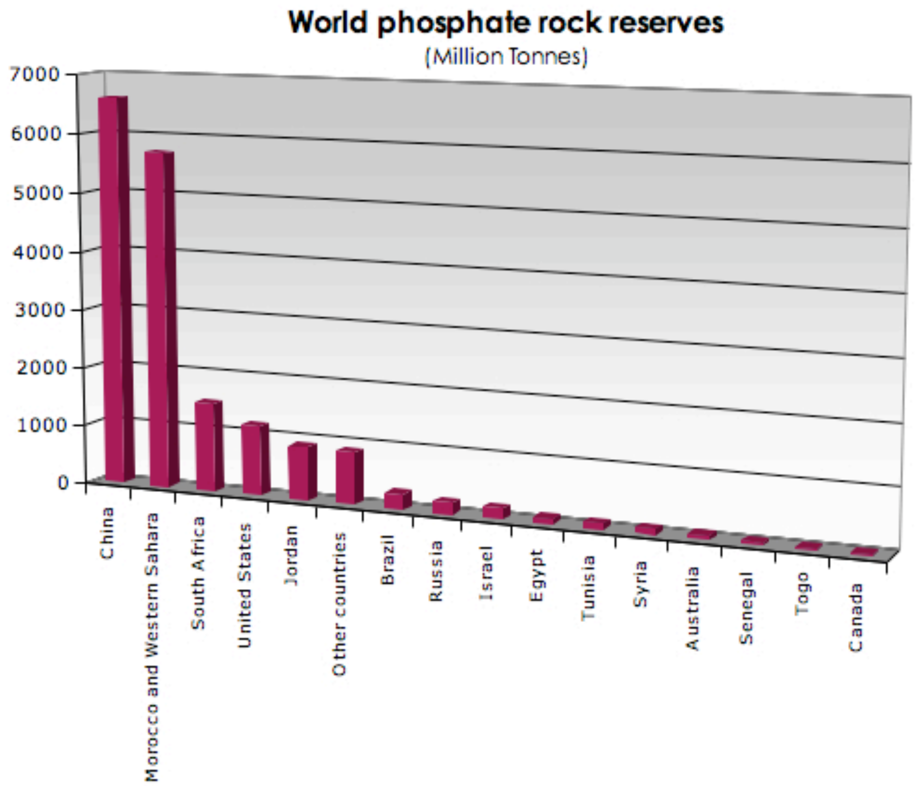


Figure 1: Global phosphorus reserves are geographically concentrated and under the control of only a handful of countries. (data: Jasinski, 2008)

Historically, crop production relied on natural levels of soil phosphorus with the addition of organic matter like manure, and in parts of Asia human excreta (Mårald, 1998). To keep up with rapid population growth and food demand in the 20th Century, concentrated mineral sources of phosphorus were discovered in guano and phosphate rock and applied extensively (Brink, 1977; Smil, 2000b). Today, we are effectively addicted to phosphorus from mined phosphate rock. Without continual inputs we could not produce food at current global yields[1].

Following more than half a century of generous application of phosphorus and nitrogen, agricultural soils in Europe and Northern America are now said to have surpassed 'critical' phosphorus levels, and thus only require application to replace what is lost in harvest (FAO, 2006; European Fertilizer Manufacturers Association, 2000). The more immediate problem in this context is phosphorus runoff from agricultural fields polluting receiving water bodies.

However in developing countries and emerging economies the situation is quite different. In Sub-Saharan Africa for example, where at least 30% of the population is undernourished, fertilizer application rates are extremely low and 75% of agricultural soils are nutrient deficient[2] thus yields are falling (IFDC, 2006; Smaling et al., 2006). While the UN and the Alliance for a Green Revolution in Africa has called for a new Green Revolution in Sub-Saharan Africa, including increased access to fertilizers (Blair, 2008; AGRA, 2008), there is little discussion on the finiteness of phosphate fertilizers in the future. Global demand is forecasted to increase by around 3% until 2010/11, with around 2/3 of this demand coming from Asia (FAO, 2007a). Box 2 outlines the short-term situation.

[1] The Green Revolution (including the production and application of mineral fertilizers) in the mid 20th Century is said to be responsible for increasing per capita nutritional intake and doubling crop yields IFPRI (2002).
[2] Soil nutrient deficiency is due to both naturally low phosphate soils and anthropogenic influences like soil mining and low application rates which have resulted in net negative phosphorus budgets in many parts of Sub Saharan Africa (Smaling et al, 2006).

Box 2: The short-term fertilizer crisis

In 2007-08, the same pressures that caused the recent global food crisis resulted in the demand for phosphate rock and fertilizers exceeding supply and a price increase of 700% (Figure 2). Increasing meat and dairy-based diets, especially in growing economies like China and India, require significantly more phosphorus fertilizer per capita (Cordell et al., in press). Phosphate rock production and especially trade is linked directly and indirectly to the price of oil. The recent sharp increase in biofuel production is not only competing for grains and productive land for food, but also for phosphorus fertilizers.

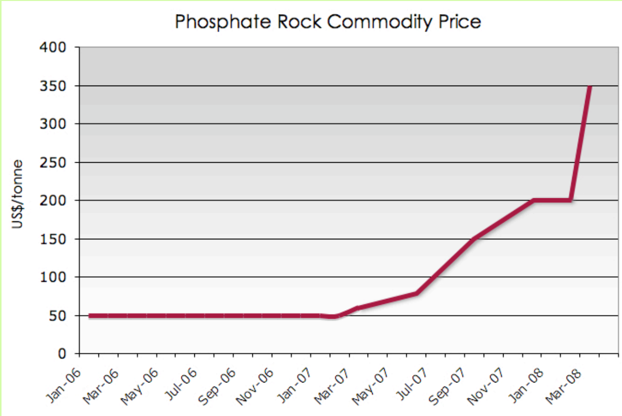


Figure 2: Phosphate rock commodity price (Morocco) increased 700% between January 07 and March 08 *(data: Minemakers, 2008)*

The International Fertilizer Industry Association expect the fertilizer market to remain tight for at least the next few years (IFA, 2008). It is therefore anticipated that the price of phosphate rock and related fertilizers will remain high in the near future, until new mining projects such as in Saudi Arabia are commissioned (Heffer and Prud'homme, 2007). Most farmers were completely unaware of the spike in price of fertilizers. In India, which is totally depended on phosphate imports, there have been instances of farmer riots and deaths due to the severe national shortage of fertilizers (Bombay News, 2008).

Given the short-term price rise of phosphate fertilizers, it is timely to start addressing the longer-term implications of global phosphate scarcity, and specific implications for Australia.

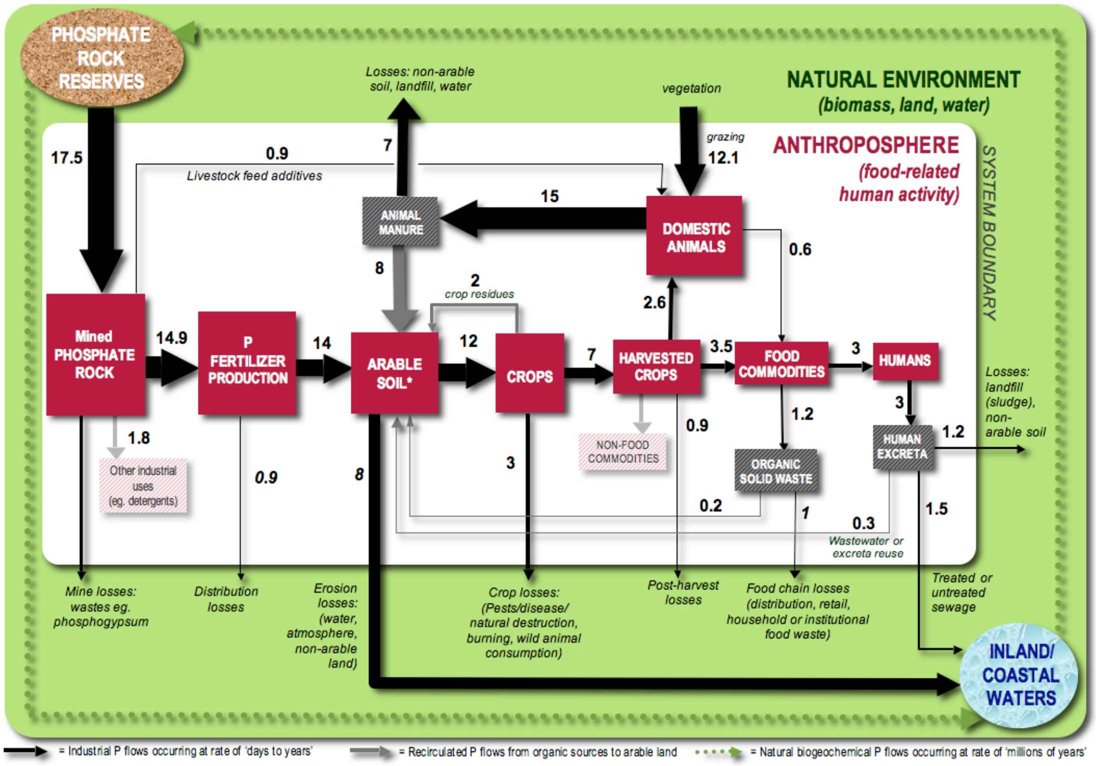
Despite increasing global demand for non-renewable phosphate rock both in the short and longer term, and its critical role in food production, global phosphate scarcity is missing from the dominant debates on global food security and global environmental change. For example, phosphorus scarcity has not received explicit mention within the Food and Agricultural Organisation of the UN (FAO, 2007a; FAO, 2006; FAO, 2005), International Food Policy Research Institute (IFPRI, 2005; IFPRI, 2002), the Global Environmental Change and Food Systems programme (GECAFS, 2006), International Assessment of Agricultural Knowledge, Science and Technology for Development (IAASTD, 2008) and the recent High-level Conference on World Food Security hosted by FAO (FAO, 2008). The implications of declining global phosphate availability and accessibility are mentioned in very few discussions by few concerned scientists[3].

[3] A recently published paper on "Long-term global availability of food: continued abundance or new scarcity?" (Koning et al, 2008) does address phosphorus scarcity as a key factor likely to limit future food availability.

Tracking phosphorus flows through the global food system

While our bodies require just 1.2 grams of phosphorus per person per day, we are mining five fold this amount in phosphate rock. So where is the missing 80% of phosphorus going? A Substance Flows Analysis (SFA)[4] can track major flows of phosphorus through the global food production and consumption system, and aid identification of the magnitude and location of losses or inefficiencies in the system and thus to potential recovery points.

The findings are summarised in Figure 3. The inner white area defines the food-related human activity system, while the outer area is the 'natural' phosphorus biogeochemical system (in which the human activity system is embedded). The arrows indicate the rough quantities of phosphorus processed between each key stage (the boxes) in food production and consumption process, beginning with mining, fertilizer production, application to agricultural soil, harvesting of crops, food and feed processing, consumption by animals and humans, excretion and the final fate of phosphorus in the anthropogenic or natural environment. Phosphorus recovered from the system and reused is also indicated.



* only a fraction of applied mineral P is taken up by crops in a given year, the balance comes from the soil stocks, either form natural soil P, or build up from previous years and decades of fertilizer application.

Figure 3: Major global phosphorus flows through the food production consumption system. Width of arrows indicates size of flux. Units are in million (metric) tonnes of phosphorus per year (MT P/yr). (*source: Cordell, Drangert and White, in press*).

Ninety percent of the use of phosphorus is for food production. Figure 3 indicates that while humans are only consuming around 3 MT P per year, we are mining about 5 times this amount (14.9 MT P) for food production (Cordell et al., in press). Significant losses occur throughout the system – from mine to field to fork. Calculations based on Smil (2000a; Smil, 2002) suggest total phosphorus in global harvests is approximately 12 MT P of which 7 MT P

[4] SFA quantifies the material inputs and outputs from processes and stocks within a system of concern (typically expressed in kg or tonnes/year) to better understand pollution loads on a given environment, and determine places to intervene in a system to increase its efficiency, or reduce wastage/pollution for example Brunner & Rechberge (2004).

is processed for feed and food and fibre, while around 40% of the crop residues remaining are returned to land[5].

Once crops take up phosphorus and are harvested for use in feed and food production, it is estimated that 55% of phosphorus is then lost in the commodity chain between 'farm and fork'. Smil (2000a) estimates that around 50% of the phosphorus consumed and hence excreted by livestock is returned to agriculture globally. However there are significant regional imbalances, such as an oversupply of manure in regions where a critical soil phosphorus has already been surpassed (such as The Netherlands or North America), and a lack of manure in regions where soils are most phosphorus-deficient (such as Sub-Saharan Africa or Australia) (Runge-Metzger, 1995; Smaling, 2005).

Every year, the global population excretes around 3 million tonnes of phosphorus in the form of urine and faeces. Given more than half the world's population is now living in urban centres, and the urbanisation trend is set to increase (FAO, 2007b), cities will become phosphorus 'hotspots' of human excreta and organic 'waste' (Cordell et al., in press). Indeed, urine is the largest single source of phosphorus emerging from cities. While most excreta ends up in water bodies or non-arable land, It is estimated that on average, around 10% is currently recirculated back to agriculture or aquaculture either intentionally or unintentionally, such as poor urban farmers in Pakistan diverting the city's untreated wastewater to irrigate and fertilize the crops (Ensink et al., 2004), or pit or composting toilets in rural China, Africa and other parts of the world (Esrey et al., 2001). Recirculating urban nutrients such as urine back to agriculture therefore presents an enormous opportunity for the future (Cordell, 2006) (see Box 3).

Box 3: A closer look at human excreta

- Human excreta - urine and faeces - are renewable and readily available sources of phosphorus.
- Urine is essentially sterile and contains plant-available nutrients (P,N,K) in the appropriate ratio. Urine alone contains around 60% of the phosphorus in urban wastewater.
- Treatment and reuse is very simple and the World Health Organisation (2006) has published 'guidelines for the safe use of wastewater, excreta and greywater in agriculture'.
- Studies suggest that the nutrients in a person's urine are sufficient to produce 50-100% of the food requirements for one person.
- Preventing phosphorus in wastewater from entering water bodies is often necessary to prevent water pollution. However capturing urine at source (at the toilet) can be much more energy efficient and cost-effective than removing high levels of phosphorus at the wastewater treatment plant and does not contain heavy metals like Cadmium.

photo: Dana Cordell

Figure 4: a Swedish flush toilet with urine diversion. Urine is typically stored in a tank for up to a year before being collected by a farmer for direct reuse as fertilizer.

[5] The actual amount lost from agricultural fields that is directly attributed to applied phosphate fertilizer is very difficult to calculate, as soil phosphate chemistry is complex and phosphorus can move from available to unavailable form.

Finally, it is estimated that meat based diets can result in the depletion of 2-3 times the phosphorus compared to a vegetarian diet (Schmid-Neset et al., 2005; Tangsubkul et al., 2005; Cordell et al., in press).

This analysis indicates that in addition to minimising phosphorus losses from the farm (losses estimated at around 8 MT P) to reduce algal blooms in receiving waterways, phosphorus scarcity must simultaneously be addressed. This means we must also investigate ways to minimise losses in the food commodity chain (losses estimated at 2 MT P) and look for alternative renewable P sources, like manure (around 15 MT P), human excreta (3 MT P) and food residues (1.2 MT P) and other important mechanisms to reduce demand (such as optimising soil carbon to improve phosphate availability or influencing diets). Further, in order to make more informed decisions, more accurate data is required.

An analysis of future scenarios to meet long-term future phosphorus demand found that if demand can be reduced substantially through changing diets, food chain efficiency and agricultural efficiency, the remaining demand can be met through recovering and reusing the majority of human and animal excreta, crop residues and remaining food waste. The remainder could be met through sources such phosphate rock, algae and bonemeal (Cordell et al., forthcoming).

Peak Phosphorus

In a similar way to oil and other non-renewable resources, the rate of global production of phosphate rock will eventually reach a maximum or peak, after which production will drop year upon year, resulting in a widening gap between demand and supply (Hubbert, 1949). A conservative analysis using industry data suggests global peak phosphorus could occur by 2033 (figure 5) (Cordell et al., in press), within decades of peak oil (estimated to be in the next decade). While small-scale trials of phosphorus recovery from excreta and other waste streams exist (CEEP, 2008), there are no alternatives on the market today that could possibly replace phosphate rock in any significant way. Significant physical and institutional infrastructure that could take decades to implement will be required.

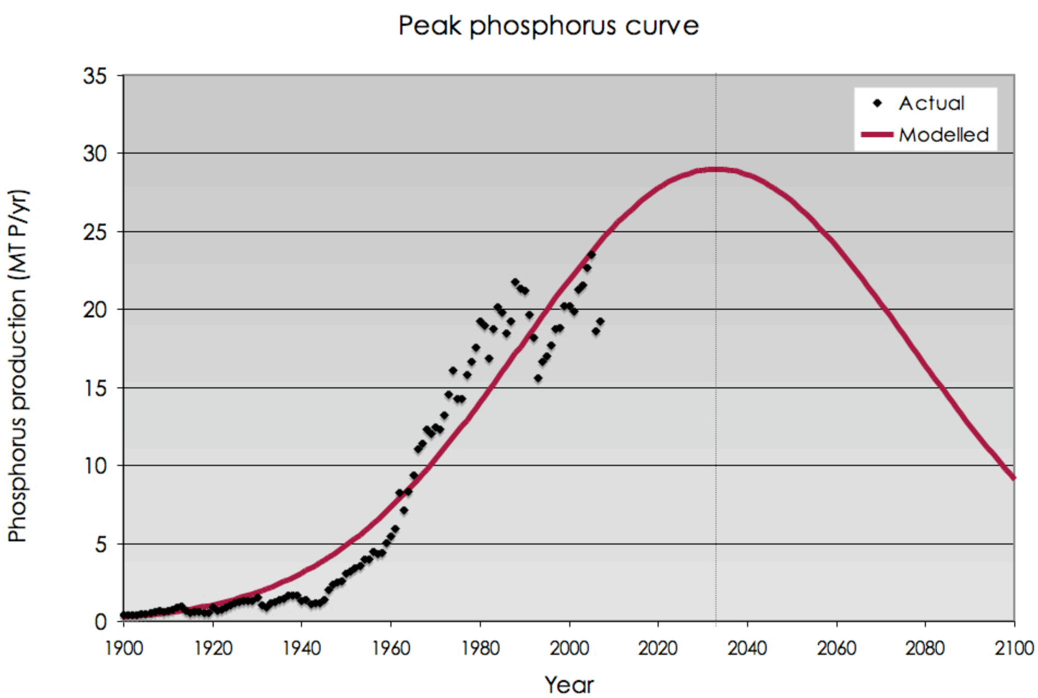


Figure 5: Peak phosphorus curve, illustrating that, in a similar way to oil, global phosphorus production is also likely to peak. (source: *Cordell, Drangert and White, in press*).

While the timing of the production peak may be uncertain, and contested[6], the fertilizer industry acknowledges that the quality of existing phosphate rock is declining, and cheap fertilizers will become a thing of the past. Processing and transporting phosphate fertilizers from the mine to the farm gate bears an ever increasing energy cost, which up to now relies on cheap fossil fuel energy. Phosphate rock is today one of the most highly traded commodities in the world - approximately 30 million tonnes of phosphate rock and fertilizers are transported across the globe each year (IFA, 2006).

With growing concern about peak oil and climate change, there is a need to reassess the current production and consumption system. Each tonne of phosphate also generates 5 tonnes of phosphogypsum with radium levels too high for reuse (USGS, 1999; Wissa, 2003) and are being stockpiled. Similarly, cadmium and other heavy metals which are increasingly present in high quantities must be removed from phosphate prior to use (Steen, 1998; Driver, 1998). Finally, the average grade of phosphate rock has been declining, and remaining reserves are less than 13% P, compared to 15% P in 1970s (IFA; 2006; Smil, 2002).

Governing global phosphorus resources – whose responsibility?

Unlike the case of water and energy resources, there is no intentional, coordinated global governance of phosphorus resources, to ensure fertilizer availability and accessibility to the world's farmers in the long-term. That is, there are no specific international regimes, policies, codes pertaining to global phosphorus security for future food production, nor are there any existing actors (such as UN agencies) responsible for global phosphorus resources (Cordell, forthcoming-b).

There is no stakeholder consensus at the international level on the nature of the phosphorus problem situation, nor on potential solutions (Cordell, forthcoming-a). The way phosphorus is perceived will determine to a large extent the nature of the solutions. Phosphorus is perceived as an 'environmental pollutant' by the freshwater ecologist, or an 'agricultural commodity' by the resource economist, a 'macro-nutrient' by the nutritionist, and so on.

In the absence of any intentional international governance structures, phosphorus resources are by default governed by the forces of the international market and its actors. Phosphorus is a tradable commodity on the international market. While the recent price spike in phosphate rock is likely to trigger further innovations in and adoption of phosphorus recovery and efficiency measures, the market alone is not sufficient to manage phosphorus in a sustainable, equitable and timely manner. For example, to achieve equitable resource distribution to farmers, and to make the required changes in institutional and physical infrastructure could take decades without concerted action.

[6] Some scientists (Pazik, 1976; Michael Lardelli pers comm 9/8/08) suggest USGS phosphate rock reserve data (on which this peak P estimate is based) is likely to represent an over-estimate, hence the real peak is likely to occur much sooner than the date predicted in this analysis. If production has been assumed to be at maximum capacity in the period to about 1990, this would suggest that peak production would have occurred at about that time (Dery and Anderson, 2007), but that reserves are approximately half of the amount estimated by the USGS. However it is likely that this observed peak was not a true maximum production peak, and was instead a consequence of political factors such as the collapse of the Soviet Union (formerly a significant phosphate rock consumer) and decreased fertilizer demand from Western Europe and North America. Data from the International Fertilizer Association indicates that the 2004-05 production exceeded the 1989-90 production (IFA, 2006).

The Australian case

Australia has a unique relationship with phosphorus, perhaps most notably due to the natural phosphorus deficiency of our soils, and simultaneous dependence on phosphorus fertilizers for agricultural exports.

Prior to the arrival of European settlers, the most significant human use of phosphorus by Aboriginal people was due to fire. They manipulated the environment through 'firestick farming' to reduce the build up of fuel in vegetation and increase the productivity of edible plants and animals. This mobilised significant quantities of phosphorus into the environment via smoke and ash, converting organic phosphorus in flammable vegetation into readily available inorganic phosphorus sources (Cordell, 2001).

Since European settlement, Australia's economy is said to have been built 'on the sheep's back', in that agricultural and livestock exports have always represented a significant share of the Australian GDP (Commonwealth of Australia, 2001; Cordell and White, forthcoming). Australia's agricultural productivity was 'revolutionised' in the 20th century by the discovery and importation of cheap, high-grade, and highly available Nauruan phosphate: guano (see box 4) (Garrett, 1996).

Box 4: Guano, politics and the Pacific Islands

Guano is bird and bat droppings that have been deposited over thousands of years. The guano deposits in Nauru were discovered by New Zealander Albert Ellis around 1906 (and around the same time in other South Pacific Islands, notably, Christmas Island, Banaban Islands, Kiribati), and subsequently claimed by the British Phosphate Commission – a joint venture between New Zealand, Australia and Britain. This led not only to exploitation of 80% of Nauru's non-renewable guano deposits, yet also resulted in the displacement of local populations and the Nauruan economy became entirely dependent on royalties from P mining (Garrett, 1996; Carty, 2007).

Figure 6 presents a simplified substance flows analysis of the major phosphorus flows through the Australian food production and consumption system. Mineral phosphate fertilizers used in Australian agriculture are either processed from domestic phosphate rock (mined at Phosphate Hill), processed from imported rock (predominantly from Morocco and Western Sahara) or imported as finished fertilizers (predominantly from the US or Morocco). Organic sources such as manure have been excluded due to substantial lack of Australian data or estimates (pers comm., Andre Leu, 12/03/08).

While Australia has some of the most naturally phosphorus-deficient soils in the world, we have simultaneously invested in phosphorus intensive export industries, like wheat, beef and wool (Cordell and White, forthcoming). Australia has a net deficit of phosphorus in the food production and consumption system. Around 80% of the phosphorus in food and fibre produced in Australia is exported off Australian shores. However most of the depleted phosphate embodied in those commodities actually ends up temporarily unavailable in soils or washed off to waterways, where it is causing eutrophication of waterways and even causing damage to the Great Barrier Reef (Commonwealth of Australia, 2001). Actual crop uptake of phosphorus from applied fertilizers can be as low as 10-30%.

Significant losses occur between harvest and food production and consumption, such as during food processing and in supermarket and household waste. These losses either end up buried in landfill, lost to water bodies or reused. Of the phosphorus reaching our wastewater treatment plants, it is estimated that as much as 40-50% is currently reused on agricultural soils in the form of treated effluent or biosolids[7] (Michael Warne, pers comm. 19/2/08). The remainder of biosolids are stockpiled, sent to landfill, or blended with compost and used as a soil conditioner.

[7] Biosolids reuse varies dramatically from state to state, from close to 100% in South Australia to negligible rates in Victoria (Michael Warne, pers comm. 19/2/08).

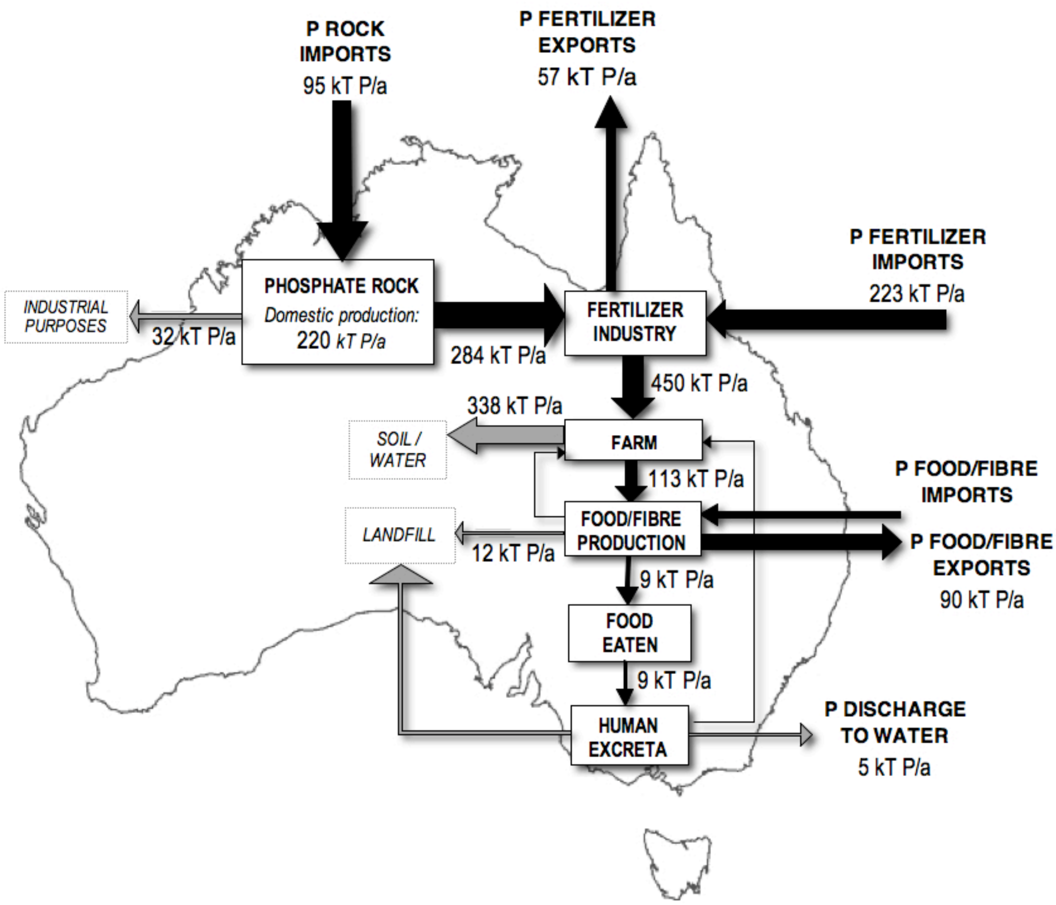


Figure 6: Major phosphorus flows in the production, consumption and trade of P commodities in Australia *(Cordell and White, forthcoming).*

The analysis indicates that only 2% of phosphorus in applied fertilizers ends up in the food Australians eat. Close to 100% of the P consumed in food is excreted from the human body. This means that while human excreta represents a significant fraction of phosphorus fertilizer needs globally (20% of current mineral fertilizer use), it presents a very small fraction (2%) of P demand in Australian agriculture. Therefore, even if 100% human excreta were recirculated, Australia would still have substantial a phosphorus deficit. While Australia does not have a food security problem per se, there is still a need to secure sustainable sources of phosphorus for food production in the future. A sustainable phosphorus future in Australia would also need to address the rising cost of fertilizers, the energy intensity of mineral fertilizer production and ethical concerns regarding the trade and current indirect support for an illegal occupation of Western Sahara by importing rock from Moroccan authorities or phosphate fertilizer from US companies.

Similar to the global situation, there is no obvious institutional home for the long-term sustainable management of Australia's phosphate resources for food production.

Discussion and conclusions

Phosphate rock fertilizers, together with nitrogen fertilizers, have been responsible for feeding the world for over a century. Yet increasing concerns about the environment, geopolitics and economics means the role of phosphate rock needs to be seriously assessed. Sustainable strategies for the long-term nutritional security of the world's population need to be debated.

There is currently a significant lack of effective, coordinated and sustainable management of the world's phosphorus resources. Given the critical role of phosphorus in sustaining global food production, phosphorus scarcity and related geopolitical and sustainability issues will need to be prioritised along side water, energy and nitrogen in the debate on global food security. Significant changes in institutional and physical arrangements are likely to be required to ensure this. In addition to introducing monitoring and feedback in the system, phosphorus efficiency and recovery options will need to be explored to ensure the long-term, equitable use and management of phosphorus resources in the global food system.

Regarding implications for Australia, many important questions remain. How can Australian agriculture adapt to increasing global phosphate scarcity? What are the implications for rural livelihoods? What will it mean for the environment and for the economy? What policy measures are appropriate for dealing with this and which sectors should be prioritised? Which actors are likely to play a role in a sustainable phosphorus future? What do we want a sustainable phosphorus future to look like in Australia?

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