Sulphur nutrition and food security

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Regional Director ANZ

Charlie Walker, Incitec Pivot Fertilizers
Sam Stacey, Adelaide University

Better Crops, Better Environment ... through Science

Creswick, November, 2010
Outline of an agronomist’s view

• IPNI – interest in S
• Demand for food, feed & fibre – role of nutrients
• Why S now?
• S fertilizer use past & present
• S management for food production – Australian
  – The 4 R’s Approach
• Summary
Establishment and Foundation

- Potash Institute and then Potash and Phosphate Institute (PPI) trace back to 1930’s in Canada.

  - Inclusion of N producers
  - Potash & Phosphate Institute (PPI) ceased to exist.
  - PPI’s Board committed its scientific staff to IPNI.

- Not-for-profit international decentralized NGO.

- Supported by leading fertilizer manufacturers.

- Australia & New Zealand program began October, 2009.
International Plant Nutrition Institute (IPNI)

• As the theme of our annual program report … we are growing the right way.
• 150 research projects in >50 countries with 35 scientific staff.
• Outputs geared to developing sustainable nutrient management strategies.

http://www.ipni.net
http://anz.ipni.net
What is the big nutrient management issue?

- Population growth
- Change in diets due to increasing household incomes in developing countries … incomes above $16,000 per yr will rise from 352 mil in 2000 to 2.1 bil by 2030 (World Bank)
- Demand for non-food uses of crops.

Food demand to double by 2050

- Static world land area
- Climate change
- Land for nature
- Energy & Resource availability
“...food production has to increase 50% by 2013 and double in 30 years...”
(Source: Global Challenges for Humanity, 2008 State of the Future, Millennium Project)

Need for nutritious foods
Highly urbanised population in developed and developing countries
Grain Supply and Food Security
Global Wheat Production, Consumption & Ending Stocks

Source, USDA

<table>
<thead>
<tr>
<th>Year</th>
<th>Ending Stocks % Consumption</th>
<th>World Production</th>
<th>World Consumption</th>
</tr>
</thead>
<tbody>
<tr>
<td>2006/07</td>
<td>2%</td>
<td>21%</td>
<td></td>
</tr>
<tr>
<td>2007/08</td>
<td>2%</td>
<td>20%</td>
<td></td>
</tr>
<tr>
<td>2008/09</td>
<td>3%</td>
<td>26%</td>
<td></td>
</tr>
<tr>
<td>2009/10</td>
<td>3%</td>
<td>30%</td>
<td></td>
</tr>
<tr>
<td>2010/11</td>
<td>4%</td>
<td>26%</td>
<td></td>
</tr>
</tbody>
</table>

Source, USDA
Degree of Food Insecurity

Access, Nutritious, Affordable
Food security also considers food quality- Example of Zinc

There are over 450,000 deaths annually < 5 years old in the developing world due to Zinc deficiency.

Grains often low in Zn – when grown on low Zn soils, even lower:

eg Australia – 23 ± 7 mg/kg

Black et al. 2008  The Lancet Maternal and Child Undernutrition Series
World cereal production and fertilizer consumption, million metric tons

Fertilizers account for 40-60% of current global food production...a major contribution to society

Source: FAO and IFA
### World Fertilizer Demand (Mt nutrient)

<table>
<thead>
<tr>
<th>Nutrient</th>
<th>2007/08 to 2009/10</th>
<th>2014/15</th>
<th>% Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>101.0</td>
<td>112.1</td>
<td>+1.8% p.a.</td>
</tr>
<tr>
<td>P₂O₅</td>
<td>36.6</td>
<td>44.0</td>
<td>+3.1% p.a.</td>
</tr>
<tr>
<td>K₂O</td>
<td>25.0</td>
<td>32.2</td>
<td>+4.3% p.a.</td>
</tr>
<tr>
<td>Total</td>
<td>162.7</td>
<td>188.3</td>
<td>+2.5% p.a.</td>
</tr>
<tr>
<td>S</td>
<td>49.2</td>
<td>62.1</td>
<td>+2.6% p.a.</td>
</tr>
</tbody>
</table>

Growth areas are East and South Asia, followed by Latin America.

*Source, Heffer, 2010, IFA*
Sources of Sulphur:

- Mined from surface or shallow deposits or extracted from salt domes – Frasch Process (no longer)
- Sulphides (ores) and sulphates (e.g., gypsum 125 Mt USGS)
- >75% from “sour gas” rich oil/gas wells (Shell-Paques Process – reacts H₂S with NaOH to produce S)
- 85% converted to H₂SO₄, half acid for fertilizer production
- USGS suggests 5 bt of S from gas, oil & tar sands
- Additional 600 bt in coal/shales, etc.
Phosphate Hill Mine

- Mine phosphate rock
- Use S from the Lead/Zinc/Silver deposits at Mount Isa.
- Production capacity of 950 kt MAP/DAP
• USA, Canada, Former Soviet Union, West Asia are the largest producers
• Canada is largest exporter of S
  • Source IFA 2010
Sulphur Demand – 2002-08 mean 46.5 Mt

- 50% of S is traded internationally.
- China, Morocco and the USA are largest importers
Growth and Consumption of S

% Growth in that Market

% of World Consumption

- Oceania
- Latin America
- Africa
- East Asia
- North America
# World Elemental Sulphur Supply/Demand

<table>
<thead>
<tr>
<th></th>
<th>2010</th>
<th>2011</th>
<th>2012</th>
<th>2013</th>
<th>2014</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Sulphur Supply (Mt)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Oil</td>
<td>23.2</td>
<td>24.7</td>
<td>26.0</td>
<td>27.6</td>
<td>28.6</td>
</tr>
<tr>
<td>Gas</td>
<td>23.9</td>
<td>25.9</td>
<td>28.0</td>
<td>29.7</td>
<td>33.2</td>
</tr>
<tr>
<td>Other</td>
<td>3.6</td>
<td>4.4</td>
<td>4.7</td>
<td>4.9</td>
<td>5.2</td>
</tr>
<tr>
<td>Total</td>
<td>50.6</td>
<td>55.1</td>
<td>58.7</td>
<td>62.3</td>
<td>67.1</td>
</tr>
<tr>
<td><strong>Sulphur Demand (Mt)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>For Acid</td>
<td>43.9</td>
<td>46.2</td>
<td>49.5</td>
<td>52.4</td>
<td>54.9</td>
</tr>
<tr>
<td>Non-Acid</td>
<td>6.6</td>
<td>6.8</td>
<td>6.9</td>
<td>7.1</td>
<td>7.2</td>
</tr>
<tr>
<td>Total</td>
<td>50.5</td>
<td>53.0</td>
<td>56.4</td>
<td>59.5</td>
<td>62.1</td>
</tr>
<tr>
<td>% Balance</td>
<td>0.2%</td>
<td>4%</td>
<td>4%</td>
<td>5%</td>
<td>7%</td>
</tr>
</tbody>
</table>

Source: M Prud'homme, IFA, June 2010
Why S and why now?

- Increased crop yields creating a higher S offtake.
- Use of high analysis fertilizers containing little incidental S.
- Less use of high S fuels so less S from atmosphere.
- Slower organic matter turnover with conservation tillage.
- Fewer S-containing pesticides.

McNeill et al., 2005, Soil Use & Management
Importance of S

- Component of essential amino acid in animal nutrition
- Key component in protein structure – disulphide bonding
- Present in several organic compounds … odours to garlic, mustard and onion, health compounds in Brassica spp.
- Crop yields!!!!!

Cysteine  Methionine
## Response to S

<table>
<thead>
<tr>
<th>Rate of S fertilizer (kg/ha)</th>
<th>Canola Yield (t/ha) after:</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Cereal</td>
<td>Pasture</td>
</tr>
<tr>
<td>0</td>
<td>2.63</td>
<td>3.25</td>
</tr>
<tr>
<td>10</td>
<td>2.74</td>
<td>4.12</td>
</tr>
<tr>
<td>20</td>
<td>2.82</td>
<td>4.38</td>
</tr>
<tr>
<td>40</td>
<td>2.91</td>
<td>4.53</td>
</tr>
<tr>
<td>LSD</td>
<td></td>
<td>0.24</td>
</tr>
</tbody>
</table>
Importance of balanced nutrition

- S is only one part of a balanced nutrition package
- Example from left of canola in Canada
- Benefits to the crop come when all nutritional limitations are met.
- Co-limitation studies
Wheat grain N:S ratio

SE Australian N/S 2009
n=140 (2*70)

Randell et al. (1981) AJAR 32, 203-212
Maize Intensification in Mozambique
7 locations – 2008-09 average yields

Maize Yield (t/ha)

- National Ave.
- Saved seed
- OPV seed
- Hybrid seed

Nutrients applied: 106 N, 72 P₂O₅, 36 K₂O, 18 S
**S deficiency in Australia**

**History of S deficiency in pastures.**

Deficiencies first seen in NSW at Lockhart.

- Soils naturally low in S.
- Declining soil OM levels
- Reduced use of single super – clear trend to AP’s
- High demand for S by canola.
- Typically on Red Brown Earths.
- Pale petal colour.
Soil S levels – ANRA Audit 2001

- Nationally
  11% < 5 mg/kg

- New South Wales
  25% < 5 mg/kg

- Victoria
  3% < 5 mg/kg

2010 Soil S test values (top 10 cm) for Victoria, South Australia, New South Wales (~1200 tests)

<table>
<thead>
<tr>
<th>KCl-40 (mg/kg)</th>
<th>Crop</th>
<th>Pasture</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;8</td>
<td>52%</td>
<td>43%</td>
</tr>
<tr>
<td>8-12</td>
<td>20%</td>
<td>30%</td>
</tr>
<tr>
<td>&gt;12</td>
<td>28%</td>
<td>27%</td>
</tr>
</tbody>
</table>
Continental S balance – ANRA Audit
Notional farm gate S balance

- S inputs from current fertilizers – Most superphosphate applied to pastures. DAP/MAP used for grain
- Notionally Australia is in positive S balance
- Not included in this balance
  - Added S from mined/biproduct gypsum (4 Mt mined)
  - Atmospheric input 4.5 ± 2.1 kg S/ha/y (NLWA 2001)
  - S input from irrigation – depends on watershed position

247 kt S/y
+2.9 kg/ha/y
113 kt S/y
S Removal in Australian Agriculture
48% removed in Grains, 42% in Livestock
Importance of getting S right

- Key aspect of sustainability is getting nutrients balanced against each other.
- At least balance total S inputs and outputs.
- Interaction with grain protein quality
- Interaction with S and Mo&Se&Cu&Zn – and many others
- Large differences among different crops in S demand
  - Export ranges from 11 to 70 kg S/ha
  - Wheat grain S content – relatively consistent (NVT analyses 2010)

<table>
<thead>
<tr>
<th></th>
<th>P</th>
<th>K</th>
<th>S</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>3329 ±671</td>
<td>4606±645</td>
<td>1742±220</td>
</tr>
<tr>
<td></td>
<td>3600±800</td>
<td>4000±800</td>
<td>1700±400</td>
</tr>
</tbody>
</table>
Zinc and Sulphur interaction

Adding S increased the Zn concentration in vegetative tissue suggesting the additional S enhanced the uptake of Zn by the plants.

High grain Zn can interfere with protein quality (disrupt S bonds?)

Zinc efficient lines may take up luxury levels and decrease protein quality

Peck et al. 2008 JCS
Principles for Fertilizer Management

- Right Product@Right Rate, Right Time, Right Place™ system
- 4 R’s approach as a summary

The concept was further developed by IPNI scientists (Bruulsema et al. 2008)

Series in Crops & Soils 2009
The Right Rate - Soil test

<table>
<thead>
<tr>
<th>Crop</th>
<th>Deficient</th>
<th>Marginal</th>
<th>Adequate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pasture</td>
<td>&lt;5</td>
<td>5-10</td>
<td>&gt;10</td>
</tr>
<tr>
<td>Canola</td>
<td>&lt;12</td>
<td>12-18</td>
<td>&gt;18</td>
</tr>
<tr>
<td>Wheat</td>
<td>&lt;3</td>
<td>3-5</td>
<td>&gt;5</td>
</tr>
</tbody>
</table>

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<tr>
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<th>Crop</th>
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<td>28%</td>
<td>27%</td>
</tr>
</tbody>
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2010 Soil S test values (top 10 cm) for Victoria, South Australia, New South Wales (~1200 tests)
S test calibrations - Pastures

- Pasture growth limited by deficiency
- Pasture growth not limited by deficiency
Problem with leaching & soil tests

- Sulphate mobile
- Sulphate supplied
  - Mineralisation OM
  - Oxidation S
- Improved tests;
  - Appropriate depth
  - Take account of some part of the other S sources.

Sulphur distribution down the profile for some New South Wales soil sites (Blair et al., 1997).
Right place & right time

• Where the plant can get it –
  – Root zone – control release rates to avoid leaching

• In synchrony with plant demand – ability to recover from nutrient stress – eg Canola

<table>
<thead>
<tr>
<th>S applied Kg/ha</th>
<th>Sowing</th>
<th>5-6 Leaf</th>
<th>Buds Visible</th>
<th>Stem Elongation</th>
<th>LSD</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>1.73</td>
<td>1.62</td>
<td>1.56</td>
<td>1.41</td>
<td><em>LSD</em></td>
</tr>
<tr>
<td>40</td>
<td>2.15</td>
<td>2.26</td>
<td>2.11</td>
<td>2.19</td>
<td>0.43</td>
</tr>
</tbody>
</table>

Hocking et al., 1996
**Right product**

- **Deliver sulphate to the rootzone at the right time**

<table>
<thead>
<tr>
<th>Product</th>
<th>N</th>
<th>P</th>
<th>K</th>
<th>S</th>
</tr>
</thead>
<tbody>
<tr>
<td>Superphosphate</td>
<td>0</td>
<td>8.8</td>
<td>0</td>
<td>11</td>
</tr>
<tr>
<td>MAP</td>
<td>10.0</td>
<td>21.9</td>
<td>0</td>
<td>1.5</td>
</tr>
<tr>
<td>DAP</td>
<td>18.0</td>
<td>20.0</td>
<td>0</td>
<td>1.6</td>
</tr>
<tr>
<td>Triple Superphosphate</td>
<td>0</td>
<td>20.7</td>
<td>0</td>
<td>1.0</td>
</tr>
<tr>
<td>Ammonium Sulphate</td>
<td>20.2</td>
<td>0</td>
<td>0</td>
<td>24</td>
</tr>
<tr>
<td>Sulphur Bentonite</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>90</td>
</tr>
<tr>
<td>Sulphate of Potash</td>
<td>0</td>
<td>0</td>
<td>41</td>
<td>18</td>
</tr>
</tbody>
</table>

- A range of S fortified products – sulphur coated urea, sulphur coated MAP & DAP.
- Usually coated with S⁰ (elemental) which requires oxidation to release sulphate & it all happens at once!
- Nutrient co-location can be important (P/S – Friesen 1989)
Rates of sulphate release from different sources

Figure 12. Predicted release of $\text{SO}_4^{2-}$ from SSP, $\text{S}_\text{o}$-fortified SSP (SF45) and various sizes of particles isolated from a commercial agricultural grade of $\text{S}_\text{o}$ (McCaskill and Blair, 1988).
Developments in Fertilizer Technology

• S\(^0\) oxidation rapid with fine particles
  – Good for sulphate release
  – Bad for handling

• Two new processes that incorporate S\(^0\) into existing products at manufacture

• For S fertilizers, keys are:
  – High nutrient density
  – Matched/balanced with other nutrients
  – Controlled release of SO\(_4\)
  – Safe to store and transport – corrosive & explosive

<table>
<thead>
<tr>
<th>Particle Size µ</th>
<th>2 weeks</th>
<th>4 weeks</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;75</td>
<td>80</td>
<td>82</td>
</tr>
<tr>
<td>75-125</td>
<td>61</td>
<td>81</td>
</tr>
<tr>
<td>125-175</td>
<td>36</td>
<td>68</td>
</tr>
<tr>
<td>175-400</td>
<td>15</td>
<td>36</td>
</tr>
<tr>
<td>400-840</td>
<td>5</td>
<td>14</td>
</tr>
<tr>
<td>840-2000</td>
<td>2</td>
<td>5</td>
</tr>
<tr>
<td>2000-4000</td>
<td>1</td>
<td>2</td>
</tr>
</tbody>
</table>
Mosaic’s MicroEssentials Products

$S^0$ fine particles in MAP or DAP matrix
Can also add Zn

12:18:0:10
N:P:K:S
Up to 14% S
50:50 $S^0$:SO$_4$
## MES Responses

<table>
<thead>
<tr>
<th>Fertilizer</th>
<th>Crop</th>
<th>No of Trials</th>
<th>Average Yield increase over MAP</th>
</tr>
</thead>
<tbody>
<tr>
<td>MES10</td>
<td>Wheat</td>
<td>10</td>
<td>8%</td>
</tr>
<tr>
<td></td>
<td>Canola</td>
<td>7</td>
<td>11%</td>
</tr>
<tr>
<td>MES10 Zn</td>
<td>Wheat</td>
<td>12</td>
<td>7%</td>
</tr>
<tr>
<td></td>
<td>Canola</td>
<td>9</td>
<td>20%</td>
</tr>
</tbody>
</table>

Sulfur response in canola at Woomelang. Left was treated with MAP (12-22-0) + urea, right was treated with 12-18-0-10. Both plots had equivalent N and P.
Thiogro S

• Technology developed by Shell to incorporate microfine S into MAP, DAP and TSP.
  – Alter S:SO$_4$ ratio, even distribution in granule – alter the rate of sulphate supply to the plant.

• Agronomic efficiency still being evaluated but there are freight benefits due to a higher S density in these products.

Flavel et al., 2010, ISSC.

Higher S & P recoveries with MAP12
Gypsum & $S^0$ mixture

- Recent product (WA) – granulated mixture of by-product gypsum with $S^0$. Called Canola Blue for canola grown in low S soils of the region.
- Relative efficiency of “Canola Blue” compared to gypsum
- Application rate to achieve the same yield.

<table>
<thead>
<tr>
<th>Site</th>
<th>Relative Efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>Site 1</td>
<td>1.13</td>
</tr>
<tr>
<td>Site 2</td>
<td>1.00</td>
</tr>
<tr>
<td>Site 3</td>
<td>0.89</td>
</tr>
<tr>
<td>Site 3</td>
<td>1.11</td>
</tr>
</tbody>
</table>

- Brennan et al. 2010 Journal of Plant Nutrition, 33: 8, 1180 — 1194
Ammonium sulphate

• Traditional fertilizer – seen as a better S source than gypsum (Khan poster).
  – Root Zone acidification, Coplacement of N/S, Reduced N loss.

• As a plant fertilizer – not enough N – looking at Urea/Ammonium Sulphate fluid fertilizers, compared to UAN/ATS fluids
Summary

- While there have been improvements in food security, continued gains in food production and enhanced food quality are still an imperative of agricultural science.
- Addressing sulphur nutrition is an important aspect of ensuring food security and this will continue into the future.
- There are adequate S resources to meet demand well into the future.
- The current tools to assist with selecting the right S rate are more art than science.
- New products will require refinement of the 4R’s approach for S management into the future.
IPNI is supported by leading fertilizer manufacturers and industry associations

- Agrium Inc.
- Arab Potash Company
- Belarusian Potash Company
- CF Industries Holdings, Inc.
- Incitec Pivot
- International Zinc Association (IZA)
- Intrepid Potash, Inc.
- K+S KALI GmbH
- The Mosaic Company
- OCP S.A.
- PotashCorp
- Simplot
- SinoFert Holdings Limited
- SQM
- Uralkali
- Arab Fertilizer Association (AFA)
- Canadian Fertilizer Institute (CFI)
- Foundation for Agronomic Research (FAR)
- International Fertilizer Industry Association (IFA)
- International Potash Institute (IPI)
- The Fertilizer Institute (TFI)