Mitigation of Nitrous Oxide Emissions

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Nitrous Oxide is the largest known anthropogenic threat to the stratospheric ozone layer.

- ODP=0.017
- High GWP - 268, long atmospheric lifetime - 114 yrs
- 10% of total greenhouse gas emissions
- 60% of all N₂O is from agriculture
Importance of Nitrogen and of Controls

• About half of today’s food supply is dependent on the addition of nitrogen originating from ammonia or nitrate based fertilizers.

• Poor management of fertilizers and animal manures (including overuse) is a major contributing factor to N₂O emissions.

• By 2050, lack of controls on N₂O will undo 25% of the benefit gained by the Montreal Protocol to reducing ODS from the ozone layer.
Impact of N$_2$O in International Agreements

Ravishankara et al, SCIENCE, Vol. 326, 2009
The Nitrogen Cycle

Fertilizers

Inhibitors
Excess Nitrogen from Fertilizers and Animal Manures

• Excessive N not used by plants leads to increased:
  (i) Nitrous oxide ($\text{N}_2\text{O}$) emissions to air,
  (ii) Elevated ammonia volatilization ($\text{NH}_3$),
  (iii) Nitrogen run-off to groundwater as nitrate ($\text{NO}_3^-$) and ammonium ($\text{NH}_4^+$).
  (iv) System eutrophication
  (v) Acidification of soils

Heavy NPK fertilizer use (160 - 250 kg N)

Damage to the barrier reef
Main Means of Mitigating $\text{N}_2\text{O}$ and Nitrogen damage

1. **Managing soil chemistry and microbiology**
   - Avoiding overuse of fertilizer/animal manures; Reduce nitrogen leaching; Ensuring $\text{N}_2\text{O}$ is fully denitrified into $\text{N}_2$; Improve N use efficiency

2. **Monitoring nitrogen flows/Modelling/Mobile ‘App’**

3. **Engineering crop plants to fix nitrogen**
1. Managing Soil Chemistry - Reducing N use in Cropping systems (e.g. Horticultural crops)

- Matching soil nitrogen supply to crop demand and irrigation cycles whilst maintaining crop productivity, and avoiding large single applications which leach N into groundwater.
1. **Synthetic organic compounds containing N**
   - Urea-formaldehydes, IBDU, triazines, etc.

2. **Physically coated N fertilizer**
   - Sulfur-coated or polymer-coated urea.

3. **Stabilized fertilizers** Nitrification (and urease) inhibitors

4. **Combination fertilizers with organics**

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Enhanced Efficiency Fertilizer Development Globally - Adoption needs policy incentives
2009 - 2019: Carbon and Nitrous Oxide Management Programs in Australia

1. Benchmark Emissions
2. Nitrification Inhibitors
3. Reduced rates & Irrigation
4. Whole Farm N Budgets
5. Perverse Outcomes (Disease, crop quality)
N$_2$O Measurement
Automatic Chambers & Micromet Systems

Automatic Chambers
Micromet systems
Improve Efficiency of Management of N and C

Intensive - >3 crops/yr

>10 tillages

O/H Irrigation

>1 t Nitrogen

Organics 5-10 t/ha 4x/year
Estimated losses of N (fertilizer/manure) in Horticultural Crops

~20% Marketed

~50% Emitted ($N_2O$, $N_2$)

>1 t N applied: (Fertilizer, Manure + Debris and Irrigation water?)

?? Immobilized and then lost?

~30%

>60% of N lost
Australian Trials 2014-2018

- Sandy soil (kudasol)
- Composted chicken manure used
- Crops grown – Celery, leeks, baby leaf (spinach, etc.)
- Automated GHG system for gas measurements
Effect of EEFs on N$_2$O Emissions

- 10 x higher emissions from manures
- 60-80% decrease in cumulative N$_2$O emissions

N$_2$O flux (µg N/m$^2$/h)

N$_2$O-N (kg/ha)

- Untreated
- Manure
- Manure + DMPP

Bar chart:
- No fertiliser
- 100% NPK
- Manure
- Manure + DMPP
Cumulative N\textsubscript{2}O emissions: Clyde

- **F F M F F**
- **Fallow**
- **Leeks**
- **Spin Fallow**
- **Celery**
- **Fallow**

![Graph showing cumulative N\textsubscript{2}O emissions for different crops and treatments.](image-url)
Inhibitors improved NUE and Yields

Celery Yields - 2013

- No Manure or fert.
- Manure only
- Manure only with inhibitor
- Fertilizer only
- Fertilizer with inhibitor (DMPP)

kg/plot

<table>
<thead>
<tr>
<th>Action</th>
<th>Yield (kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0N</td>
<td>195N</td>
</tr>
<tr>
<td>Inhibitor</td>
<td>408N</td>
</tr>
<tr>
<td>Fertilizer with inhibitor (DMPP)</td>
<td>603N</td>
</tr>
</tbody>
</table>
Effect of Inhibitors on Manure on Yield and Profit in vegetable production systems

60% increase
Mitigation Advantages with Inhibitors (Enhanced efficiency fertilizers)

- **Manures**: Up to 60% decrease in N$_2$O emissions
- **Fertilizers**: >50% reduction in N$_2$O emissions and nitrate leaching.
- **Increased N conversion**: From < 20% to > 50%
- **Profit**: Over $US1,500/ha in cost savings and reduced labour costs
- **Large Fertilizer (and manure) use reductions**: 25-50%

- Limit on nitrates in waterways to 50 mg/L, some countries tighter values

- 170 kg nitrogen per hectare per year from animal manures

Direct benefit – some reduction in $N_2O$ emissions
Global models/Emission inventories predict that approx. 5.3 (Tg, i.e.- million tonnes) of anthropogenic N$_2$O-N is produced each year, with two-thirds coming from direct and indirect fertilizer and animal manure emissions.

International models predict that N$_2$O mitigation measures could avoid emissions equivalent to approx. 60 Gt CO$_2$ eq.

An improvement of 20% in NUE (achievable in many systems) would save an estimated 23 million tonnes of nitrogen globally (i.e. $US23 billion) (UNEP 2013)
N$_2$O mitigation options can dramatically improve fertilizer use efficiency, crop yields, food supply, and environmental damage.

It can be profitable for companies and industry and is a win-win for ozone and climate.
Nitrous Oxide

- High GWP - 298 (311)
- Long residence time in atmosphere – 114 years
- 10% of total greenhouse gas emissions
- 60% of all $N_2O$ is from agriculture

Smith et al. 2007; de Klein & Eckard 2008
Estimated N\textsubscript{2}O from Cropping and Animal Production

- Fertilisers: 18%
- Grazing: 26%
- Atmospheric Deposition: 25%
- Leaching and Run-Off: 17%
- Animal Waste: 5%
- Nitrogen Fixing Crops: 4%
- Crop Residue: 6%
- Cultivation of Histosols: Minor

Australian Federal Govt - DCCEE 2011
Sources of Nitrous Oxide Emissions

- **Denitrification**
  - Warm, water-logged soils
  - Excess N in soil

- **Nitrification**
  - Warm, aerobic soils
  - Minor losses

- **Inefficient use of nitrogen**
  - >60% N inputs lost from production and grazing systems
Nitrification inhibitors interfere with activity of *Nitrosomonas* bacteria, slowing the nitrification process.

More N exists in the ammonium form, thus reducing \( \text{N}_2\text{O} \) emissions leaching and denitrification, and therefore environmental damage.

- **Manures**
- **Fertilizers (NPK, Urea)**
<table>
<thead>
<tr>
<th>Crop</th>
<th>Date 2014/15</th>
<th>Activity</th>
<th>N Rate (kg ha(^{-1}))</th>
</tr>
</thead>
<tbody>
<tr>
<td>Celery</td>
<td>25/2/14</td>
<td>Celery planting</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>25/2, 20/3, 18/4, 8/5</td>
<td>Fertiliser application</td>
<td>192</td>
</tr>
<tr>
<td></td>
<td>28/3</td>
<td>Manure application (Surface)</td>
<td>167</td>
</tr>
<tr>
<td></td>
<td>5/6</td>
<td>Celery harvest</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>13/6</td>
<td>Residue incorporation</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>Total N applied</strong></td>
<td><strong>473</strong></td>
</tr>
<tr>
<td>Leek</td>
<td>19/8</td>
<td>Manure application (Incorporated)</td>
<td>291</td>
</tr>
<tr>
<td></td>
<td>20/8</td>
<td>Leek planting</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>18/9, 15/10</td>
<td>Fertiliser application</td>
<td>48</td>
</tr>
<tr>
<td></td>
<td>2/12</td>
<td>Leek harvest</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>4/12</td>
<td>Residue incorporation</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>Total N applied</strong></td>
<td><strong>425</strong></td>
</tr>
<tr>
<td>Spinach</td>
<td>13/1</td>
<td>Spinach planting</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>6/2</td>
<td>Spinach harvest</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>17/2/15</td>
<td>Residue incorporation</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td></td>
<td><strong>Total N applied</strong></td>
<td><strong>9.5</strong></td>
</tr>
<tr>
<td>All Crops</td>
<td>(*Water =160 N)</td>
<td><strong>Total N applied/yr</strong></td>
<td><strong>907 (238)</strong></td>
</tr>
</tbody>
</table>
Effect of Inhibitors on Manure on Yield and Profit in vegetable production systems

![Graph showing yield and profit comparison]

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Yield (kg/5m)</th>
<th>Gross income at $1.80/kg (adjusted)</th>
<th>Potential extra profit compared to the existing commercial practice</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chicken on surface and NPK base (SGP)*</td>
<td>3.86</td>
<td>$7,195</td>
<td>-</td>
</tr>
<tr>
<td>Chicken on surface and Piadin+NPK base</td>
<td>6.19</td>
<td>$13,247</td>
<td>$6,052</td>
</tr>
<tr>
<td>Chicken on surface and ENTEC+NPK base</td>
<td>6.17</td>
<td>$12,647</td>
<td>$5,452</td>
</tr>
<tr>
<td>Chicken incorporated + K base</td>
<td>3.96</td>
<td>$7,951</td>
<td>-</td>
</tr>
<tr>
<td>Chicken incorporated with Piadin+NPK base</td>
<td>4.52</td>
<td>$8,979</td>
<td>$1,029</td>
</tr>
<tr>
<td>Chicken incorporated with ENTEC+NPK base</td>
<td>5.91</td>
<td>$12,028</td>
<td>$4,078</td>
</tr>
</tbody>
</table>

60% increase