IAEA-CN-191-99

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

Mark Peoples & Ian Fillery

CSIRO Australia

Why legumes?

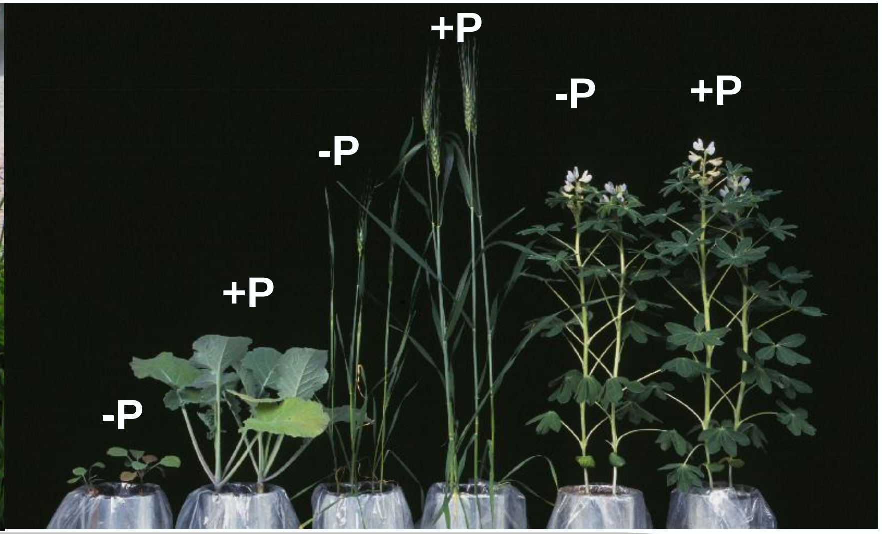
Food security & adaptation to future climates

- 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



See also Session 4 Poster 152

Photo: courtesy of Janet Sprent, Dundee, UK

Photo: courtesy of the late Peter Hocking, CSIRO

Source: Herridge *et al* (2008) *Pl. & Soil* **311**:1-18; Peoples *et al* (2009) *Symbiosis* **48**:1-17

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
- Underexploited legumes an untapped pool of genetic diversity for adaptation

- N content of foliage & seed protein not as affected by e[CO_2] as non-legumes

Source: Herridge *et al* (2008) *Pl. & Soil* **311**:1-18; Peoples *et al* (2009) *Symbiosis* **48**:1-17;
Rogers *et al* (2009) *Pl. Physiol.* **151**:1009-1016

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
- Underexploited legumes an untapped pool of genetic diversity for adaptation
- N content of foliage & seed protein not as affected by e[CO_2] as non-legumes

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

Source: Herridge *et al* (2008) *Pl. & Soil* **311**:1-18; Peoples *et al* (2009) *Symbiosis* **48**:1-17, Rogers *et al* (2009) *Pl. Physiol.* **151**:1009-1016; Jensen *et al* (2012) *Agron. Sustain. Dev.* **32**: 329-364.

Stable isotopes of Nitrogen

Element	Isotope	% Atmospheric abundance	Range in plants	Variable
Nitrogen	^{14}N	99.6337		
	^{15}N	0.3663	-2 to +26‰*	Plant species

*** $\delta^{15}N$ (‰) = 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

Source: Peoples *et al* (2009) *Am. Soc. Agron.* Monograph **52**: 125-170

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 :

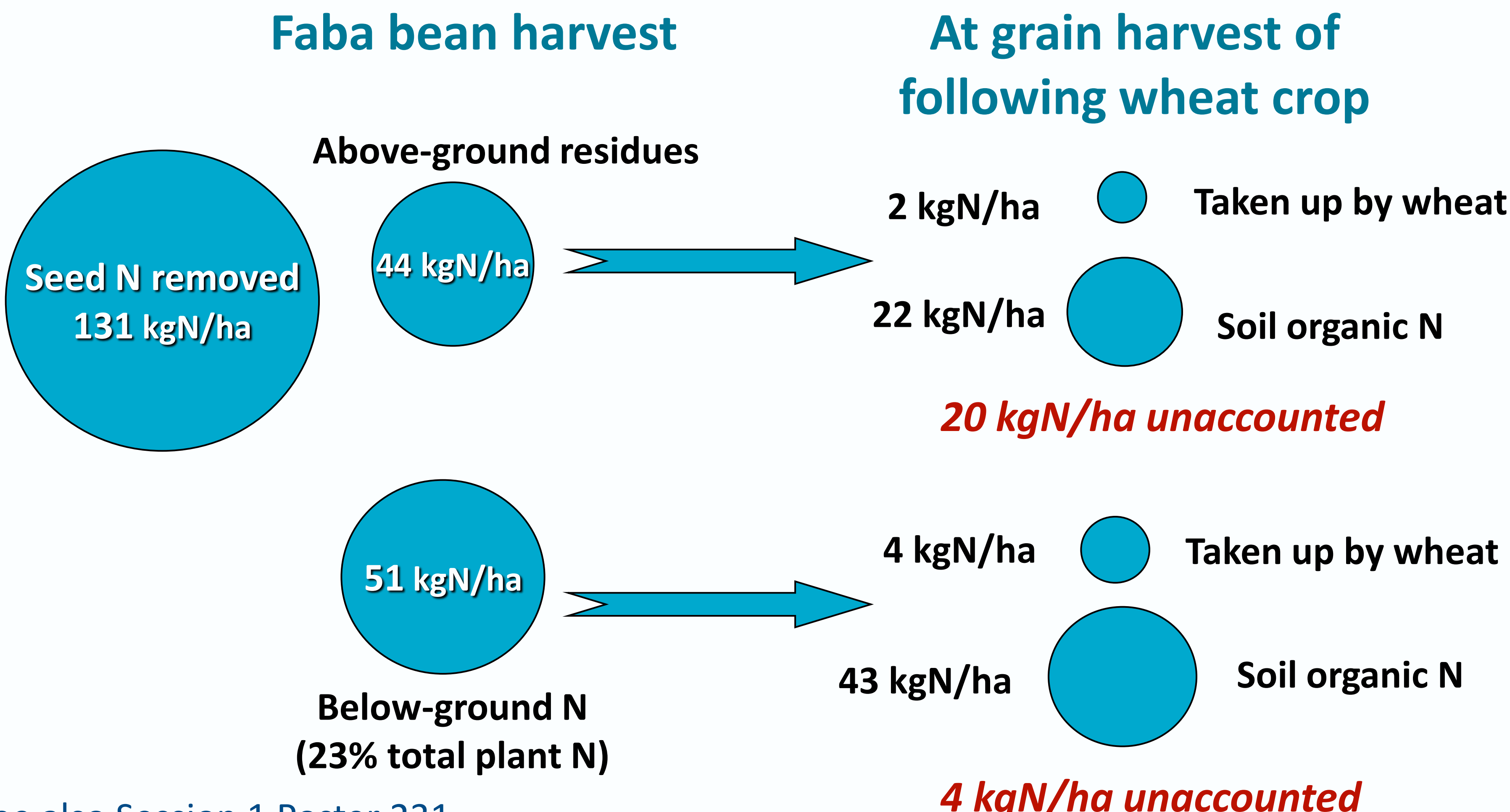
- **Low supply of available P**
- **Elevated temperatures**
- **What other factors?**

See also Session 1 Poster 187

CSIRO

Source: Lilley *et al* (2001) *New Phytol.* **150**: 385-395;
Lam *et al* (2012) *Crop & Pasture Sci.* **63**: 53-62; Fitzgerald *et al* (2012) *Proc. Aust. Agron. Conf.*

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



See also Session 1 Poster 231

Source: Khan (2000) PhD thesis University of Melbourne; McNeill & Fillery (2008) *Pl. & Soil* **302**: 297-316

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

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

Source: van Groenigen *et al* (2006) *Ecol. Studies* **187**: 373-391;
Rogers *et al* (2009) *Pl. Physiol.* **151**: 1009-1016; Armstrong *et al* (unpubl)

CSIRO

Total N_2O emissions per growing season or year

Category	Number of site-years of data (171 in total)	Measured emissions (kg N_2O-N/ha)	
		Range	Mean
Legume-based pasture	25	0.10-4.57	1.38
N-fertilized grass pasture	19	0.30-18.16	4.49
Crop legumes	46	0.03-7.09	1.02
N-fertilized crops	48	0.09-12.67	2.71
Soil: no legume or added N	33	0.03-4.80	1.20

See also Session 4 Paper 67 & Poster 66

Source: Jensen *et al* (2012) *Agron. Sustain. Dev.* **32**: 329-364.

Application of ^{15}N to quantify losses of legume N

Mitigation of climate change - green-house gas emissions

Further studies required

- **Identify the sources of N_20 emissions during legume growth**

- **Quantify the subsequent losses of N from legume residues**

  N_2O *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]

Conclusions – Use of ^{15}N to gain new knowledge

GRDC Grains Research & Development Corporation

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]

Mitigation of climate change – Green-house gas emissions

- **N_2O losses from legume-based systems**

    Confirm origin of N_2O release

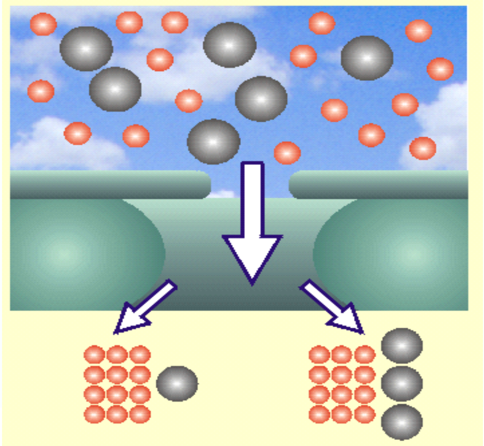
    Consider how N_2O emissions might be influenced by future climates

CSIRO

Isotopes of Carbon

Element	Isotope	% Atmospheric abundance	Range in plants	Variable
Carbon	^{12}C	98.98		
	^{13}C	1.11	-20 to -34‰	C_3 photosynthesis
			-9 to -17‰	C_4 photosynthesis
	^{14}C			

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

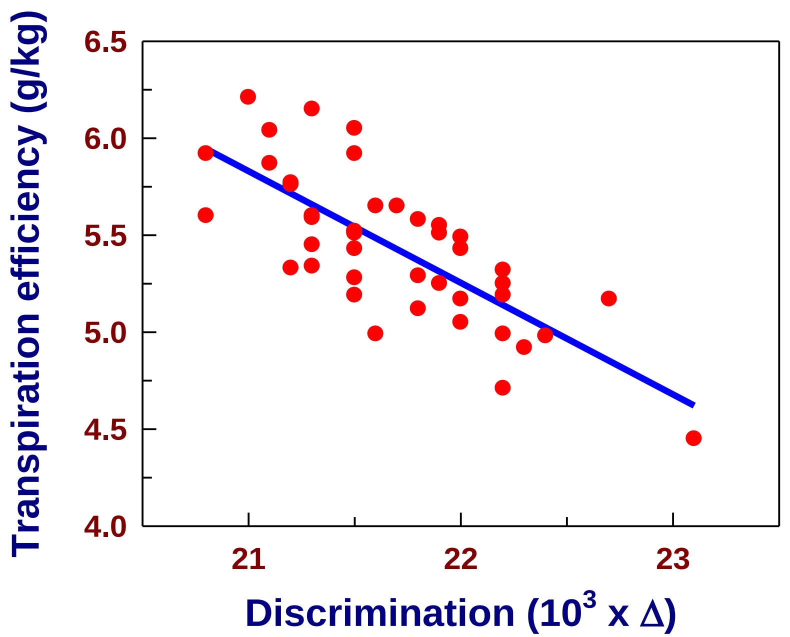
- Discrimination ($\Delta^{13}C$) is LESS in species or varieties which have GREATER transpiration efficiency.

- **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.

Source: Armstrong *et al* (1994) *Aust. J. Pl. Physiol*. **21**:517-532; Wright *et al* (1994) *Crop Sci.* **34**: 92-97; Hall *et al* (1994) *Field Crops Res.* 36: 125-131; Turner *et al* (2007) *J. Integ. Pl. Biol.* **49**: 1478-1483

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

Source: Gregorich *et al* (2001) *Can. J. Soil Sci*. **18**:21-31;
Bhupinderpal-Singh *et al* (2005) *Eur. J. Soil Sci.* **56**: 329-341

CSIRO

How will soil C sequestration be affected by future climates?

The fate of organic C in e[CO_2] environments

- **Meta-analysis of soil C affects under e[CO_2] :** ***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[CO_2]**
- **Identify strategies to increase sequestration of organic C into more stable pools**

Source: van Groenigen *et al* (2001) *Ecol. Studies* **187**:373-391

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 GxExM interactions.

  Define how soil C-dynamics are affected by e[CO_2].

  Evaluate whether it is possible to sequester more C into stable pools.