The shift from chemical to biologically based crop production

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Soil and food security

• We need to produce enough food to feed existing and growing populations.
• All plants require mined nutrients
  – The minerals K and P can only be derived from rock sources
  – N fertiliser production (in particular) depends on petroleum production
• We hear about ‘peak phosphorus’
• Will conventional fertilisers be sufficient?
• What might the alternatives be?
The price of fertilisers has boomed:
Fertiliser prices

• Prices peaked in 2008
• N and P price rises matched those of oil, and came down to pre-2008 levels
• K has stayed high
• K reached $1000/tonne in some markets in 2008
• K remains twice the price it was
What about phosphorus?

16 countries produce 95% of the world’s P (159 MT phosphate rock)
The phosphorus paradox

- People talk about ‘peak phosphorus’, based on analogies with oil

This does not take into account the huge resource base; very different from oil.

Reserves are only part of the story. Phosphorus (P) resources are enormous (USGS).
The phosphorus paradox

• Why do we throw away so much P?
• Phosphate pollution is a major issue – how can we use P more sustainably?
  – Struvite (NH$_4$MgPO$_4$.6H$_2$O)
  – Sewage as a source of P
Potash (K)

• Very different to P
• Much more soluble
• More limited in terms of sources
• Not a pollutant, apparently
Why is K so important?

K is a vital mineral component of all crops:

<table>
<thead>
<tr>
<th>100g of ..... contains:</th>
<th>K (mg)</th>
<th>Ca (mg)</th>
<th>Mg (mg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bananas</td>
<td>393</td>
<td>9</td>
<td>36</td>
</tr>
<tr>
<td>Kiwi</td>
<td>295</td>
<td>38</td>
<td>24</td>
</tr>
<tr>
<td>Papaya</td>
<td>211</td>
<td>21</td>
<td>41</td>
</tr>
<tr>
<td>Apples</td>
<td>144</td>
<td>7</td>
<td>6</td>
</tr>
<tr>
<td>Fennel</td>
<td>494</td>
<td>109</td>
<td>49</td>
</tr>
<tr>
<td>Broccoli</td>
<td>373</td>
<td>105</td>
<td>24</td>
</tr>
<tr>
<td>Potatoes</td>
<td>411</td>
<td>6</td>
<td>20</td>
</tr>
<tr>
<td>Carrots</td>
<td>290</td>
<td>41</td>
<td>18</td>
</tr>
</tbody>
</table>

K that is consumed has to be replaced.
Demand for potash

- Although northern hemisphere countries have enough K inputs, there are major shortfalls in K addition elsewhere.
- Nutrient balance studies show that replacement of K removed with crops is often inadequate.
- Worldwide potash mine production needs to double to balance offtake.
Africa, for example:

Sheldrick and Lingard (2004):
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Sheldrick and Lingard (2004): From FAO data:

- Africa consumes 485,000 T potash/year.
- 47/57 African countries buy no K fertiliser.
- About 1.5% of world potash production feeds 15% of the world’s population.
For specific countries:

Each year:
- Kenya takes ten times as much K in crops (32 kg/ha) as is replenished using fertilisers
- Malawi takes 14 times as much (42 kg/ha)

Overall:
- China takes 60 kg/ha K per year
- The world is mining 20 kg/ha K per year
- Europe and N America add too much K to soil (Sheldrick et al, 2002).
12 countries produce 99% of the world’s K (33.5 MT $K_2O$ equivalent)
Potash is big business
Potash price and supply

• Unlikely to go below $400/tonne
• World production needs to double
• Suppliers control the market
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- World production needs to double
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Is an alternative needed?
Potash production is focused on the needs of the global north.
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- Leonardos et al (1987): “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 the glacial and rock-debris-rich soils of the northern hemisphere our present fertilizers might have been quite different.”
## Mineral sources of K

<table>
<thead>
<tr>
<th>Mineral</th>
<th>Formula</th>
<th>% K$_2$O</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Potash salts</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sylvite</td>
<td>KCl</td>
<td>63</td>
</tr>
<tr>
<td>Carnallite</td>
<td>MgCl$_2$.KCl.6H$_2$O</td>
<td>17</td>
</tr>
<tr>
<td><strong>Potassium silicates</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>K-feldspar</td>
<td>KAlSi$_3$O$_8$</td>
<td>17</td>
</tr>
<tr>
<td>Leucite</td>
<td>KAlSi$_2$O$_6$</td>
<td>21</td>
</tr>
<tr>
<td>Nepheline</td>
<td>(Na,K)AlSiO$_4$</td>
<td>15</td>
</tr>
<tr>
<td>Micas, e.g.</td>
<td>KAl$_3$Si$<em>3$O$</em>{10}$(OH)$_2$</td>
<td>11</td>
</tr>
</tbody>
</table>
How effective are rocks as sources of K?

It is the dissolution rate of silicate minerals, not the K content, that has greatest effect on K availability:

![Graph showing K release over days for different minerals (Nepheline and Feldspar)]
## Dissolution rate matters

<table>
<thead>
<tr>
<th>Mineral</th>
<th>Formula</th>
<th>Weight % K$_2$O</th>
<th>Relative dissolution rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Potassium feldspar</td>
<td>KAlSi$_3$O$_8$</td>
<td>16.9</td>
<td>1-2</td>
</tr>
<tr>
<td>Leucite</td>
<td>KAlSi$_2$O$_6$</td>
<td>21.6</td>
<td>nd</td>
</tr>
<tr>
<td>Nepheline</td>
<td>(Na,K)AlSiO$_4$</td>
<td>15.7</td>
<td>40-100</td>
</tr>
<tr>
<td>Kalsilite</td>
<td>KAlSiO$_4$</td>
<td>29.8</td>
<td>nd</td>
</tr>
<tr>
<td>Muscovite</td>
<td>KAl$_3$Si$<em>3$O$</em>{10}$(OH)$_2$</td>
<td>10.9</td>
<td>n/a</td>
</tr>
<tr>
<td>Biotite</td>
<td>K$_2$Fe$_6$Si$_6$Al$<em>2$O$</em>{20}$(OH)$_4$</td>
<td>9.2</td>
<td>n/a</td>
</tr>
<tr>
<td>Phlogopite</td>
<td>K$_2$Mg$_6$Si$_6$Al$<em>2$O$</em>{20}$(OH)$_4$</td>
<td>11.3</td>
<td>n/a</td>
</tr>
</tbody>
</table>

Feldspar family | Feldspathoid family | Mica family: cation exchange
Published trials

In a recent review (Manning 2010; Agronomy for Sustainable Development 30, 281-294), 20 trials have been described:

- Alfalfa
- Clover
- Grass
- Legumes
- Maize
- Okra
- Rice
- Spruce
- Tomatoes
- Wheat

These are mainly pot trials.
Rock types:

• Granite, feldspar and granitic gneiss most commonly used (highest K content):
  – For granite, increased yield for clover and rye grass (Coroneos et al, 1996)
  – For feldspar, increased crop yields reported for tomatoes (Badr, 2006), okra (Abdel Mouty & El Greadily, 2008), legumes (Sanz-Scovino & Rowell, 1988)

• Some work with nepheline-bearing rocks:
  – Bakken et al (2000) increased grass yields with nepheline-bearing rocks, equivalent to KCl.
Rock types:

- Granite - a mixture of feldspars of different types with micas of different types
  - Multiple sources of K
  - Varied reaction rates for components of a complex mixture

- Nepheline-bearing rocks:
  - Mixtures again: feldspar and biotite as well as nepheline

Grass: Bakken et al., 2000
Yields, uptake and significance

• In general, trials with application of a silicate rock can give increased yield and K uptake – but often the increases are weakly or not significant statistically.

• In general, conclusions in studies published until now are that silicate rocks are not interesting as a source of K, in competition with KCl which until now has been cheap.

• Economics and need both challenge that conclusion.
Basic rocks (basalts etc).

• Although not usually regarded as K sources, some basic rocks contain the mineral leucite, which will dissolve quickly like nepheline, unless it reacts first.

• Weathering/alteration can lead to the production of zeolites within such rocks, adding Cation Exchange Capacity.

• So, basic rocks can be an effective source or K.
Unit price of potash

• In the mid 1990s we developed MSL-K as a crushed rock source of K for organic farmers
• MSL-K was at a disadvantage, because KCl was cheaper, and the Soil Association eventually permitted the use of KCl.
• Now things are different:
  – Unit price of K in KCl sold at $600/tonne: $1.15
  – Unit price/kg K in MSL-K sold at $65/tonne: $1.12
• Can a mine produce and sell a crushed rock at $65 per tonne?
Conclusions

• To feed the world’s population, we need all the help we can get
• Geological minerals are dynamic components of soil, acting as sources of nutrients
• There is much we can do to exploit minerals as nutrient sources, but we need to embed rigorous mineralogy into crop trials