Peak phosphorus – Implications for soil productivity and global food security

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Abstract
Phosphorus is a key element in food production, but is a non-renewable resource. Recent estimates suggest that global production of P fertilizers will peak in 2033 and will be one third of that peak level by the end of the 21st century. Population and income growth will increase demand for food, and especially animal protein, the production of which will accelerate the reduced availability of P and consequential rising fertilizer prices. The global distribution of current P fertilizer use divides countries into the 'haves' which in many cases face severe pollution problems from excess P, and the 'have-nots' in which low input use annually drains soil P reserves. Coping strategies include improvements in the efficiency of fertilizer P manufacture and use, and recycling of P in liquid and solid wastes. The latter approach offers win-win solutions by reducing the environmental pollution of water in highly populated areas. Future utilisation of scarce P reserves requires policy decisions that take account of equity, productivity, environmental and trade considerations.

Key Words
Phosphate fertilizer, food production, trade, pollution, recycling.

Introduction

The 20th Century saw massive increases in food production that generally kept pace with a global population increase from 1.6 billion to 6 billion. Some of the production increase was due to opening new land for cultivation, but the green revolution in the high-potential areas, particularly in Asia, contributed significantly in the countries with major population growth. During that century, as modern fertilizer-responsive rice, maize and wheat became widely available, use of P fertilizers increased 3.5-fold (Tilman1999). In sub-Saharan Africa the 20th century saw declines in per capita food production and very limited use of fertilizers (Vlek 1990). In Latin America large areas of land in the Cerrados were opened to agriculture only after adequate fertility management using liming and P application was developed. P fertilizers also played a key role in agricultural production gains made in North America and Australia.
As one of the three major essential elements for plant growth, P supplies have and will continue to assert significant influence on efforts to expand food production. Importantly, plants concentrate P in the grains and fruiting bodies, which when harvested create a significant drain of P reserves in soil, so high yielding systems require P inputs at a minimum level that replaces harvest losses; unlike nitrogen, which can be fixed from the atmosphere, P is mined from limited deposits. Furthermore, to the extent that energy-intensive industrial N fixation can be replaced by biological nitrogen fixation by legumes, that process requires adequate P supplies.

Bruinsma (2009) estimated that to feed a projected population of 9 billion in 2050 will require a 66% increase in crop production from the base level in 2005/2007, while during the same period meat production will have to increase 85%. The latter projection is high because it takes account of increased incomes, particularly in the more populous countries of Asia. Demand for P fertilizers will therefore accelerate as the quantity and quality of food and feed grain production increases. However, P is a non-renewable resource with finite reserves; recent concerns about the future availability of P fertilizers (Cordell *et al.* 2009) have presented this as a major global challenge.

This paper reviews the global distribution of P use, transfers between regions, rates of soil P depletion and prospects for improving the P fertilizer efficiency and P re-cycling, in the context of peak P production.

P resources, use, balances and transfers

P resources

Annual global production of P rock in 2008 was 167 million tons, with China, the USA and Morocco and Western Sahara as the main producers (Table 1). Global reserves total 15,000 million tons but the country rankings in terms of reserves are not the same as for annual production – the data for the USA indicate an annual rate of use of 19% of global production with only 7-8 % of the worlds' reserves. On the other hand, China's production is proportional to its reserves. Morocco and Western Sahara are conservative in their P extraction, as are minor producers such as Jordan and South Africa.

Table 1. Production of P rock and reserves in main producing countries (Jasinski 2009).

	Proportion of global total P rock (%)		
Country	2008 annual production	Reserves	Reserve base[1]
China	30	28	21
United States	19	8	7
Morocco/Western Sahara	17	38	45
Russia	7	1	2
Tunisia	5	<1	1
Brazil	4	2	<1
Jordan	3	6	4
South Africa	1	10	5
Global total P rock (Mt)	167	15,000	47,000

[1] Reserve base: P rock with a 'reasonable potential for becoming economically available within planning horizons beyond those that assume proven technology and current economics'

A simple calculation (reserves divided by annual extraction rate) of the life of the P rock reserves at current rates of global production results in a 90 year lifespan for the USGS-classified reserves plus 281 years for the 'reserve base' (see Table 1 footnote for the definition). The calculation of future rates of production and peak P requires an understanding of the future rate of increase in demand, market price movements, and potential improvements in technology, especially to remove impurities economically. Cordell *et al*. (2009) have recently prepared a Hubbert curve that suggests a peak in P production of 29 Mt P/year in 2033. The rate of production reduces to 10 Mt P/ year in 2100. World trade issues, price rises over time that make deposits more economic to mine, and market forces will influence the life of P resources. A critical factor that is already changing markets and distorting availability is cadmium legislation. For example, a Finnish proposal to pass on new EU limits, would render no longer importable much of North African P, as long as cadmium removal remains an expensive proposition. P being a finite resource, there will be a peak. Needed more detailed studies of the issue are in progress, but current evidence suggests that peak P will become a reality and a serious problem facing the next two human generations.

P resources

The evidence reviewed above shows that P reserves are being utilised at an unsustainable rate. While the distribution of P rock reserves across countries of the world is uneven, the rate of use of the P is also extremely uneven. Figure 1 shows the 2005 annual consumption of P as fertilizer broken down by region, as well as projections to the year 2030, which is approximately when Cordell *et al.* (2009) expect P production to peak. Note that the global total consumption in 2030 that Tenkorang and Lowenburg-DeBoer (2009) project is 23 Mt of P, whereas Cordell *et al*.'s projection of peak production is 29 Mt. The highest level of P consumption in 2005, and projected to 2030, is in Asia, which reflects the high population as well as the intensive cropping systems, based on the use of irrigation and modern high-yielding varieties. Europe, North America and Latin America utilise proportionally less fertilizer, but the most striking contrast is the low consumption of P in Sub-Saharan Africa, and the low trajectory of the projected future use.

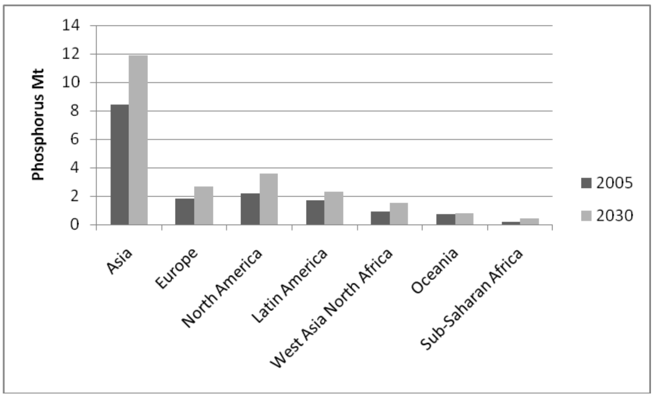

Figure 1. The annual consumption of P fertilizer in different world regions in 2005 and projections to 2030. Adapted from Tenkorang and Lowenburg-DeBoer (2009).

P balances
The low rate of fertilizer use is Sub-Saharan Africa is well documented (Batiano *et al*. 2006). Twenty five years ago, Vlek (1993) raised concern about nutrient exports from sub-Saharan Africa. In 2007, the export of stimulant crops alone removes around 50,000 tons of P from this region or one-fifth of the annual P use. This amounts to a doubling in P exports against a stagnant use of P fertilizer over the past 20 years. Over 30 years of repeated harvests without matching fertilizer applications has resulted in an estimated depletion of 75 Kg P/ha from 200 million ha of cultivated land in 37 African countries. This estimate is consistent with the figure of 3.3 kg P/ha/yr published by Sheldrick and Lingard (2004), who projected a rise in depletion rates to 6 kg P/ha/yr in 2020 unless rates of growth of fertilizer P use increased to 7% per year. There is a clear case for urgent action to address this problem, particularly viewed against a background of peak P. Fortunately some countries of Sub-Saharan Africa have native deposits of P rock that could be developed locally for direct application to help solve the problem if the fertilizer sector develops.
At the other end of the scale are 'nutrient surplus' countries (Craswell *et al.* 2004) in Western Europe, such as Belgium, Denmark, and the Netherlands, which import feed grains for livestock production creating a surplus of nutrients in the environment, and therefore face serious pollution problems. The same applies to some of the intensive production systems in North America and Asia. Excess P use can cause eutrophication of waterways and toxic algal growth that can cause red tides in coastal zones. This is a key area for environmental policy action, including international agreements; Bach and Frede (1998) report progress in reducing P surpluses in agricultural land in Germany by 60% in the last decade of the 20th century. In Australia, low rates of P over extended pasture and crop areas have led to neutral or slightly positive P balances. In Latin America P balances are generally positive for cash and plantation crops but negative in low yield subsistence cropping areas.

P transfers
The transfer of P and other nutrients in agricultural commodities in international trade is an area of increasing interest (Craswell *et al*. 2004), because like 'virtual water' trade it provides insights into whether particular countries should choose to grow their own food or import it (Grote *et al*. 2006). In many cases grounds for such a decision may be dominated by water availability but the consequences in terms of P flows are real, not virtual, and will become more important as P resources decline. The Figure 2 shows the positive and negative balances of P in traded agricultural commodities projected to 2020. Major food exporting countries and regions, especially the Americas, have large P deficits whereas importers are positive. Interestingly sub-Saharan Africa has a positive P balance due to food imports. Since these imports are largely consumed in cities, the opportunity for the use of P in municipal and animal wastes to improve peri-urban agriculture has been advocated by Cofie *et al.* (2001). The same applies to large cities in other regions such as Bangkok where Faerge *et al*. (2001) showed that only 10% of P is recovered and recycled whereas, of the P losses, 41% could be accounted for by elevated levels in the Chao Phraya River.

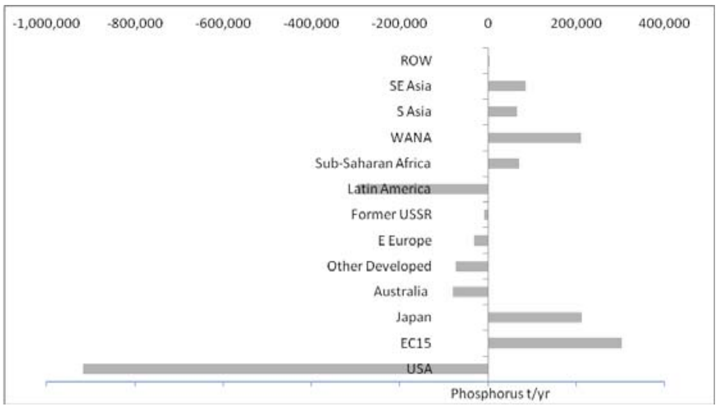

Figure 2. Projected regional flows of P in net trade of agricultural commodities in 2020. (Craswell *et al.* 2004)

Conclusion
The need for global action to address the need to increase agricultural production while finite P resources continue to decline is clear. Technological and policy options should be explored to form the basis for coping strategies. At the P production level, research is needed to improve the efficiency of processing in P fertilizer manufacture, including minimally heated P rock treatments (A. Roy, personal communication 2009.) Furthermore, the revision of market regulations for the water soluble P content of fertilizers will become

more important as reserves decline. In the P-rich countries and regions, including hotspots, such as intensive animal production systems or urban and peri-urban areas, the emphasis should be on recycling which has the win-win advantage of also reducing environmental pollution. In crop production systems in both high and low potential areas, the efficiency of P fertilizer use should be improved through better timing and placement of P, as well as research on the improvement of P uptake by innovations such as inoculation with VA mycorrhiza.

Policy measures are needed that ensure a more equitable global P balance in which measures require both developed and developing countries to take action (Grote *et al.* 2005). In this context the wisdom of P investment in soils that have other major production constraints (semi-arid Africa for instance) will have to be judged against equity considerations. Furthermore such alternatives need to be assessed against the use of high P seeds for "renewable" energy production. Also important was recent experience with the collapse of fertilizer use when subsidies are removed or prices rise (e.g. in 2008). Developed countries need to reduce production subsidies, regulate nutrient disposal, and implement nutrient trading permits. On the other hand most developing countries should increase input subsidies, implement credit schemes, and extension and training programs to encourage P consumption. Major exporting countries need access to P supplies whereas importing countries need to address problems of P excess in large urban areas, especially where peri-urban animal production creates re-cycling problems (Grote *et al*. 2006).

References

Bach M, Frede H-G (1998) Agricultural nitrogen, phosphorus and potassium balances in Germany: Methodology and trends 1970 to 1995. *Zeitschrift für Pflanzenernährung und Bodenkunde* **161**, 385-393.

Bationo A, Hartemink A, Lungu O, Naimi M, Okoth P, Smaling E, Thiombiano L (2006) African Soils: Their Productivity and Profitability for Fertilizer Use. Background paper for the Africa Fertilizer Summit. 9-13 June 2006 in Abuja, Nigeria.

Bruinsma J (2009) The resource outlook to 2050: By how much do land, water and crop yields need to increase by 2050? *Expert Meeting on How to Feed the World in 2050,* 24-26 June 2009. (Food and Agriculture Organization of the United Nations, Rome)

Cofie OO, Drechsel P, Amoah P, Danso G, Gyiele,L (2001) Improving rural-urban nutrient flows through urban and peri-urban agriculture. In 'Rural-Urban Encounters: Managing the Environment of the Peri-urban Interface', Development Planning Unit, University College London, 9-10 November 2001.

Cordell D, Drangert J-O, White S (2009) The story of phosphorus: Global food security and food for thought. *Global Environmental Change* **19**, 292-305.

Craswell ET, Grote U, Henao J, Vlek PLG (2003) Nutrient flows in agricultural production and international trade: Ecological and policy issues. ZEF Discussion Paper on Development Policy, Center for Development Research, University of Bonn No. 78.

Faerge J, Magid J, Penning de Vries FWT (2001) Urban nutrient balance for Bangkok. *Ecological Modelling* **139**, 63-74.

Grote U, Craswell ET, Vlek PLG (2005) Nutrient Flows in International Trade: Ecology and Policy Issues. *Environmental Science & Policy* **8**,439-451.

Grote U, Craswell ET, Vlek PLG (2006) Nutrient and virtual water flows in traded agricultural commodities. In 'Land Use and Soil Resources'. (Eds A Braimoh, PLG Vlek) pp. 121-143 (Springer Science+Business Media B.V.)

Jasinski SM (2009) Phosphate rock. Mineral commodity summaries, US Geological Survey http://minerals.usgs.gov/minerals/pubs/mcs/2009/mcs2009.pdf

Sheldrick WF, Lingard J (2004) The use of nutrient budgets to determine nutrient balances in Africa. *Food Policy* **29**, 61-98.

Tenkorang F, Lowenberg-DeBoer J (2009) Forecasting long-term global fertilizer demand. *Nutr. Cycl. Agroecosyst.* **83**, 233-247.

Tilman D (1999) Global environmental impacts of agricultural expansion: the need for sustainable and efficient practices. *Proc. Natl. Acad. Sci. USA.* **96**, 5995-6000.

Vlek PLG (1990) The role of fertilizers in sustaining agriculture in sub-Saharan Africa. *Fertilizer Research* **26**, 327-339.

Vlek PLG (1993) Strategies for sustaining agriculture in sub-Saharan Africa the fertilizer technology issue. In 'Technologies for sustainable agriculture in the tropics' (Ed. Ragland J, R Lal). (ASA Special Publication No 56. American Society of Agronomy. Madison, Wisconsin, USA.)