Where in the world is the potash that we need?

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Abstract
Since January 2007, the price of muriate of potash (KCl) has increased 4 times, reaching US$1000/T K_2O equivalent for some contracts during 2008. Independently, estimates of nutrient balance suggest that global production needs to double to replace observed agricultural offtake of K. In these circumstances, it is appropriate to consider the use of crushed silicate rocks as a cost effective alternative way of replenishing soil K stocks. Such rocks are widely distributed, and could play a significant role in maintaining soil fertility for the poorest farmers.

Key Words
Potash, feldspar, crushed rock, fertiliser.

Introduction
Potassium (K, or potash, K_2O), like nitrogen (N) and phosphorus (P), is vital for the growth of healthy plants and crops. Without it, plants are unable to make good use of other fertilisers, especially N. Both P and K fertilisers are exclusively derived from geological (rock) sources, and almost all N is obtained from natural gas or atmospheric sources. N, P and K fertilisers are produced by a global industry that derives raw materials from a limited number of locations, and the resulting fertiliser products are traded globally as bulk products. The price of fertilisers has changed dramatically since the beginning of 2007 (Figure 1). As examples, the prices of diammonium phosphate (DAP) and urea tend to follow changes in the oil price, partly because ten times as much energy is used in the manufacture of nitrogen fertilisers compared with potash (Lægrid *et al*. 1999). N and P prices decreased at the end of 2008, as part of the global recession, and are now at or below the prices for the start of 2007. In contrast, the price of K, as muriate of potash (MOP), has stayed high. At its peak in 2008, MOP reached an index price of US$800 per tonne, and in some markets (e.g. Brazil) prices of US$1000 per tonne were achieved. The MOP price has fallen back to about US$650 per tonne, almost 4 times higher than in January 2007, and over 5 times higher than the price in 2000 (US$120/tonne).
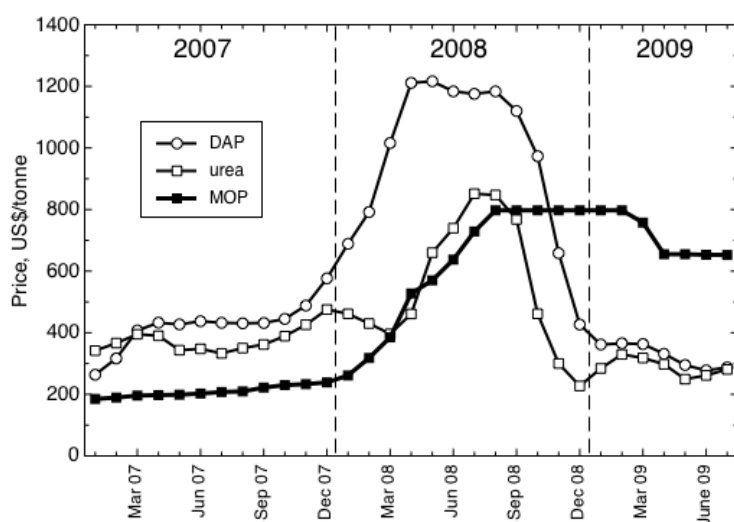

Figure 1. Variation in prices of phosphorus (diammonium phosphate; DAP), nitrogen (urea) and potassium (muriate of potash; MOP) fertilisers since 2007. Calculated using data from www.icis.com).

Potash demand
Global potash production in 2007 was around 30 million tonnes/year as K_2O (USGS, 2008), dominated by production from Canada (11 million tonnes/year), Russia (6.3 million tonnes/year) and Belarus (5.4 million tonnes/year).

According to the Food and Agriculture Organisation of the United Nations (FAO 2008), supply of potash is expected to meet demand, which will grow at about 2.4% per year. However, this approach does not necessarily fully consider the underlying need for potash in developing countries. Taking Africa as an example, the FAO reports that on a continental scale 47 out of 57 African countries do not consume fertiliser products in any significant way, and that the entire continent consumes only 485,000 tonnes of potash annually. This again is expected to grow at around 2% annually, and is all imported. Thus about 1.5% of global potash production is currently being used to support about 15% of the world's population. Under these circumstances, demand must surely exceed supply, although it may not exceed ability to purchase.

The need for fertiliser inputs can be estimated using an alternative approach, in which a nutrient budget is determined that balances nutrients removed by cropping against inputs from fertilisers, crop residues and manures or composts (Sheldrick et al. 2002). Using this approach, Sheldrick et al. (2002) showed that, compared with N and P, K is the nutrient that is most seriously in deficit. Globally, there is an annual deficit of 20 kg K per hectare. In order to balance nutrient offtakes, Africa needs to find inputs equivalent to 4.1 million tonnes of K per year, or around 5 million tonnes of K_2O, or ten times the continent's current consumption (Sheldrick and Lingard 2004). At current prices, this would cost several billion dollars. At a global scale, Sheldrick et al. (2002) analysis suggests that worldwide potash consumption needs to be doubled to maintain soil nutrient balances, requiring an additional 60 million tonnes of KCl ore to be mined. This deficit is currently being removed from the soils by current agricultural practices, representing nutrient mining on an evidently unsustainable scale.

Alternative potash sources
Given that conventional potash sources might be unable to respond to demand, it is appropriate to consider alternatives. Over the years (e.g. Harley and Gilkes 2000), a number of studies have investigated the possible use of potassium silicate minerals, such as feldspars or their host rocks, especially granites. These materials are widely distributed, and are readily available. As parent soil-forming materials, they undoubtedly provided much of the original K content of a soil. However, critical reviews (Harley and Gilkes 2000; Manning 2009) show that it is difficult to identify reports where there is a sound statistical basis for promoting their use, although these materials are traded commercially for some agricultural sectors. In some cases (e.g. Sanz Scovino and Rowell 1988), the use of feldspar gives a measurable yield response, but the low cost of conventional K at that time led the authors to conclude that feldspar is not a viable alternative. Table 1 lists the most common potassium silicate minerals, giving not only their K contents but (where available) their dissolution rates relative to that determined for potassium feldspar (orthoclase; Blum and Stillings 1995), which has a value for the dissolution rate, log k^+, of -10.2. It is the dissolution rate, rather than the absolute K content, that determines whether or not K is available to the soil system within a given period of time appropriate for crop growth.

Table 1. Summary of the composition of the major potassium silicate minerals, and their relative dissolution rates (Manning 2009).

Mineral	Mineral family	Formula	Weight % K	Weight % K_2O	Relative dissolution rate
Potassium feldspar	Feldspar	$KAlSi_3O_8$	14.0	16.9	1-2
Leucite	Feldspathoid	$KAlSi_2O_6$	17.9	21.6	nd[1]
Nepheline	Feldspathoid	$(Na,K)AlSiO_4$	13.0	15.7	40-100
Kalsilite	Feldspathoid	$KAlSiO_4$	24.7	29.8	nd
Muscovite	Mica	$KAl_3Si_3O_{10}(OH)_2$	9.0	10.9	n/a[2]
Biotite	Mica	$K_2Fe_6Si_6Al_2O_{20}(OH)_4$	7.6	9.2	n/a
Phlogopite	Mica	$K_2Mg_6Si_6Al_2O_{20}(OH)_4$	9.4	11.3	n/a

[1] not determined
[2] not applicable

Referring to Table 1, it can be seen that there are limited data for mineral dissolution rates, and it is not really appropriate to consider dissolution rates for the micas given the importance of cation exchange in controlling their ability to release K. Importantly, however, the dissolution rate of nepheline, a feldspathoid, is two orders of magnitude greater than that of orthoclase feldspar (Blum and Stillings 1995; Tole et al. 1986). In the absence of additional information, it can be assumed that the other feldspathoids have similar dissolution rates to nepheline given similarities in their crystal structur. It must be recognised that leucite within

volcanic rocks and shallow intrusives is very commonly hydrothermally altered to zeolites that include potassic species such as phillipsite (e.g. Weisenberger and Spurgin 2009), and that these may provide a source of K with a high cation exchange capacity.

Crop trials with potassium silicate rocks

The use of potassium silicate rocks lies within the domain of the 'remineralise the Earth' movement, and has largely attracted support from the alternative agricultural sector. In theory, there are sound mineralogical reasons for this approach to succeed, and there are many satisfied users of such rocks. However, the value of this practice has yet to be demonstrated widely in rigorous scientific trials. Although the use of feldspars and feldspathic rocks has tended to give disappointing results (Manning 2009), experiments carried out with nepheline-bearing rocks have been more positive (Bakken *et al.* 1997; 2000). In pot trials using ryegrass (Bakken *et al.* 1997) and field trials using timothy and meadow fescue (both grasses; Bakken *et al.* 2000), increased dry yields were reported with application of nepheline-bearing rock powders. In field experiments lasting 3 years, application of nepheline bearing rock powders gave similar yields to the equivalent initial application of muriate of potash (Bakken *et al.* 2000). These results are entirely consistent with the observed differences in dissolution rate.

Implications for fertiliser supply

Leonardos *et al.* (1987) are critical of conventional fertiliser practice: "Unfortunately, the standard concept and technology of soil fertilizer is behind that of the superphosphate concept developed by J. B. Lawes in England, 150 years ago. Had this technology been originally developed for the deep leached laterite soils of the tropics instead for (sic) the glacial and rock-debris-rich soils of the northern hemisphere our present fertilizers might have been quite different." For many poor farmers raising crops on oxisols, the use of crushed rock, including crushed granite, might be the only option that is available to them (Theodoro and Leonardos 2006). In terms of economics, the per unit cost of potash derived from silicate rock sources is now less than the price of conventional muriate of potash, so economic conditions are far less of an obstacle than they once were. The cost of crushing and milling a silicate rock to produce a fertiliser product can be considered against the price of conventional K. For example, using 2007 prices, a feldspar-based product at 16% K_2O would have to be produced at U\$50/tonne or less to compete with MOP, with correspondingly lower target production prices for lower grades. With the price rises that occurred in 2008 and 2009, a feldspar-based product could have a production cost per unit of US\$150/tonne, and still be cheaper per unit of K than muriate of potash. Rocks with 8% and 4% K_2O, in 2009, need production costs of 90 and 45US\$/tonne to have a cost directly comparable to muriate of potash. Although transport costs will be greater (the K content of crushed silicate rocks being less than high grade fertiliser products), the manufacturing costs, for local use, are feasible.

Conclusion

Given the current very high price for K, and the need to maintain soil K stocks and to compensate for extensive nutrient mining especially in deeply weathered soils, potassium-bearing silicate minerals and their host rocks are potentially able to act as an alternative where the cost of conventional K sources prevents their use. On the basis of dissolution rate, it is preferred to use rocks that contain feldspathoids, such as nepheline and leucite. Such rocks are rare, but widely distributed, and may be attractive within an overall strategy to optimise global use of scarce K resources.

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