Agronomic practices and input-use efficiency

Robert Norton,
Regional Director, International Plant Nutrition Institute, Australia and New Zealand;
Associate Professor, Melbourne School of Land and Food, The University of Melbourne.

“Preparing Agriculture for Climate Change”
February 6-8, 2011 at the Punjab Agricultural University, Ludhiana, India.
International Plant Nutrition Institute

• IPNI is a not-for-profit, scientific organization
  – established in 2007 from the Potash Phosphate Institute (PPI)
  – Agronomic programs in Africa, China, India, Eastern Europe & Central Asia, Middle East, Oceania, North and South America

• We provide a unified, scientific voice for the world’s fertilizer industry; independent, but scientifically credible

The mission of IPNI is to develop and promote scientific information about the responsible management of plant nutrition for the benefit of the human family.
Overview of Presentation

• Situation summary – Population, Food Security & Climate Change
• Responses by Australian farmers
• Resource Use Efficiency, definitions & progress
  – Phosphorus
  – Nitrogen
• Impact of elevated carbon dioxide
• Short, Medium & Long Term adaptations

“Will efficiency improvements be enough to deal with climate change impacts?”
“...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)

- Static world land area
- Land for nature
- Energy & Resource availability
- Short term disasters becoming protracted crisis
- Climate change
Australian Wheat Production

Spring Wheats – sow May, harvest December
South-eastern Australia

- Farmers have faced difficult times
- Warmer temperatures
- Lower rainfalls
  - LTA Horsham = 417 mm (±107)
  - Decade 2000-2009 = 346 mm
- Yield strongly linked/limited rainfall

\[
WUE = \frac{Y}{(ET-SE)} \quad WUE = \frac{Y}{ET}
\]
Water limitation to yield

10 kg/ha/mm \( WUE = \frac{Y}{ET} \) (Means)

High degree of regional variation

- WUE can be normalised using other variables
  - VPD, Temperature/Daylength – Gives a regional mean/benchmark

Mega Environment
Water Use Efficiency \( Y/WU \)
(691 crops in the literature)

China Loess – 9.8 kg/ha/mm
Medit Basin – 7.4 kg/ha/mm
NA Plains – 6.1 kg/ha/mm
SE Aust – 9.9 kg/ha/mm

Sadras & Angus, 2006

Doherty et al, 2009
Farmers response to a changing climate

- Increase in stubble retention and direct drilling
- Increased use of fallows to conserve moisture
- Decrease plant densities
- Gear inputs to seasonal conditions – Yield forecasting
  - Nitrogen now applied in-crop rather than pre-crop (rule of thirds)
  - Deferred decisions as season unfolds
- Opportunity cropping
  - If early break = canola.
  - If late break = barley
- Select short season crop varieties
- Become more flexible and willing to change quickly
What is the potential for further intensification?

  - Modeled options for increasing WUE from these farms – Y/ET (kg/ha/mm)

<table>
<thead>
<tr>
<th>Current</th>
<th>150 pl/m²</th>
<th>Early Sowing</th>
<th>Optimum N</th>
<th>All Options</th>
</tr>
</thead>
<tbody>
<tr>
<td>10.7</td>
<td>10.7</td>
<td>11.6</td>
<td>11.7</td>
<td>12.9</td>
</tr>
</tbody>
</table>
Impact of Climate Change

For Australia by 2050

- 1-2°C warmer
- 50-100 mm drier
- 550 ppm CO₂

Effect on grain yield (Grace, 2006)
Adaptation strategies

- Ash et al. (2008) – modeled wheat yields in the Victorian wheat belt with a climate change overlay (CSIRO Climate System model)
What role for nutrients?

<table>
<thead>
<tr>
<th>Nutrient</th>
<th>2007/08 to 2009/10</th>
<th>2014/15</th>
<th>% Change</th>
<th>Reserves &amp; Base</th>
</tr>
</thead>
<tbody>
<tr>
<td>N</td>
<td>101.0</td>
<td>112.1</td>
<td>+1.8% p.a.</td>
<td>Oil</td>
</tr>
<tr>
<td>P&lt;sub&gt;2&lt;/sub&gt;O&lt;sub&gt;5&lt;/sub&gt;</td>
<td>36.6</td>
<td>44.0</td>
<td>+3.1% p.a.</td>
<td>380/900</td>
</tr>
<tr>
<td>K&lt;sub&gt;2&lt;/sub&gt;O</td>
<td>25.0</td>
<td>32.2</td>
<td>+4.3% p.a.</td>
<td>256/510</td>
</tr>
<tr>
<td>Total</td>
<td>162.7</td>
<td>188.3</td>
<td>+2.5% p.a.</td>
<td></td>
</tr>
<tr>
<td>S</td>
<td>49.2</td>
<td>62.1</td>
<td>+2.6% p.a.</td>
<td>Oil</td>
</tr>
</tbody>
</table>
World cereal production and fertilizer consumption, million metric tons

Cereals
Fertilizer

Source: FAO and IFA
Climate Change & Fertilizers

- Fertilizer life cycle contributes 2.5% of GHG emissions
  - Manufacture (~0.9%)
  - Transport (~0.1%)
  - Use (~1.5%) (N\textsubscript{2}O)
- Significantly contribute to food security – Stewart et al. estimated 40-60% of total food due to fertilizer
- Intensification mitigates by lower GHG associated with land clearing

# Nutrient use efficiency terminology

- Frequently stated that P is used inefficiently in agriculture
  - percent recovery of P applied in fertilizers usually between 10 and 25%

## Example:

<table>
<thead>
<tr>
<th>P applied (F)</th>
<th>Grain yield (Y)</th>
<th>P Uptake (U)</th>
<th>P removal (U_H)</th>
</tr>
</thead>
<tbody>
<tr>
<td>kg/ha</td>
<td>Kg/ha</td>
<td>kg P/ha</td>
<td>kg P/ha</td>
</tr>
<tr>
<td>0</td>
<td>Y_0 = 2,624</td>
<td>U_0 = 17</td>
<td></td>
</tr>
<tr>
<td>20</td>
<td>Y = 3,160</td>
<td>U = 20</td>
<td>16</td>
</tr>
</tbody>
</table>

### Percent recovery

\[
\text{Percent recovery} = \frac{\text{Uptake}_{\text{Fert}} - \text{Uptake}_{\text{No fert}}}{\text{Fertilizer Applied}} \times 100
\]

- Agronomic efficiency: \((Y-Y_0)/F\)
- Recovery efficiency by balance\(^*\): \(U_H/F\)

\* Also referred to as “partial nutrient balance” or “removal to use ratio”.

---

*IPNI*
Progress in improving nutrient efficiency

Since 1975:
- 12% increase in N fertilizer use
- 51% increase in N efficiency

Data sources: USDA Ag Chem Use Survey & Annual Crop Production.
**P nutrient balance (kg/ha/yr) in corn-based agricultural systems –**

<table>
<thead>
<tr>
<th></th>
<th>Midwest U.S.</th>
</tr>
</thead>
<tbody>
<tr>
<td>P applied as fertilizer</td>
<td>14</td>
</tr>
<tr>
<td>P removed in harvested crop</td>
<td>23</td>
</tr>
<tr>
<td>Balance</td>
<td>-9</td>
</tr>
<tr>
<td><em>Recovery by balance method</em></td>
<td><strong>1.64</strong></td>
</tr>
</tbody>
</table>

Potential yield in these systems were similar, but realized yields were 2 t/ha/yr in Kenya; 8.5 in China, and 8.2 in the U.S. Wheat yielded another 5.8 t/ha/yr in China and soybeans 2.7 t/ha/yr every other year in Illinois.

Vitousek et al., Science, 2009

Illinois Median Bray P in 2005 = 36 ppm, in 2010 = 24 ppm
Improving P use efficiency

- Fertilizer P
- Plant Available
- Exchangable P
- Not Plant Available
- Fixed P
- Microbes
- Plant mechanisms
- Chemical Protection
- Root Features

< 15% of applied P ↔ > 85% of applied P
Improving P use efficiency

• Selecting the right product
  – Microbial inoculants such as *Penicillium bilaii* – a phosphorus solubilizing soil fungus. Commercialised in Australia.
  – Chemical protectants – dicarboxylic acid co-polymer coating to control P release into rhizosphere. Commercial product US (Avail®)
Genetic approaches

- Is there variation in P use efficiency?

- P Harvest Index  (Rose et al, 2010)

- Root exudates  (Valizadeh et al, 2002, Schefe et al. 2008)

- Root distribution  (McDonald et al, 2010)

McDonald et al, 2010
Climate Change Impact & P

Only one study
- Newton et al. (2006) reported lower labile P levels under FACE rings in New Zealand.
- Higher removal?
- Lowered soil pH?
- Interaction with mycorrhizae?

As go yields, so follows P
- if yields increase, P will be more depleted
- if yields decrease, P will be less depleted

Prediction is very difficult, especially about the future. Neils Bohr,
Nitrogen Use Efficiency

• Low average N use efficiency in field:
  – global average estimated from 30 to 35% in the year of application.

• Vastly different scenarios between developed and developing countries.

PFP for Maize (US), for cereals, oilseeds & potato (China)
N nutrient balance (kg/ha/yr) in corn-based agricultural systems –

<table>
<thead>
<tr>
<th></th>
<th>Midwest U.S.</th>
<th>Western Kenya</th>
<th>North China</th>
</tr>
</thead>
<tbody>
<tr>
<td>N applied as fertilizer</td>
<td>93</td>
<td>7</td>
<td>566</td>
</tr>
<tr>
<td>Biological N fixation</td>
<td>62</td>
<td></td>
<td></td>
</tr>
<tr>
<td>N removed in harvested crop</td>
<td>145</td>
<td>23 (+36)</td>
<td>361</td>
</tr>
<tr>
<td>Balance</td>
<td>+10</td>
<td>-52</td>
<td>+205</td>
</tr>
</tbody>
</table>

Potential yield in these systems were similar, but realized yields were 2 t/ha/yr in Kenya; 8.5 in China, and 8.2 in the U.S. Wheat yielded another 5.8 t/ha/yr in China and soybeans 2.7 t/ha/yr every other year in Illinois.

Vitousek et al., Science, 2009
Making the best use of nutrients

• N and P approaches differ
  • N has more loss pathways than P
    • leaching, denitrification, or volatilization
  • Fertilizer P not removed by the crop at harvest remains in the soil

• N efficiency also has a strong environmental driver
  – N₂O production – potent GHG (~1% applied N)
    • ~23% N₂O & ~5% of total GHG emissions*
  – Nitrate leaching
  – Ammonia particulates and re-deposition

*2005 – World Resources Institute
Developing the approach

- IPNI Nutrient Stewardship Framework
- Right Source@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
Right Sources

Enhanced Efficiency Fertilizers

- Synthetic organic compounds containing N
  - urea-formaldehydes, IBDU, triazines, etc.
- Physical coating or barrier around soluble N fertilizer
  - Sulfur-coated or polymer-coated urea.
- Stabilized materials
  - urease and nitrification inhibitors
@Right Rate

- Lowest economical rate
  - Marginal cost v Marginal return
- Lower rates have lower NUE *(if a high efficiency = low rate)*
- Lower rates have lower N\textsubscript{2}O emissions

Lowering rates to the plateau of the yield response curve has little effect on yield, but a large effect on NUE, and a large environmental GHG impact.

Figure 5. Balanced median N\textsubscript{2}O emission rates as a function of applied N (adapted from Bouwman, Boumans, and Rattin, 2000).
Right Time

• Asynchrony between demand & supply of nutrients
  – Nutrient losses if not taken up

• Split applications
• Controlled release fertilizers
• Banding

(Source: Robertson et al. 1997)
Right Place (site specific)

- Whole paddock @ one rate = -$17/ha
- Treat on a site specific rate = +$90/ha
Best Management Practices to Minimize Greenhouse Gas Emissions Associated with Fertilizer Use

IPNI Better Crops article, Issue 4 of 2007

IPNI Review Paper

Greenhouse Gas Emissions from Cropping Systems and the Influence of Fertilizer Management

http://www.ipni.net/ppiweb/bcrops.nsf/$webindex/6F2F57CBF1C5209685257394001B2DD0/$file/07-4p16.pdf
Nutrient Recovery and Nutrient Use Efficiency are Affected by Other Essential Nutrients

Figure 6. Proper P nutrition improves corn yield and maximizes response to N rate (Schlegel et al., 1996).

Figure 7. Adequate P nutrition reduces residual soil NO₃-N in corn (Schlegel et al., 1996).

Figure 8. Apparent N recovery by corn using balanced fertilization (assuming 25 kg N/t grain or 1.4 lbs of N uptake/bu) (Gordon, 2005).
Genetic Improvement in NUE

• Improve water use efficiency
  – Often associated with improved transpiration efficiency and reduced soil evaporation
• Increase access to N
  – Root traits
• Increase uptake efficiency (transporters)
• Increase physiological use efficiency – remobilization, storage, NR’ase
• Selection under low/high N

<table>
<thead>
<tr>
<th></th>
<th>TDM (t ha⁻¹)</th>
<th>WU (mm)</th>
<th>Soil E (mm)</th>
<th>TE (kg ha⁻¹ mm⁻¹)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0 N</td>
<td>2.66</td>
<td>299</td>
<td>86</td>
<td>38</td>
</tr>
<tr>
<td>140 N</td>
<td>4.17</td>
<td>304</td>
<td>61</td>
<td>46</td>
</tr>
</tbody>
</table>

(Norton & Wacchsman, 2006)
GM approaches to NUE

- Over-express enzyme alanine aminotransferase (AlaAT)
- Expressed naturally in roots under stress (e.g., waterlogging)
- Provides a storage reserve of N as alanine in the root.
- NUE canola yielded 2.80 t/ha using two-thirds less nitrogen fertilizer than the conventional variety needed to generate the same yield.
- Most effective at moderate levels of N where the problem is capturing the N in the plant before loss processes occur.
- BASF, DuPont & Syngenta – not before 2015 & probably in Maize & canola

Gains in N Use Efficiency

- In the short and medium term, most of gain in NUE is expected to come from improved agronomy.
- Biotechnology is likely to contribute in the long term and then only modestly.

Rennie & Heffer, 2010
What about climate change?

• In C3 plants – CO₂ & O₂ compete for active sites on ‘RuBisCO’ shift to increase gross photosynthetic C fix and reduce C loss in photorespiration.

• In both C3 and C4 plants, stomatal aperture narrows reducing water use.

• Therefore C↑ increases & W↓ decreases so TE increases.

• Increase in CO₂ from 350 ppm to 550 ppm increases TE by 50%.

• Expect 20-30% increase

Ainsworth & Long 2005 New Phytologist
Summary of N dynamics

- +27% Top Growth
- +20% N Uptake
- -6% Plant N content
- Less N in grain
- 27% biomass to soil
- ~44 C:N in straw

385 ppm CO₂

550 ppm CO₂

Progressive Nitrogen Limitation (PNL): The decline of the availability of mineral N over time (e.g. 6-7 years) at elevated [CO₂] when compared to ambient, if there is no new N input or reduction in N losses (Luo et al. 2004).
Will efficiency be enough?

- Increasing complexity, cost and risk
- Transformation from landuse or distribution change
- New products such as ecosystem services
- Climate ready germplasm
- Climate-sensitive precision-agric
- Diversification and risk management
- Varieties, planting times, spacing
- Stubble, water, nutrient and canopy management etc

Howden et al. (2007)
Transformational Changes

- Pastoral zone
- Significant loss
- Some loss
- Little change
- Significant gain
- Some gain

Murray-Darling Basin

100,000 Head (Beef Cattle)
Summary

• Dealing with climate change is not going to be “business as usual” — there are efficiency gains that must be taken.
  
• P use efficiency – as measured by balance – is quite high anyway
  – Good agronomic opportunities (products, placement)
  – Limited genetic opportunities

• N use efficiency – can be increased significantly
  – Nutrient Best Management Practices
  – Some genetic opportunities
  – Has environmental and economical payoff.

• Higher carbon dioxide will – generally – increase C3 yields, and may compensate somewhat for the lower rainfall and higher temperatures expected – will demand higher nutrient input.

• Incremental change will take us only so far – at some stage, change will need to be transformational.
“It is not the strongest of the species that survives, nor the most intelligent that survives. It is the one that is the most adaptable to change.”

Better Crops, Better Environment ... through Science
Thank You

www.ipni.net

Better Crops, Better Environment ... through Science