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How will minerals feed the world in 2050?

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ABSTRACT

By 2050, the world's population will have reached 9 billion. To feed that many people, soil fertility will have to be maintained artificially. All fertiliser materials depend on a geological resource: nitrogen (N) fertilizer production needs fossil fuels, and both phosphate (P) and potassium (K) are derived by mining. Irrespective of new biological techniques in plant breeding and genetic modification, soils still need to supply the mineral nutrients that plants require, and these are exported from soil with every harvest.

Studies of global offtake of N, P and K from soils through crop production show that although N and P are roughly in balance, removal of K from soils greatly exceeds inputs. World mine production of K needs to double to replace the amount removed in crops. Recent revision of reserve estimates for potash and phosphate rock show significant increases for phosphate rock and reductions for potash. Potash supply is now potentially of much greater concern than phosphate.

Against this background, it is clear that new potash mining ventures are required. In the developed world, the supply of potash from conventional sources will continue. However, in other countries the high price of potash means that novel unconventional sources are being considered. K silicate minerals (such as micas, feldspar and nepheline) have the potential to provide an adequate source of K for communities that cannot afford conventional fertiliser. However, it is not the total K content of these materials that controls their ability to supply plant nutrients, but the rate at which they dissolve.

1. Introduction

Food security is one of the greatest global 'grand challenges' of the 21st Century. The world's population reached 7 billion in 2012, and will rise to 9 billion in 2040 (median projection for growth; United Nations, 2014). The rate of change varies from one part of the world to another; the corresponding increase in the population of Africa will more than double from 1 billion to 2 billion over this period (Fig. 1).

A growing population requires a continuing supply of the essential raw materials, for construction, as fertilisers, and as raw materials for the manufacture of consumer goods. The global consumption of metals and minerals more closely correlates with GDP than with global population, reflecting links between the demands of a population with an overall increasing standard of living (Rogich and Matos, 2008). Demand for energy minerals (fossil fuels) is expected to peak, then fall, within the period 2010–2050 depending on the scenario used for modeling, and recognizing that alternative energy sources are available (Bentham, 2014; Hallock et al., 2014). There are no alternatives to mined materials for fertilizer manufacture.

In the context of food supply, the key plant nutrients are phosphorus (P), potassium (K) and nitrogen (N). P and K are mined as phosphate rock (dominated by minerals from the apatite group) and potash respectively. The term potash is used to describe the traded commodity, with grade (potassium content) given as equivalent % K_2O, and includes a number of evaporite minerals, mainly chlorides (sylvite, KCl; carnallite $MgCl_2{\cdot}KCl{\cdot}6H_2O$) but also sulphates (e.g. polyhalite, $K_2SO_4{\cdot}2CaSO_4{\cdot}MgSO_4{\cdot}2H_2O$). In contrast, nitrogen is derived from the atmosphere through the Haber process. The availability of phosphate rock has received considerable attention in the context of 'peak phosphorus' (Cordell et al., 2009). In contrast, potash availability has received much less attention, despite the small number of producers and associated political controls on its supply (Rittenhouse, 1979; Manning, 2010).

This paper addresses the demand for P and K fertilisers through analysis of the amounts removed annually by harvesting crops ('offtake'), and then considers the availability of P and K in the context of estimates of known reserves and their global distribution.

2. Demand for P and K fertilisers

The amount of a fertilizer that is required is determined by the ability of a soil to provide the nutrient concerned. In general, farmers maintain the nutrient status of a soil so that crops can continue to be produced. Thus the amount of 'offtake' removed

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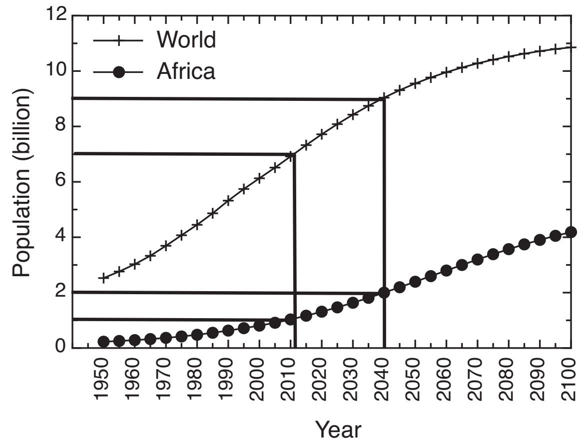

Fig. 1. Population growth for Africa and the World over the period 1950–2010, extrapolated to 2100.
Source: Data from United Nations (2014).

with each crop is balanced by the 'input' added by the farmer to maintain constant nutrient status.

A global evaluation of nutrient balances (Sheldrick et al., 2002) considers the overall requirements for N, P and K on a country-by-country basis for the latter part of the 20th Century. Using data from this study, Fig. 2 shows that offtakes of N and P globally are approximately balanced by inputs, which include composts, manures and crop residues as well as fertilisers. The situation for K is very different, with inputs from all sources being less than half the offtake (creating the 'potash gap'; Fig. 2). Fertiliser K inputs are typically less than 10% of the offtake. The low use of K especially in Africa is confirmed by statistics produced by the Food and Agriculture Organization of the United Nations, which show that Africa consumes just 1.5% of the world's potash fertilizer production, yet has 15% of the world's population (FAO, 2010). The evidence from nutrient balance studies indicates that while P is roughly in balance, K is being mined from the world's soils at a rate that far exceeds counterbalancing inputs.

To place the global assessment in a national context, the importance of balancing offtake and inputs in crops consumed in the UK can be illustrated by comparing potatoes and bananas. In 2011, the UK produced 6.3 million tons of potatoes from 146,000 ha of land (DEFRA, 2014a). Potatoes contain around 4 g K/kg, so the corresponding K offtake in the potatoes themselves (ignoring offtake in the foliage) is of the order of 25,000 T K or 29,000 T K_2O. The

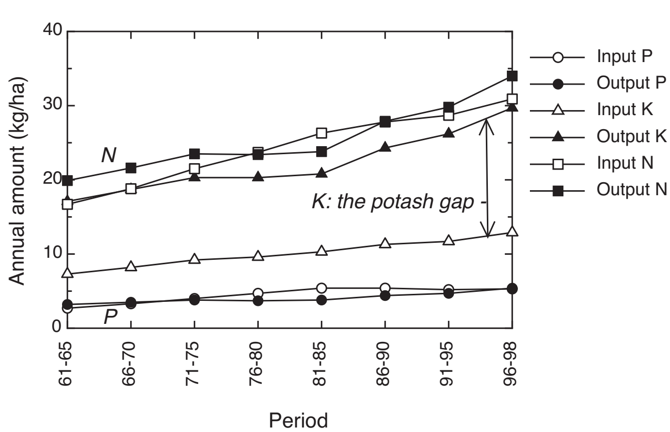

Fig. 2. Global nutrient balances for N, P and K, comparing outputs removed as harvest and inputs from all sources.
Source: Data from Sheldrick et al. (2002).

corresponding fertilizer input for 2011 was approximately 30,000 T K_2O (DEFRA, 2014a), which shows that offtake and fertilizer inputs roughly balance. The value of potash applied to produce potatoes is around US$10 million, or £6 million. The UK's consumption of bananas is approximately 1 million tonnes (DEFRA, 2014b), with a similar potash content to potatoes, so the corresponding value of the potash consumed as an import hidden within the crop is of the order of £1 million. What is unknown is whether or not the potassium removed from the soil where bananas are grown is replenished with an equivalent amount of K fertiliser.

3. Availability of P and K

Cordell et al. (2009) highlight the issue of 'peak phosphorus', arguing that P would become increasingly difficult to source in the early part of the 21st Century. In part these arguments were based on the cited reserves of phosphate rock, which are reported by the British Geological Survey and the United States Geological Survey (Table 1; Jasinski, 2014a). Recently reported figures for reserves and annual production rates can be used to predict the life expectancy of a mineral resource (Fig. 3). Importantly, there is a sudden increase in reserves, and subsequently in projected life, in 2010 (Fig. 3). This is due to revision of the way in which reserves of phosphate rock were calculated – the term 'reserve' is strictly defined to encompass the amount of material that can be mined profitably using present-day technology (USGS, 2012a). The constant values for projected life (around 100 years) over a period of 15 years indicates the way in which estimates of reserves are being constantly updated. It now appears that phosphate reserves will last 300 years. Bearing in mind that the concept of 'peak phosphorus' was introduced in 2009, it appears to have been overtaken by events.

In addition to revision of estimates of reserves, it needs to be born in mind that phosphorus is widely distributed as a commodity. Chernoff and Orris (2002) and Orris and Chernoff (2002) report over 1600 mines, deposits and occurrences of phosphate rock globally that are of economic interest. According to Jasinski (2014a), 16 countries produce 95% of the world's phosphate rock production, with 23 countries producing a significant amount.

Table 1
Production statistics and reserves estimates for phosphate rock (Jasinski, 2014a). All figures are in thousands of tons.

	2012	2013	Reserves
China	95,300	97,000	3,700,000
USA	30,100	32,300	1,100,000
Morocco/Western Sahara	28,000	28,000	50,000,000
Russia	11,200	12,500	1,300,000
Jordan	6380	7000	1,300,000
Brazil	6750	6740	270,000
Egypt	6240	6000	100,000
other countries combined	5500	5630	520,000
Tunisia	2600	4000	100,000
Peru	3210	3900	820,000
Israel	3510	3600	130,000
Saudi Arabia	3000	3000	211,000
Australia	2600	2600	870,000
South Africa	2240	2300	1,500,000
Mexico	1700	1700	30,000
Kazakhstan	1600	1600	260,000
Algeria	1250	1500	2,200,000
India	1260	1270	35,000
Senegal	1380	920	50,000
Togo	870	900	30,000
Syria	1000	500	1,800,000
Iraq	200	350	430,000
Canada	900	300	2000
Total	216,790	223,610	66,758,000