The use of isotopes to define the role of legumes in contributing to food security & in adaptation & mitigation of climate change

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Why legumes?

Food security & adaptation to future climates

- Leguminosae 20,000 species (*cf 10,000 Gramineae & 3,500 Brassicaceae*)
- Many hundreds of species used for human &/or animal food globally
- Only 20 species grown commercially over large areas (~300Mha in total)
- Underexploited legumes an untapped pool of genetic diversity for adaptation

*Climate change & variability*

*Combat incursions of new diseases & pests*

*Provide options to grow more food in hostile or deficient soil environments*

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Mitigating climate change

- Lower fossil energy use than N-fertilized systems
- Believed to have lower green-house gas emissions than N-fertilized systems
- Contribute to C sequestration in soil
- Opportunities to replace petroleum products - as a source of feedstock for biofuels & biorefineries

Stable isotopes of Nitrogen

<table>
<thead>
<tr>
<th>Element</th>
<th>Isotope</th>
<th>% Atmospheric abundance</th>
<th>Range in plants</th>
<th>Variable</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nitrogen</td>
<td>$^{14}$N</td>
<td>99.6337</td>
<td>-2 to +26‰*</td>
<td>Plant species</td>
</tr>
<tr>
<td></td>
<td>$^{15}$N</td>
<td>0.3663</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

* $\delta^{15}$N (‰) = 1000 x (sample abundance – 0.3663) / (0.3663)

Quantification of $N_2$ fixation requires a measurable difference in $^{15}$N content between atmospheric $N_2$ & available soil N

% legume N fixed = 100 x ($^{15}$N non-legume – $^{15}$N legume) / ($^{15}$N non-legume)

Where $^{15}$N non-legume is assumed = $^{15}$N plant-available soil N used by legume

Application of $^{15}$N to quantify N$_2$ fixation

Adaptation to future climates – Impact of elevated [CO$_2$]

Further studies required

• Genetic variation in response to e[CO$_2$]
  $<$+10% to $>$+40% by 5 different field pea varieties cf ambient over 2 years

• Effects of soil type
  +20% to +86% for chickpea
  +44% to +51% for field pea
  +114% to +250% for annual medic

• Effects of pasture composition
  +29% for subclover

Stimulation negated by:
  • Low supply of available P
  • Elevated temperatures
  • What other factors?

See also Session 1 Poster 187

Application of $^{15}$N to quantify the partitioning & fate of legume N

Faba bean harvest

- **Seed N removed**: 131 kgN/ha
- **Above-ground residues**: 44 kgN/ha
- **Below-ground N (23% total plant N)**: 51 kgN/ha

At grain harvest of following wheat crop

- **2 kgN/ha** taken up by wheat
- **22 kgN/ha** soil organic N
- **20 kgN/ha unaccounted**

- **4 kgN/ha** taken up by wheat
- **43 kgN/ha** soil organic N
- **4 kgN/ha unaccounted**

See also Session 1 Poster 231

Adaptation to future climates – Impact of elevated CO$_2$

Further studies required

• Below-ground partitioning of legume N
  e[CO$_2$] often increases nodulation (but not always).
  Effects of N rhizodeposition?

• Subsequent availability of legume N

  Gross N mineralization rates unaffected by e[CO$_2$], but N immobilization
  can be 30% higher.

  In controlled conditions wheat obtained 11% of its N supply from
  previous field pea under e[CO$_2$] cf 20% under ambient conditions.

  Are these few results representative of other legume systems?

See also Session 4 paper 61
## Total N₂O emissions per growing season or year

<table>
<thead>
<tr>
<th>Category</th>
<th>Number of site-years of data</th>
<th>Measured emissions (kg N₂O-N/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>(171 in total)</td>
<td>Range</td>
</tr>
<tr>
<td><strong>Legume-based pasture</strong></td>
<td>25</td>
<td>0.10-4.57</td>
</tr>
<tr>
<td><strong>N-fertilized grass pasture</strong></td>
<td>19</td>
<td>0.30-18.16</td>
</tr>
<tr>
<td><strong>Crop legumes</strong></td>
<td>46</td>
<td>0.03-7.09</td>
</tr>
<tr>
<td><strong>N-fertilized crops</strong></td>
<td>48</td>
<td>0.09-12.67</td>
</tr>
<tr>
<td><strong>Soil: no legume or added N</strong></td>
<td>33</td>
<td>0.03-4.80</td>
</tr>
</tbody>
</table>

See also Session 4 Paper 67 & Poster 66

Application of $^{15}\text{N}$ to quantify losses of legume N

Mitigation of climate change - green-house gas emissions

**Further studies required**

- Identify the sources of N$_2$O emissions during legume growth

- Quantify the subsequent losses of N from legume residues
  
  N$_2$O *cf* losses of other forms of N?

- Determine the likely impact of future climates
  
  Effect of increased microbial immobilization of N under e[CO$_2$]? 
  Effect of higher temperatures &/or more variable rainfall?

See also Session 4 Paper 61,67 & Poster 66
Conclusions – Use of $^{15}$N to gain new knowledge

Adaptation to future climates – Impact of elevated CO$_2$

- N$_2$ fixation & below-ground partitioning of N
  - Quantify affects of e[CO$_2$]
  - Explore genetic variability in response
  - Determine how response is modified by GxExM interactions
- Subsequent availability legume N
  - Quantify importance of legume below-ground N for following crops
  - Define how soil N-dynamics in legume-based systems are affected by e[CO$_2$]
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Mitigation of climate change – Green-house gas emissions

- N$_2$O losses from legume-based systems
  - Confirm origin of N$_2$O release
  - Consider how N$_2$O emissions might be influenced by future climates
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<tbody>
<tr>
<td>Carbon</td>
<td>$^{12}\text{C}$</td>
<td>98.98</td>
<td>-20 to -34‰</td>
<td>$\text{C}_3$ photosynthesis</td>
</tr>
<tr>
<td></td>
<td>$^{13}\text{C}$</td>
<td>1.11</td>
<td>-9 to -17‰</td>
<td>$\text{C}_4$ photosynthesis</td>
</tr>
<tr>
<td></td>
<td>$^{14}\text{C}$</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Application of C isotopes for adaptation to future climates – More efficient use of variable rainfall

Use of $^{13}$C to identify improved water use efficiency

- $C_3$ plant species discriminate against $^{13}$CO$_2$ during photosynthesis
- Discrimination ($\Delta^{13}$C) is LESS in species or varieties which have GREATER transpiration efficiency.
- Greater transpiration efficiency (lower $\Delta^{13}$C) may result from:
  1. Lower stomatal conductance,
  2. Greater photosynthetic capacity,
  3. Some combination of these.

Identifying genetic differences in plant water-use efficiency (WUE)

\(^{13}\)C discrimination

- Has already been used as a selection tool
  - WUE by semi-leafless field pea superior to conventional genotypes.
  - Drought adaptation in peanut & cowpea.

- Comparative measures of WUE
  - Between seasons & between species.

*However, some legume studies have failed to find correlations with water use*

Further studies required

- Explain apparent inconsistencies
  - Intra- & inter-specific comparisons.
  - Define influence of environment, management & sampling protocols.

Application of C isotopes for mitigation of climate change – Quantifying contributions to C sequestration in soils

Following the fate of legume organic C – Contributions to soil C

• Exploiting differences in $^{13}$C content of $C_3$ & $C_4$ species
  Long-term lucerne (alfalfa)-maize rotations - >50% C in lucerne contributed to soil organic C cf <15% of C from maize residues

• $^{14}$C methodologies
  Quantify the extent of losses of C from legume residues & flow of C through different soil organic matter pools

Further studies required

• Quantify the effect of different strategies on rate of change of soil C stock
  Legumes or species combinations x management
  Influence of environment

How will soil C sequestration be affected by future climates?

The fate of organic C in e[CO₂] environments

- Meta-analysis of soil C affects under e[CO₂]: note – this is not legume specific
  - Total soil C increase by 4% on average, but dependent upon N supply
    - nil difference from ambient @ inputs <30 kgN/ha per year
    - +4% @ inputs 30-150 kgN/ha per year
    - +8% @ inputs >150 kgN/ha per year
  - Increase in soil C largely in labile C pools

Further studies required

- Determine how legumes influence soil C accretion under e[CO₂]
- Identify strategies to increase sequestration of organic C into more stable pools

Conclusions – Use of C isotopes to gain new knowledge

Adaptation to future climates – Efficient use of variable rainfall

- Can $^{13}$C discrimination be used to measure WUE by legumes?
  
  Explore genetic variability.
  
  Explain apparent inconsistencies between studies.
  
  Identify conditions & sampling protocols where $^{13}$C is most reliable.

Mitigation of climate change - Soil C sequestration

- Quantifying the fate of legume organic C
  
  Determine how rate of change in soil C is modified by GxE interactions.
  
  Define how soil C-dynamics are affected by e[CO$_2$].
  
  Evaluate whether it is possible to sequester more C into stable pools.