Pete Iannetta, James Hutton Institute
pete.iannetta@hutton.ac.uk

Novel Crops and Novel Cropping Systems (RD2.1.8)

Plant-Soil-Water Interactions (RD2.1.7)

Scottish Government
Riaghaltas na h-Alba
gov.scot

SEFARI

The Future of Scottish Agriculture: *an agroecological vision*

SEFARI

1. Sustainable growth in profits from agriculture
2. Agricultural supply chain resilient to shocks

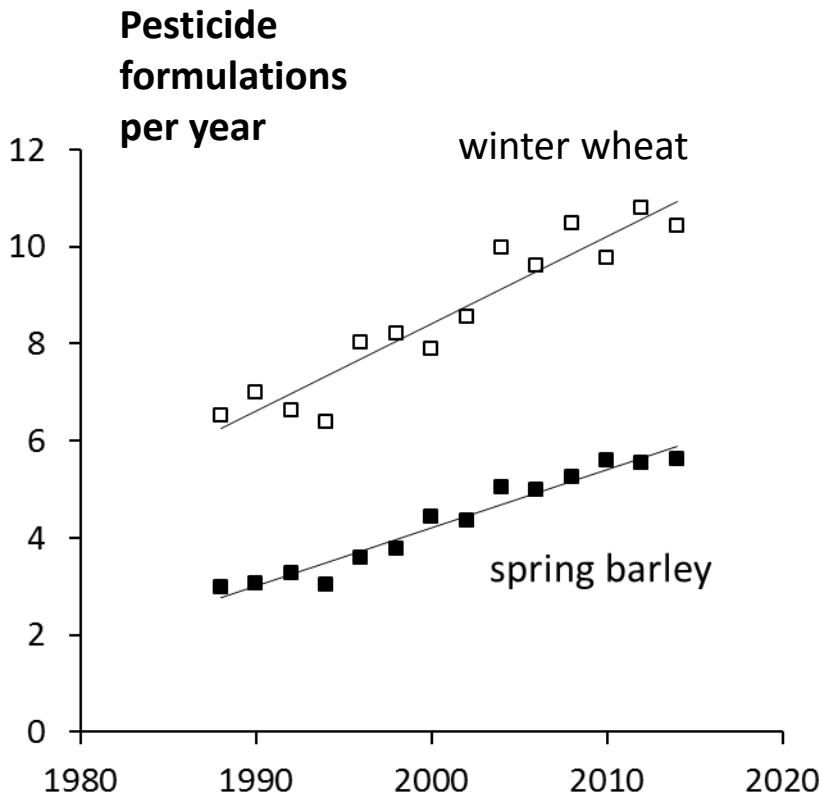
3. Training and skills for farmers to improve their profitability and be greener
4. Agriculture works as part of our food and drink sector

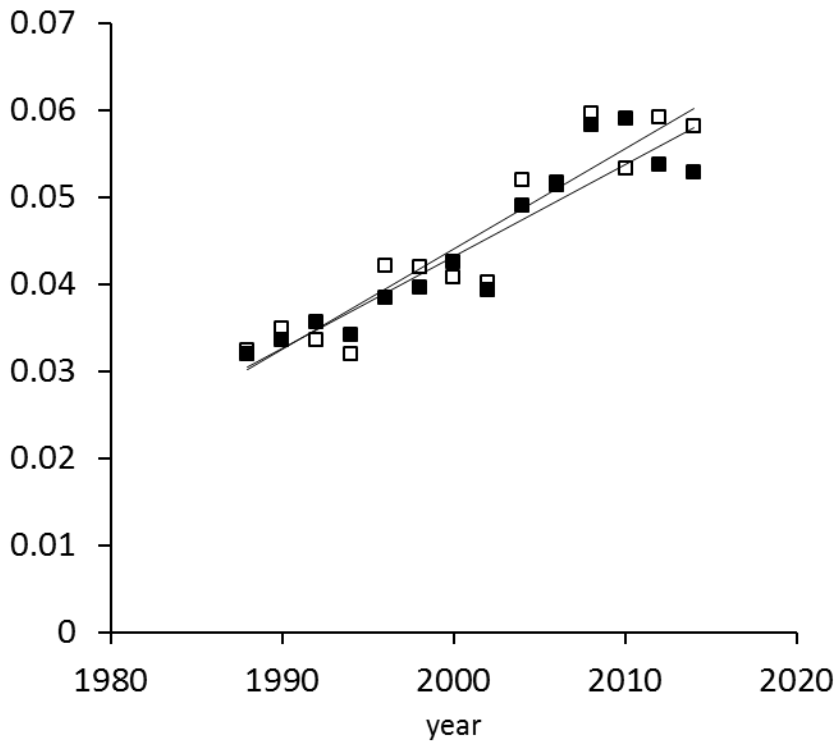
5. Farmers boost performance by embracing innovation and best practice
6. **Scotland is a world leader in green farming**

7. Agriculture recognised as a rewarding career, accessible to new entrants
8. Agriculture valued for its contribution to Scottish society

9. Scotland to take a leading role in agricultural issues in UK, EU and globally

While national yields flat-line….





Crops that get more nitrogen need more pesticide

Where are we now?

long term trajectories for inputs and crop yield

- Grain output peaked in the late 1980s despite innovation
- N fertiliser and pesticide = major pollutants
- No indication of any reduction in pesticide or N usage

LEGUMES ARE PRINCIPLE MEANS OF DISRUPTING OUR DEPENDENCE ON NITROGEN AND PESTICIDE

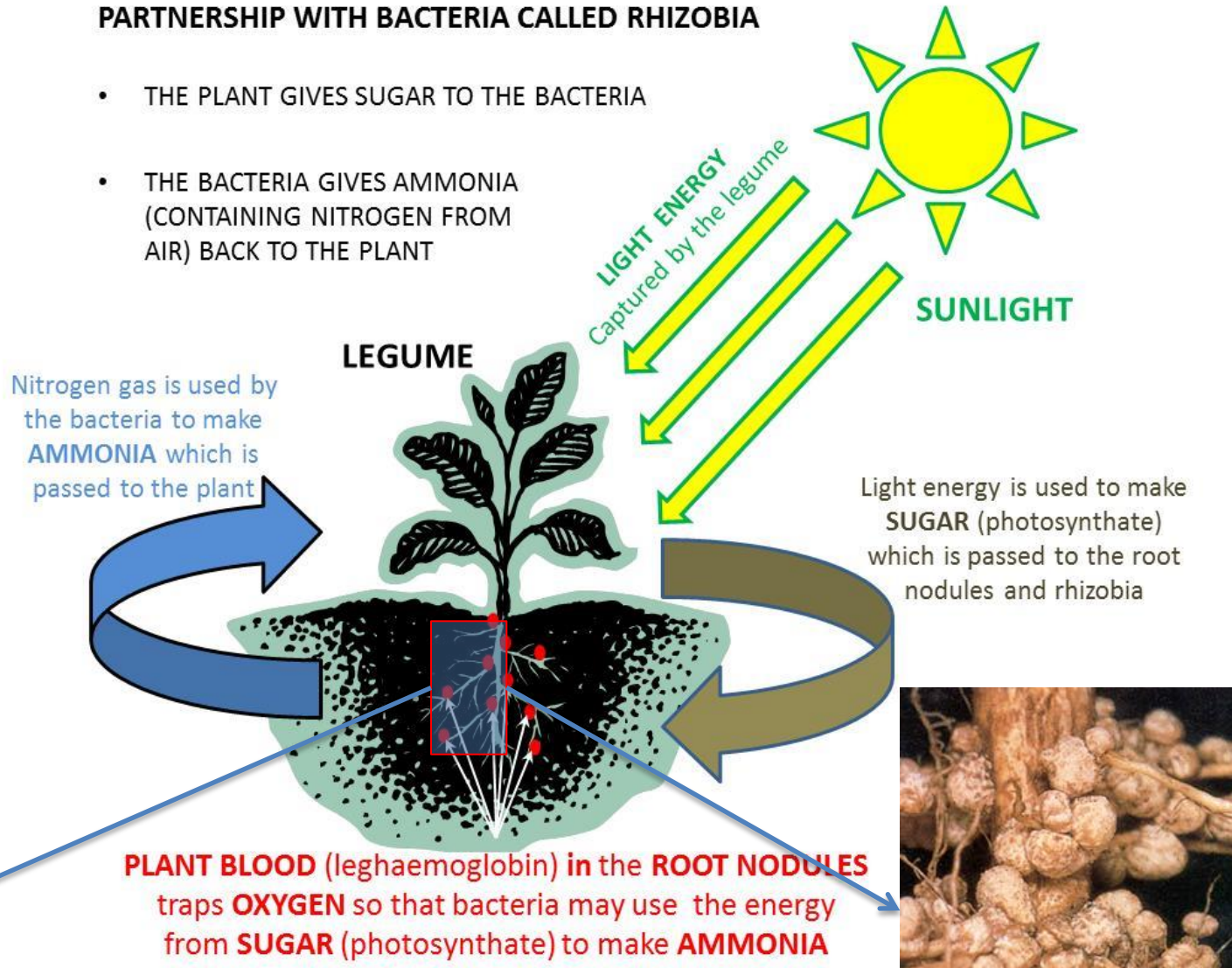
- The proportion of N fixation crops in the rotation is very low
- Legumes mainly for animal feed, and only 2-4% of acreage (70 y)
- Legume inclusion is very low compared to world leaders in sustainable ag.

BIOLOGICAL NITROGEN FIXATION (BNF)

LEGUMES NEED NO NITROGEN FERTILISER!

BIOLOGICAL NITROGEN FIXATION BY LEGUMES RELIES ON A SYMBIOSIS OR PARTNERSHIP WITH BACTERIA CALLED RHIZOBIA

- THE PLANT GIVES SUGAR TO THE BACTERIA
- THE BACTERIA GIVES AMMONIA (CONTAINING NITROGEN FROM AIR) BACK TO THE PLANT



"Symbiotic Microbiome"

(more that rhizobia)

There are two main classes of legumes

GRAIN – for feed and food

Peas (*Pisum*)

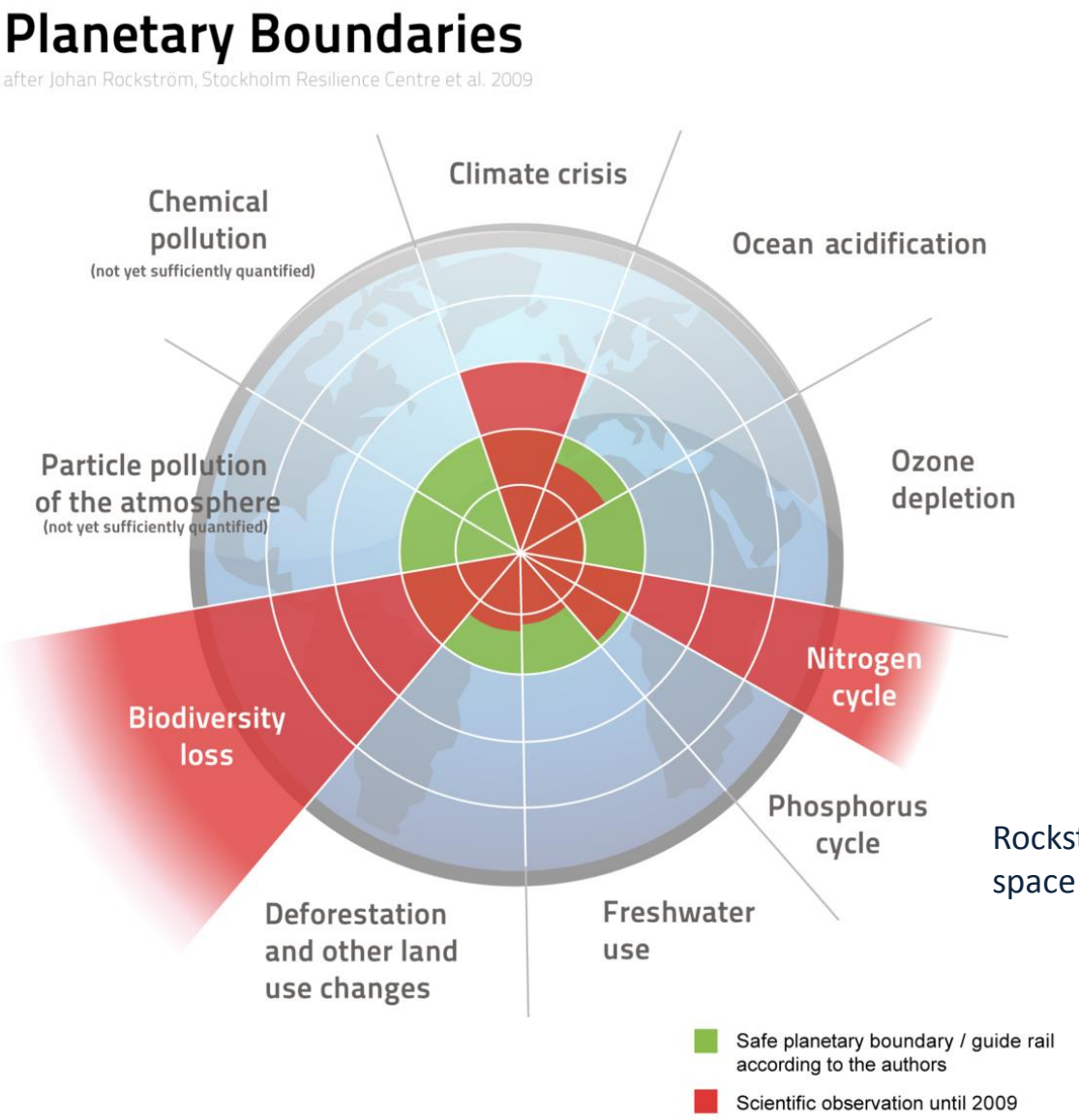
Faba beans (*Vicia*)

FORAGE - feed, green- & living-manures, cover crops

Clovers

Vicia spps

Transforming the nitrogen cycle

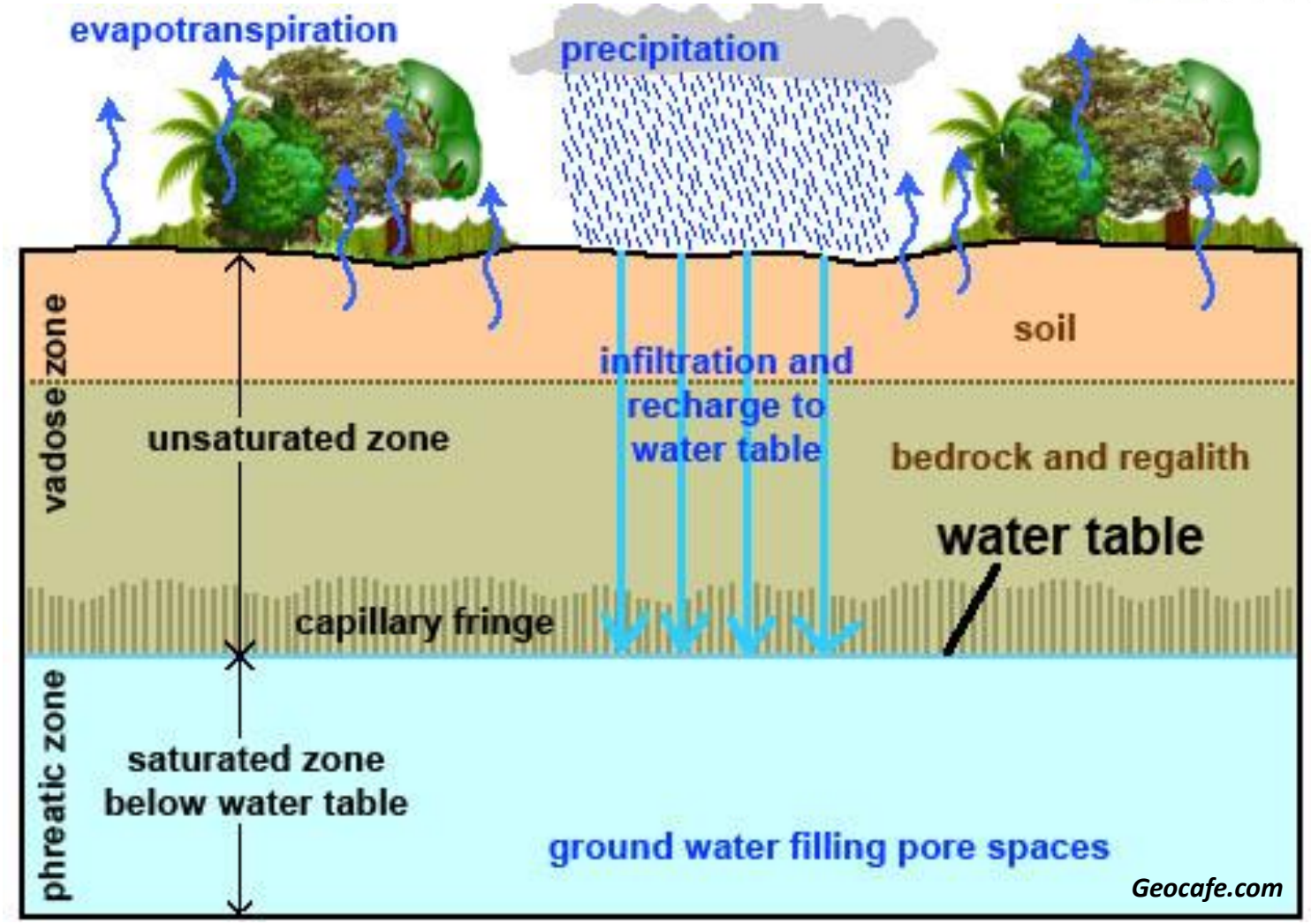


Planetary Boundaries

Rockström et al., (2009). A safe operating space for humanity. *Nature* **461**, 472.

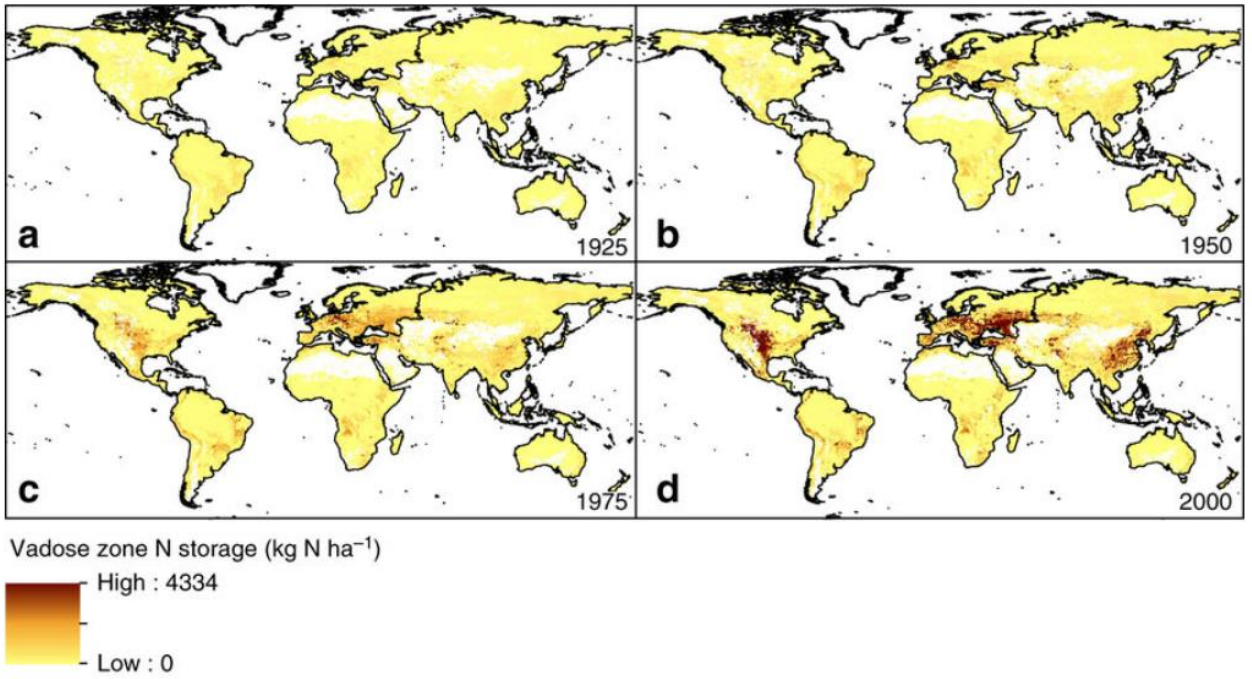
The “nitrate time-bomb”

SEFARI



The “nitrate time-bomb”

From: Global patterns of nitrate storage in the vadose zone



Spatial distribution of nitrate stored in the vadose zone. Global vadose zone N storage (in kg N ha^{-1}) is shown for 1925 (**a**), 1950 (**b**), 1975 (**c**) and 2000 (**d**)

Ascott, M.J., Gooddy, D.C., Wang, L., Stuart, M.E., Lewis, M.A., Ward, R.S., Binley, A.M. (2017) Global patterns of nitrate storage in the vadose zone. *Nature Communications*, *8*(1), p.1416.
https://www.nature.com/articles/s41467-017-01321-w
http://www.bbc.co.uk/news/science-environment-41945650

An analysis of legume supported crop rotations

SEFARI

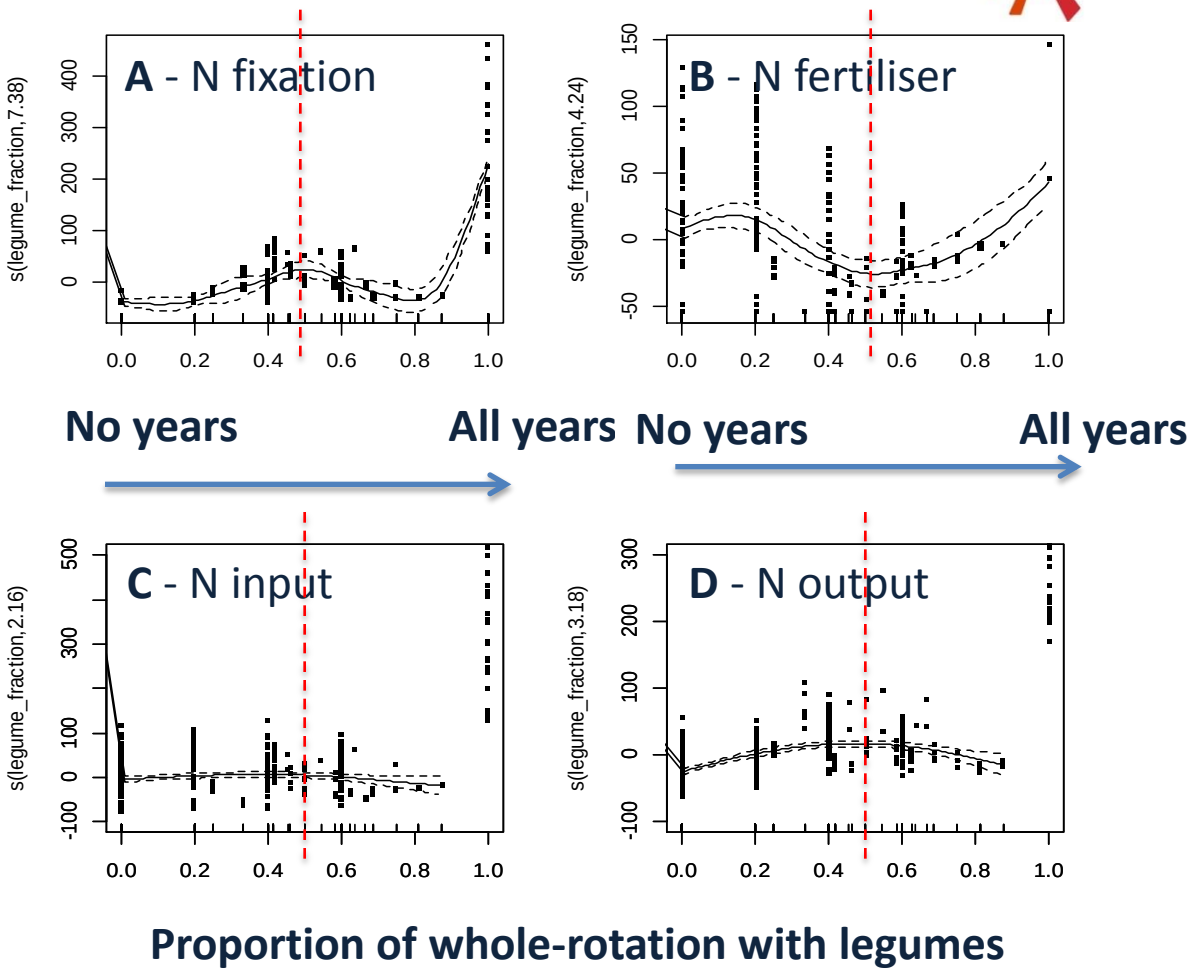
At 50% legume inclusion

A - BNF fixation peaked

B - inorganic N use lowest

C - N input greatest

D - N output peaked



Legume (BNF) supported systems need not compromise yield

www.legumefutures.eu

Conventional cropped systems:
barley in Scotland as a case study

SEFARI

- **~55% of the Scottish arable area is cultivated with mainly spring barley**
  - *This is a 'crop sequence' not a crop rotation in the intended holistic sense*

- ~½ is malted for use in the brewing & distilling
  - Beer and whisky production contribute **£10 billion** UK annual tax revenue
- ~½ is used for animal feed or meat production
  - Scottish meat export value ~£80 million
  - ~½ is used for animal feed or meat production

- ***Can INTERCROPPING with legumes 'green' barley production?***

Transitioning away from mono-cropping:

encouraging NUE, and diversification

SEFARI

If just UK barley was intercropped,….

….and in terms of accounting units which are tangible

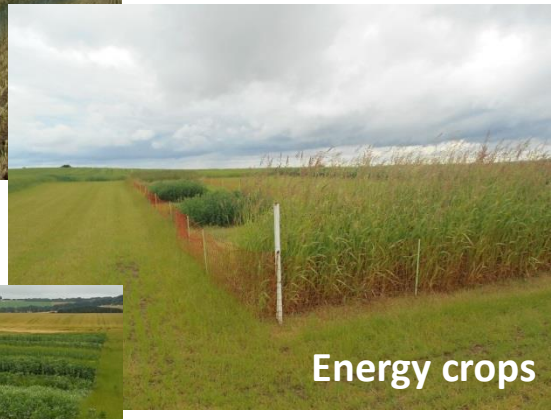
Equivalent No. cars removed from the /year	Intercropping barley contribution to total CO_2e of UK Agric.
176,000	**0.8%**

UK agriculture ~ 12 % of total UK emissions 54 Mt CO_2e

The savings listed here probably underestimated

- Fertiliser price is low (saving would be higher in future)
- Reduced pesticide applications of intercropping are not accounted
- Increased yield and yield qualities of intercropping are not accounted
- Improved soil qualities are not accounted

Crops and intercrops with diverse / multifunctional end-uses



- **Food / feed / bedding**
- **Energy -** AD process
  - grass/ legume feedstocks
- **Protein -** replace soya imports
  - Range of species combinations
  - No drying nec. for silage
- **Environmental**
  i. biodiversity, soil and nutrient use efficiency

Pathways to Impact

There are many practical examples of co-innovation and dissemination

Dissemination at KT events

i. Presentations, Farm Advisory Service, SRDP
ii. Demonstrations, Cereals in Practice, EU-PLAID,
iii. Education, Student groups, school visits, teaching packs

PLAID
PEER-TO-PEER LEARNING:
ACCESSING INNOVATION
THROUGH DEMONSTRATION

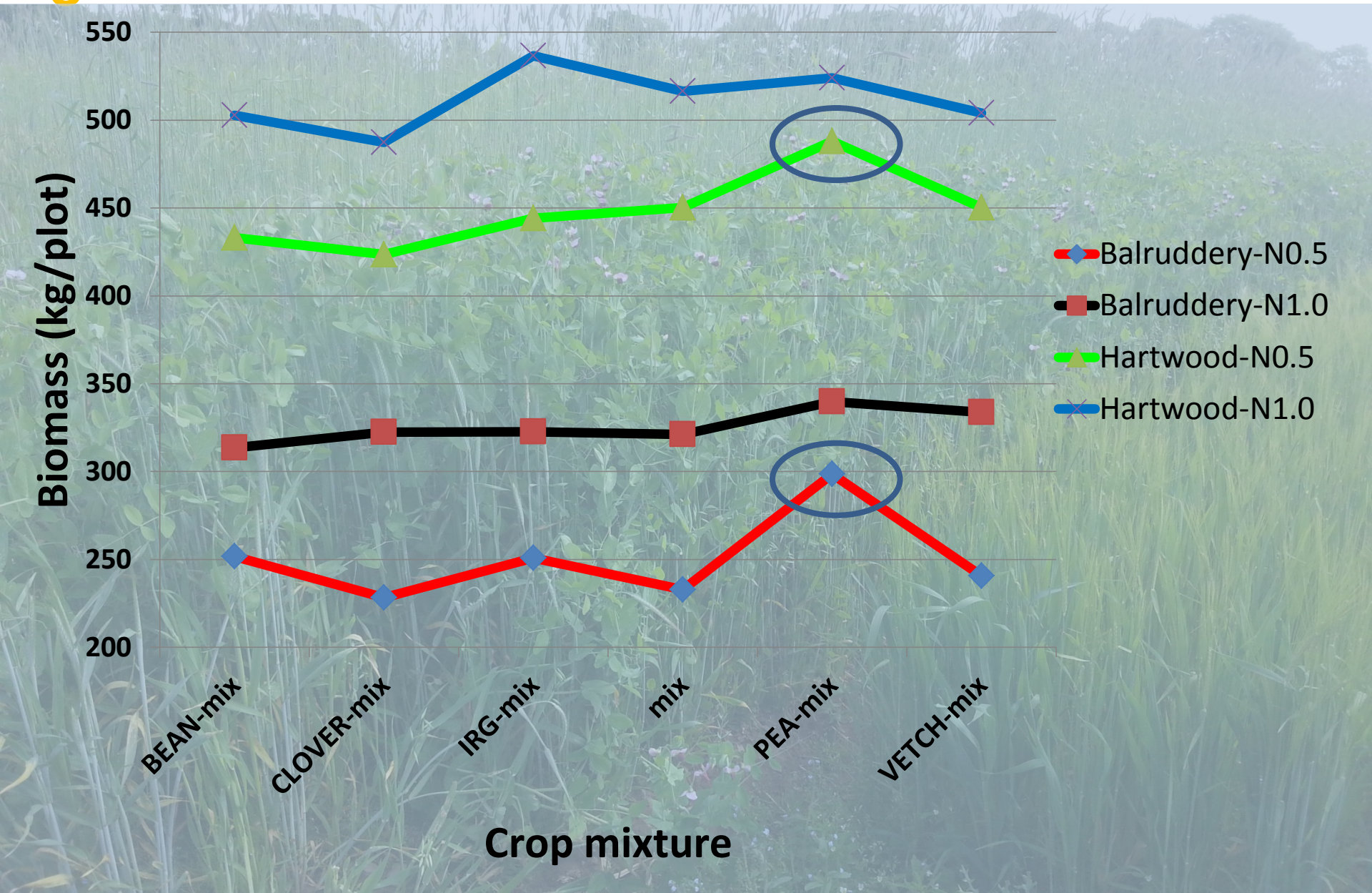
Forthcoming examples

- Association of Applied Biologists
  Advances in Legumes Science & Practice (Glasgow, 3/18)

- Legume Innovation Workshops
  (Annually 2017-21, EU-TRUE, next week at PGRO)

TRUE

Legume supported production across agricultural LCA classes



Examples - directing policy

SEFARI

RD2.1.8 outputs to help direct policy :

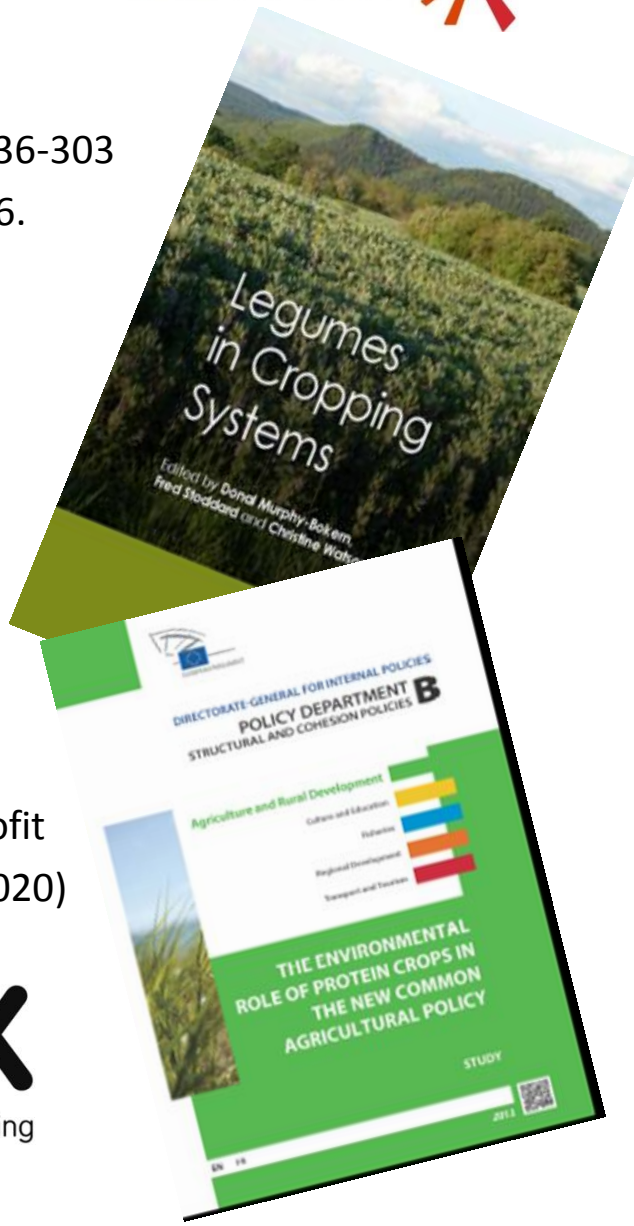
- Grain legume production and use in Europe. *Adv. Agron.* **144**, 236-303
- Can legume farming survive in Europe? *Agron. Sus. Devel.* **36**, 26.

Committees

- Scottish Organic Forum
- Scottish Government CAP Greening Group

KE messages

- CAP greening and protein crop demonstration plots (CiP)
- AHDB Roadshows 2017 (4 events across Scotland)
- NE Organic Discussion Group
- Elgin Arable Group - Cropping Alternatives for Efficiency and Profit
- Farmer participatory research - WP2.1.8 staff in EU-ReMIX (H2020)



ReMIX

Species mixtures for redesigning European cropping systems

Examples of current EU-funded projects which add value

TRUE (2017-21)

- ***TRansition paths to sUstainable legume-based systems in Europe (SFS - €5m)***
- **www.TRUE-project.eu,** Hutton-Agroecology Coordinating, SRUC WP Leaders

DIVERSify (2017-21)

- ***Designing InnoVative plant teams for Ecosystem Resilience***
- ***and agricultural Sustainability (SFS - €5m)***
- **www.plant-teams.eu,** Hutton-Agroecology Coordinating

TomRes (2017-21)

- ***Breeding crops for nitrogen and water stress tolerance (SFS - €6m)***
- **www.TOMRES.eu ,** Uni. Turin, Italy Coordinating
- JHi-Agroecology WP4 Leaders, Nutrient and Water Use Efficiency

NASSTEC (2014-2018)

- ***Native Seed Science, Technology and Conservation (Marie-Curie ITN; €3m)***
- **www.NASSTEC.eu,** MUSE, Trento, Italy Coordinating
- Hutton-Agroecology Coordination Team & Training Coordination

Salmon farming in the Scotland:
the potential of field beans

SEFARI

Scottish Salmon

- Scotland's second largest export

- £600m at farm gate

- Feed Conversion 1.25
- Salmon feed high in grain legume protein

- **To serve just Scottish aquaculture, beans need grown 1/12 (~8% of rotation)**

- Faba bean concentrates (50%+) required

www.beans4feeds.net

Breeding beans for key traits - germplasm collection

- **Germplasm collection (400 types) screened**
- **239 grown over 5 y**
- **Seven lines with consistently high N content were identified**
- **Early and short type (for intercropping?)**

Protein-N (%)	2012	2013
Early_Longpod	30.39	32.68
ILB_287	30.41	35.10
ILB_369	30.57	32.86
Closed_Flower	31.84	35.80
Martock_Bean	31.94	35.30
Dacre	32.90	36.80
Crimson_Flower	33.01	35.74


ILB287

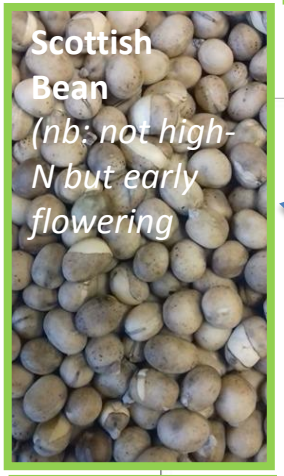

Martock Bean


ILB369

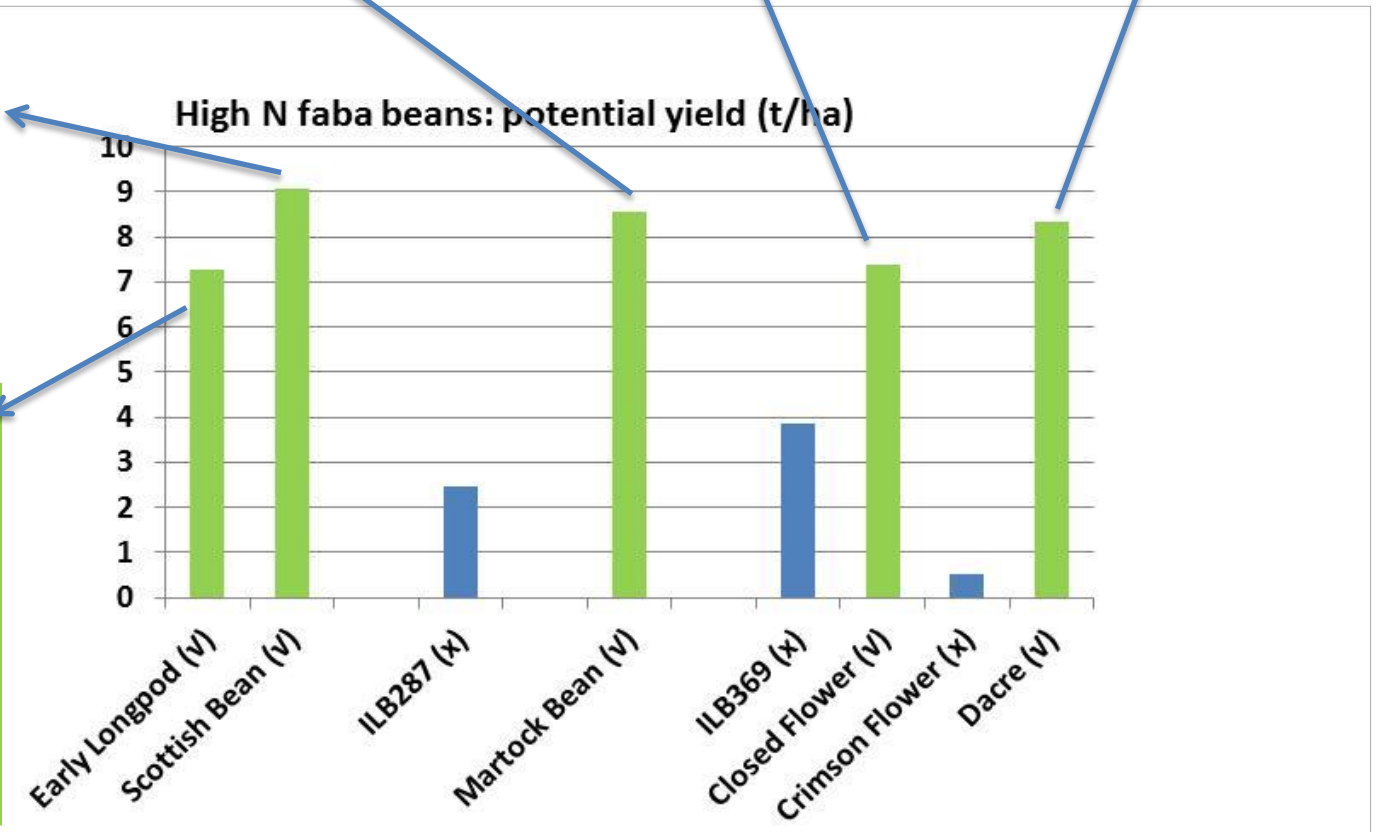

Closed Flower


Crimson Flower


Dacre

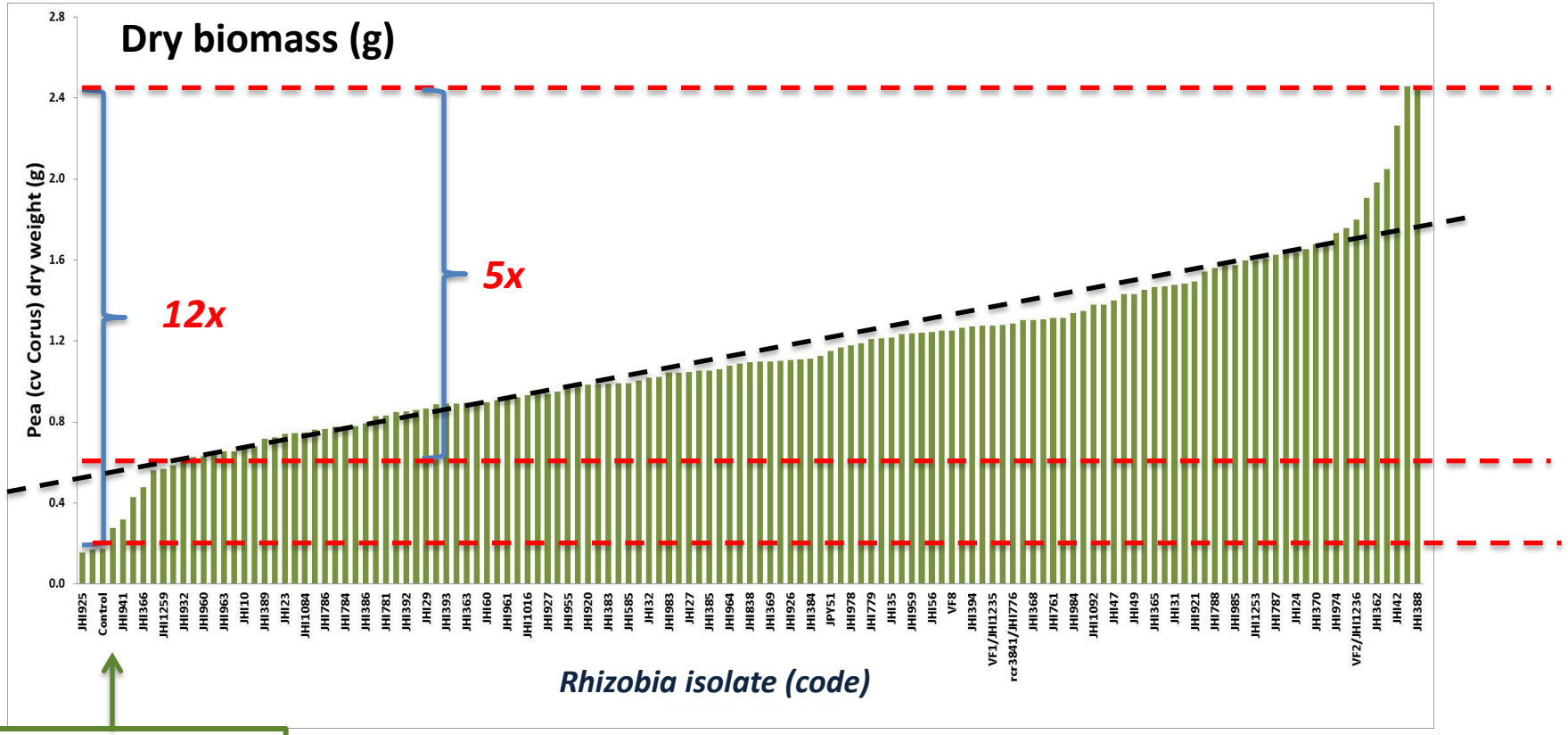

Scottish Bean
(nb: not high-N but early flowering


Early longpod


High N faba beans: potential yield (t/ha)
10
9
8
7
6
5
4
3
2
1
0
Early Longpod (√)
Scottish Bean (√)
ILB287 (x)
Martock Bean (√)
ILB369 (x)
Closed Flower (√)
Crimson Flower (x)
Dacre (√)

Greenhouse screening of elite rhizobia

(pea cv. Corus biomass increase 0-60d)



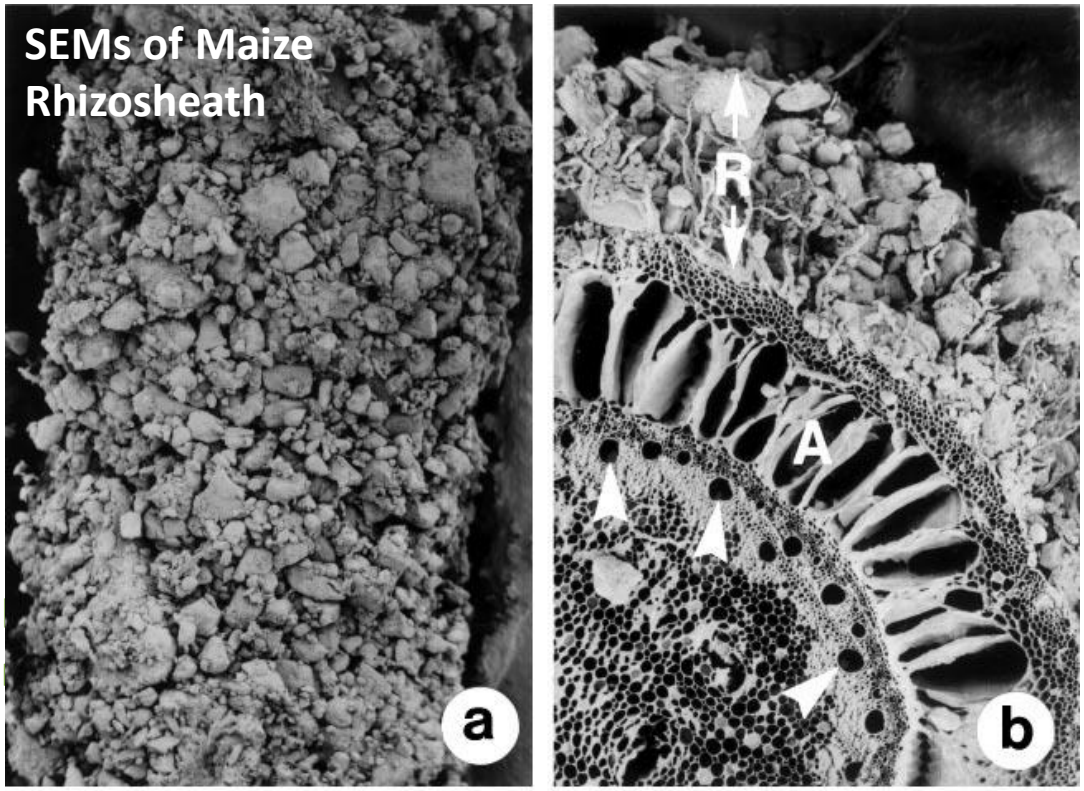
Existing commercial strains

Root Traits for Agricultural Sustainability: The Rhizosheath

SEFARI

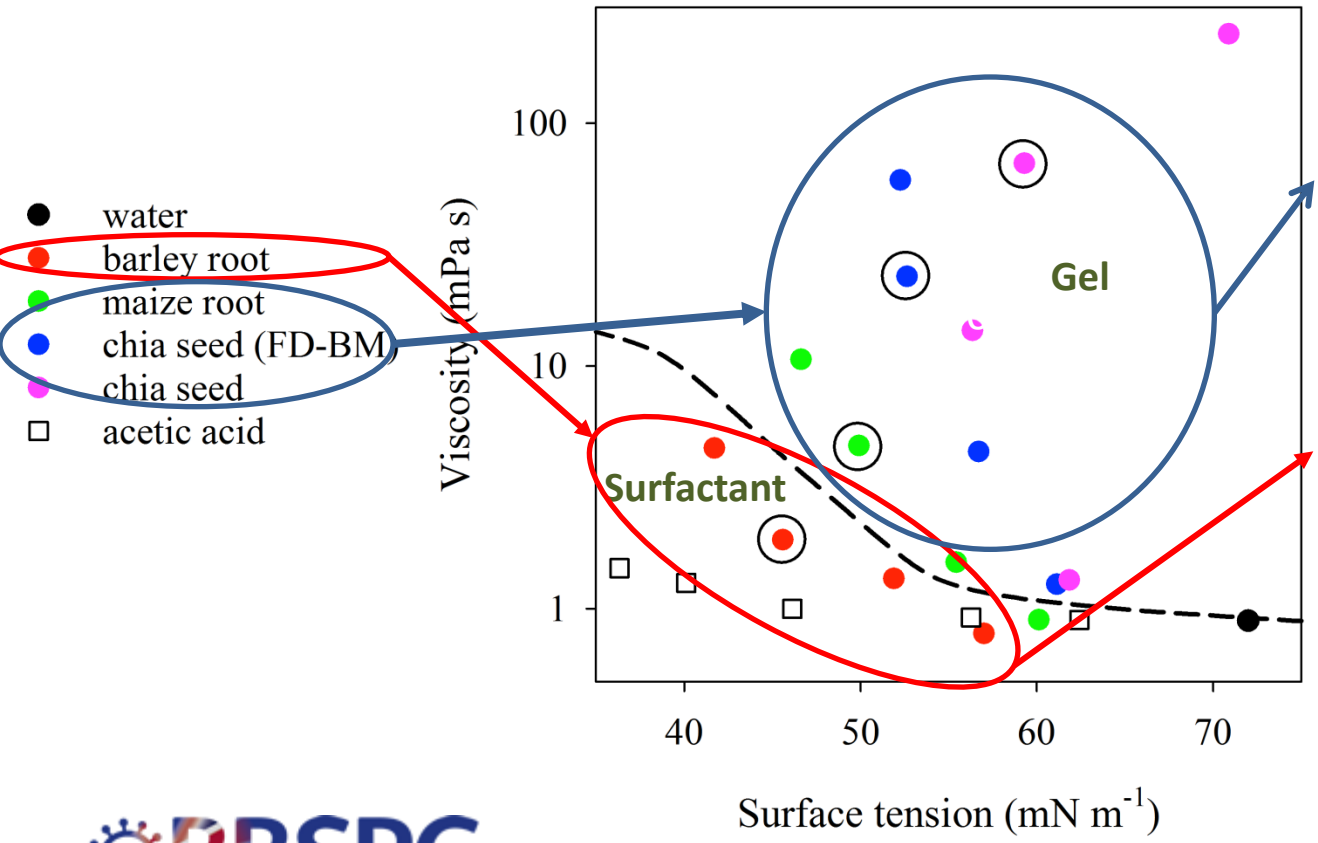
Aristida pungens – Sahara, North Africa

"a peculiar sheath of agglutinated particles of sand"



Rhizosheath formation is a function of root-hairs and -mucilage

Rhizosheath formation and function



Gel

- Increases soil water retention
- Maintains soil structure
- Lower N_2O emissions

Surfactant

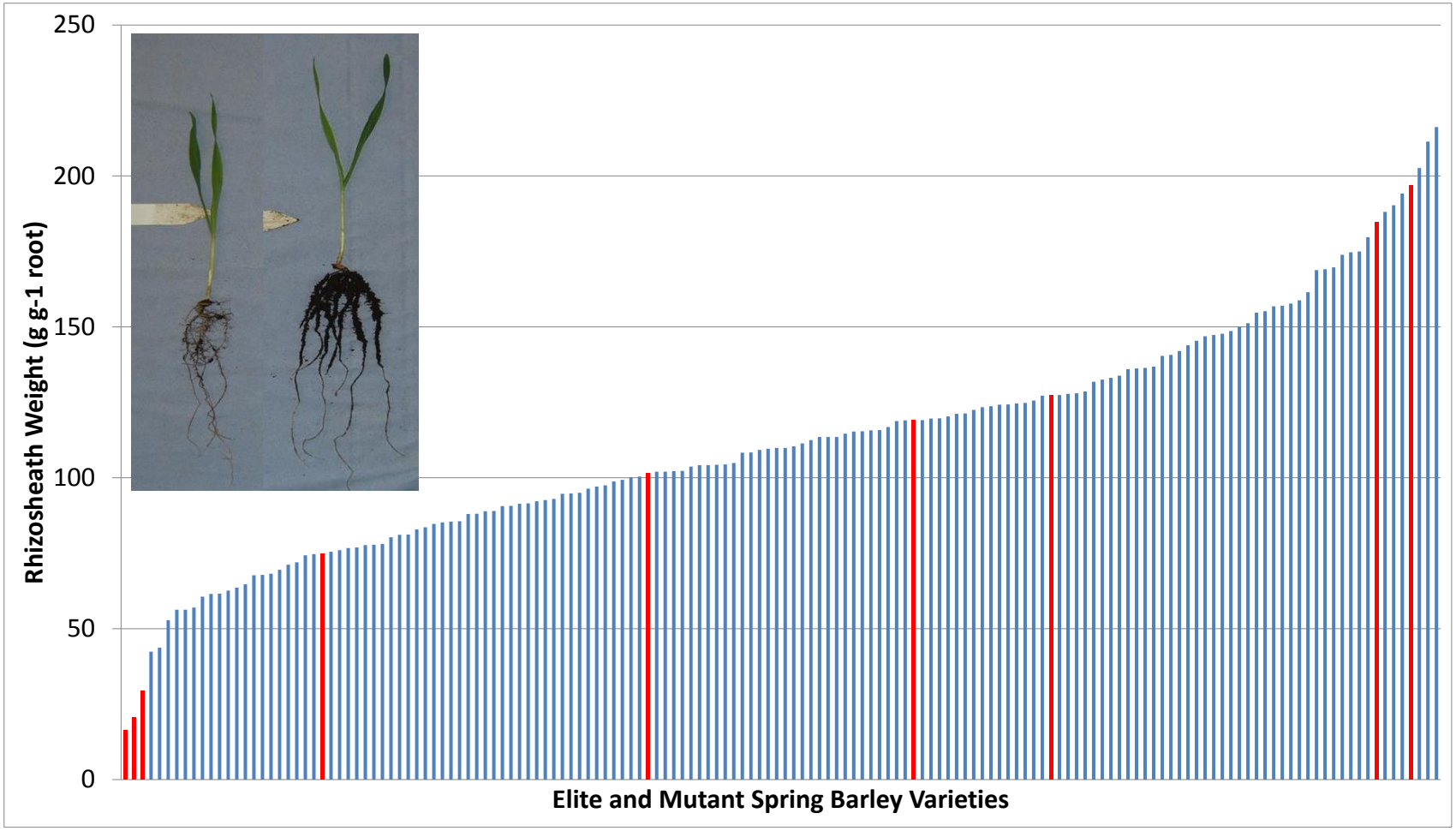
- Lower soil water retention
- Unstable soil structure

BBSRC 20 Years of Pioneering Great British Bioscience

SSP Soil Security Programme

1495 UNIVERSITY OF ABERDEEN

Large genotypic variation in rhizosheath weight (barley)



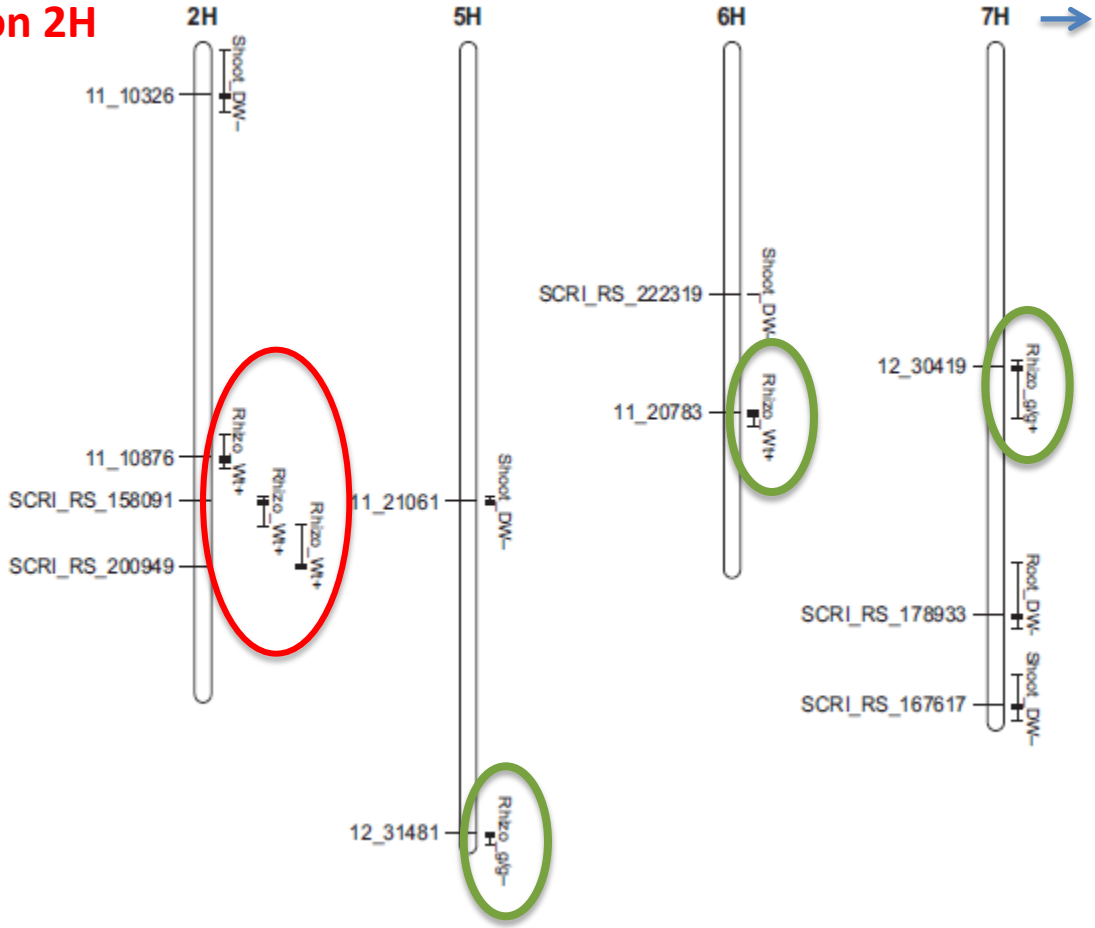
144 Genotype = 12.1-fold variation (mutants - red)

5.1-fold variation (association population - blue)

Rhizosheath has been genetically mapped to chromosome 2

Putative candidate genes include:

- **calcium/calmodulin-dependent protein kinase (OsCDPK7)** → **Drought tolerance**
- **glutamate receptor (GLR3.1)** → **Root elongation**
- **QTL's on 2H** → **Root length, Root dry weight**



Other significant loci on 5, 6 and 7. What do these represent?

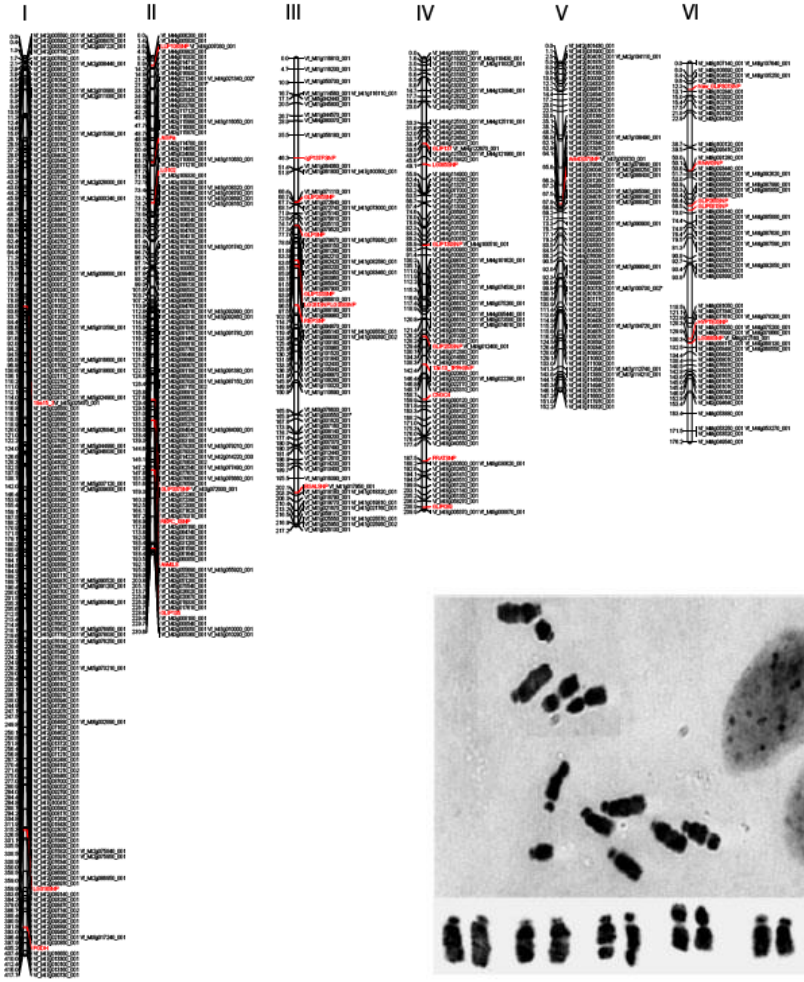
Vicia faba L. genetic mapping - of key traits

Plant Biotechnology Journal

Plant Biotechnology Journal (2016) **14**, pp. 177–185 doi: 10.1111/pbi.12371

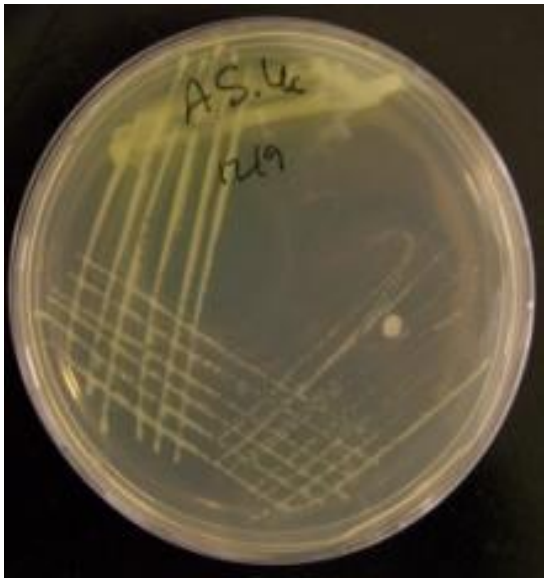
A SNP-based consensus genetic map for synteny-based trait targeting in faba bean (*Vicia faba* L.)

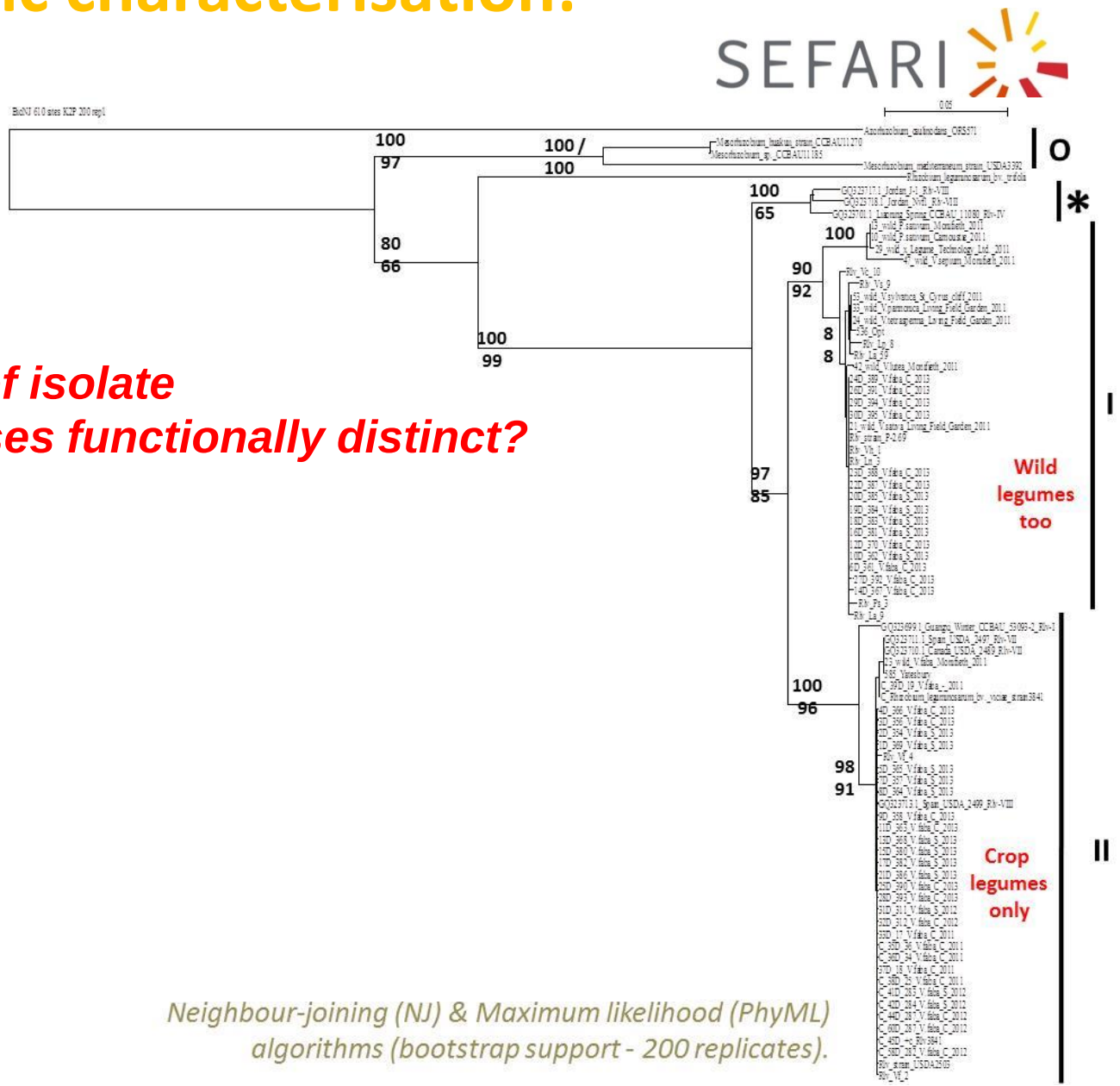
- Genome size ~13000 Mb not yet sequenced
- 687 SNP markers
- delineates the six chromosomes of bean
- SNPs = standard genotyping tool in breeding
- KASP™ assay - robust clean data
- 150 SNPs identified for genome wide markers
- Mapped against model legume
  Medicago truncatula



Rhizobial genetic characterisation:

- ***2 main classes of isolate***
  - are they classes functionally distinct?





Neighbour-joining (NJ) & Maximum likelihood (PhyML) algorithms (bootstrap support - 200 replicates).

Nutritional Quality, Innovative Farming and Novel Products

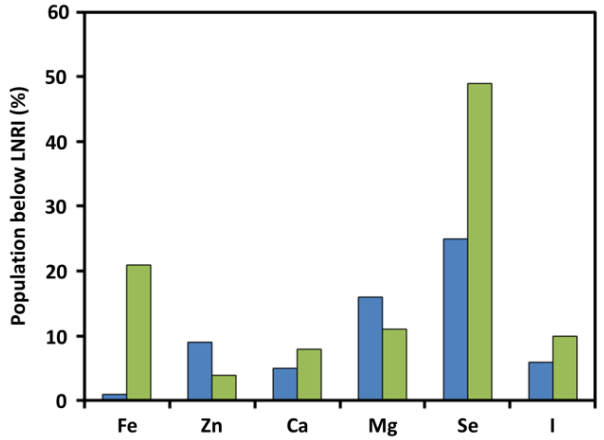


Figure 1. Proportion of the UK population aged between 18 and 65 with dietary mineral intakes less than the Lowest Reference Nutrient Intakes (LRNI). These people have a high risk of mineral deficiency. Blue = Men. Green = Women. [Data from: Bates et al. (2014) National Diet and Nutrition Survey: Results from Years 1–4 (combined) of the Rolling Programme (2008/2009-2011/2012)]

- **Novel Products & Processing**

- UK diets lack sufficient minerals, fibre, ….
- ….resistant starches, key secondary metabolites
- This affects health, well-being, NHS, GDP…

How can the opportunities for sustainable protein be realised?

fava bean

buckwheat

hemp

pea

lupin

Previous Strategic Partnership – 2011-2016*

- crops fully characterised
- acute human study informed on bioavailability/metabolism
- highly-controlled short RCT, microbial health
- chronic study, biomarkers of human health

… rolled over into SRP 2016-2021

Current Focus:

Integration into Food Supply Chain/Public Engagement

Progressing Novel Technologies

Developing Food Formulations and Reformulation Strategies

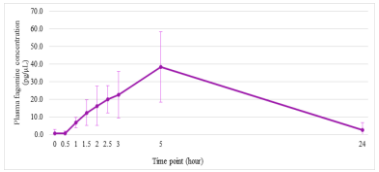
How can the opportunities for sustainable protein be realised?

SEFARI

buckwheat

Valuable bioactives being developed as food formulations

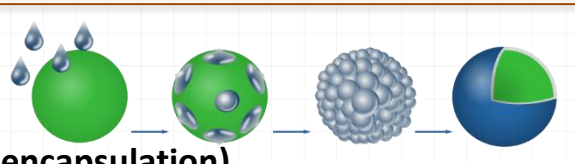
- **fagomine**
- **myo-inositol**



fava bean

Revalorisation of co-products

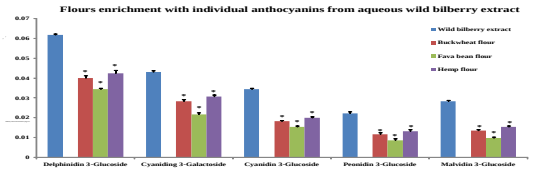
- **Extraction Technologies (Protein Extraction, Microencapsulation)**



hemp

Matrix for novel protein-rich food formulation

- **anthocyanin-rich, low sugar**



pea

Bioactive spermidine (gut health)

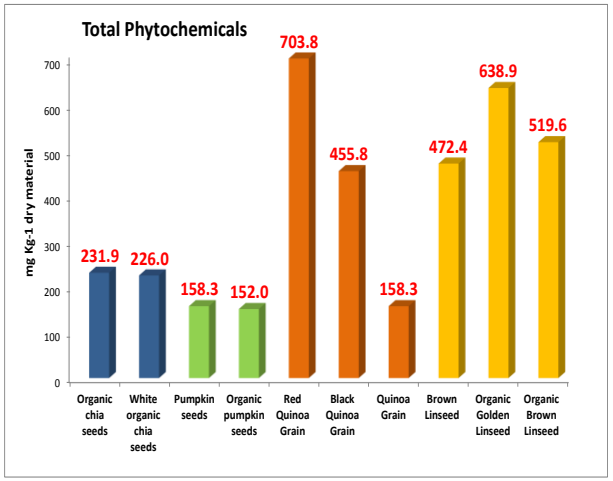
- **microbial metabolites identified (in vitro)**
- **correlation with human study data**

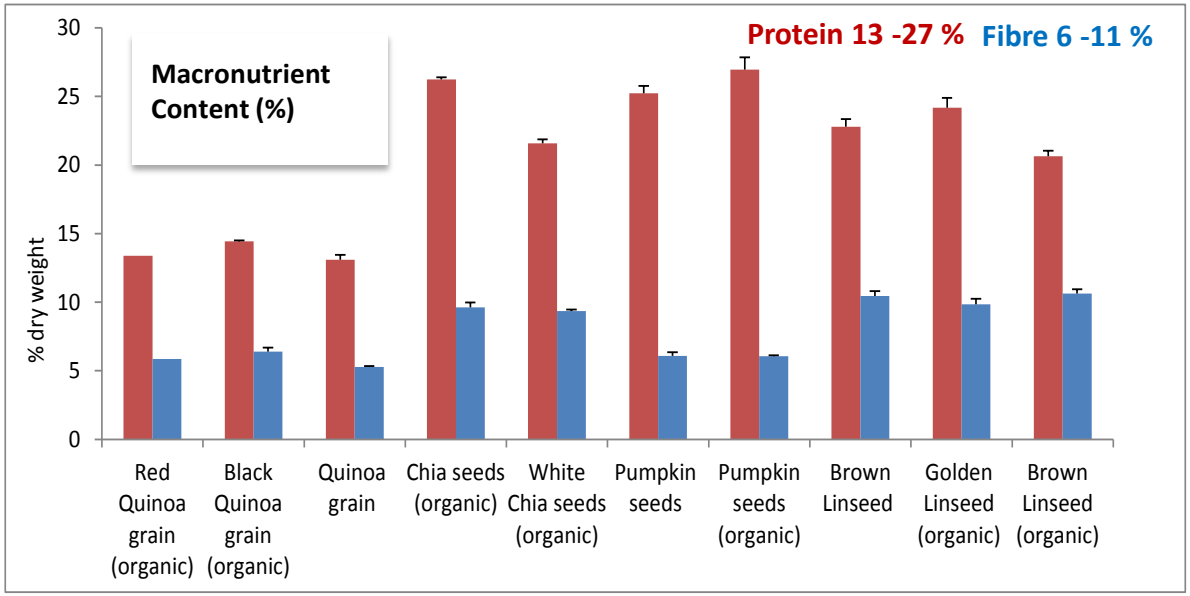
lupin

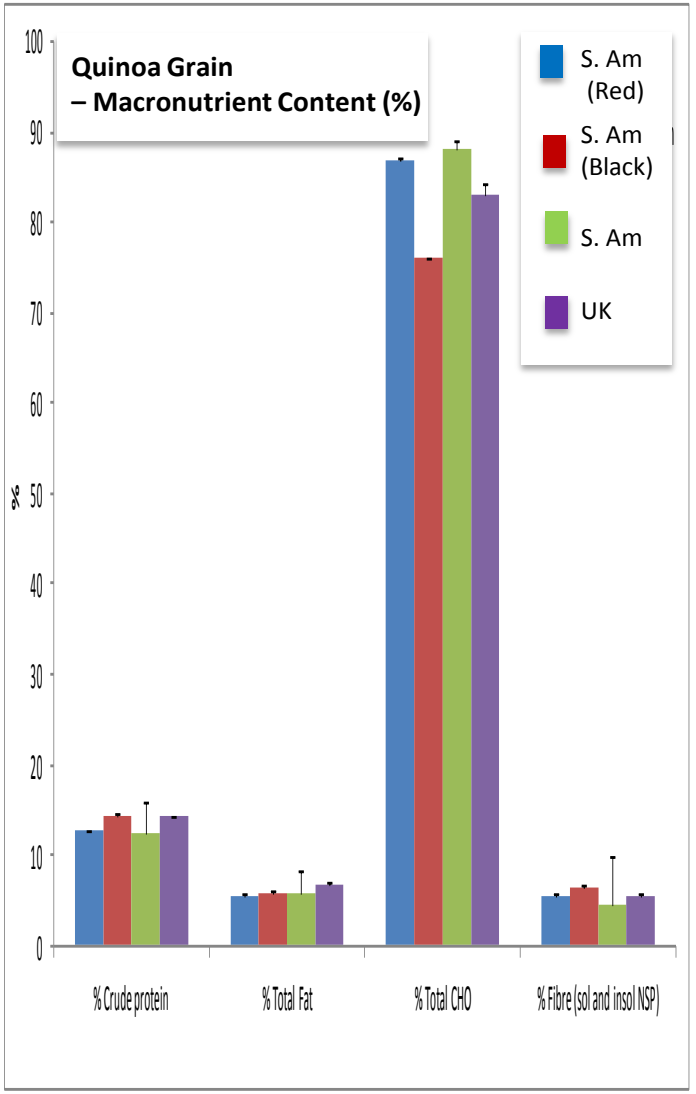
All products going forward are gluten-free and non allergenic

Are there non-native species that could be valuable for Scotland?

- quinoa, chia, pumpkin, linseed

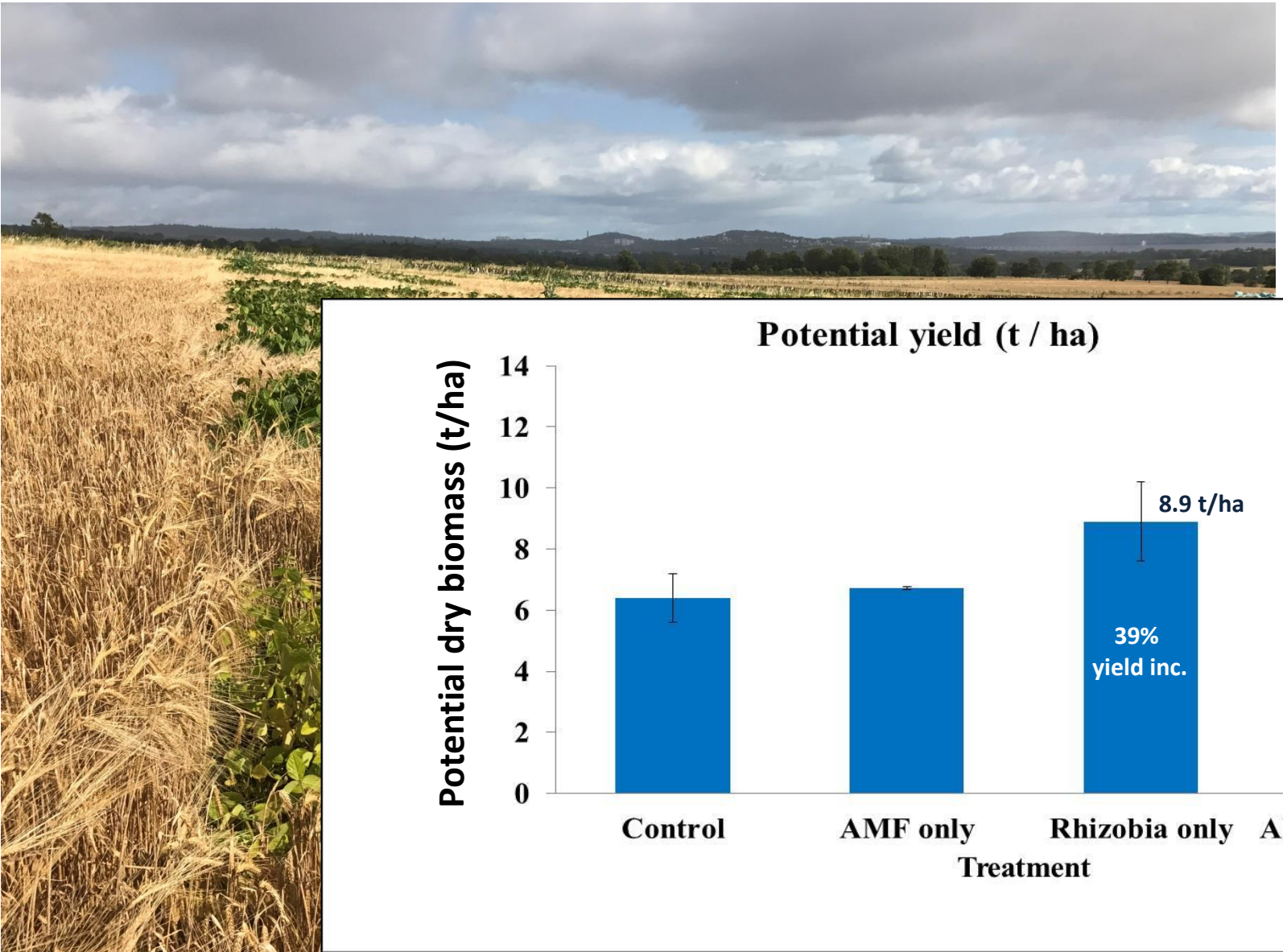






Non-traditional crops:
soybean in Scotland?

Non-traditional crops:
soybean in Scotland?



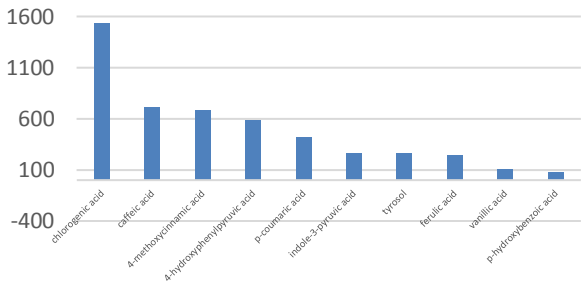
Nutritional benefits delivered through utilisation of wild species?

SEFARI

Wild Crops

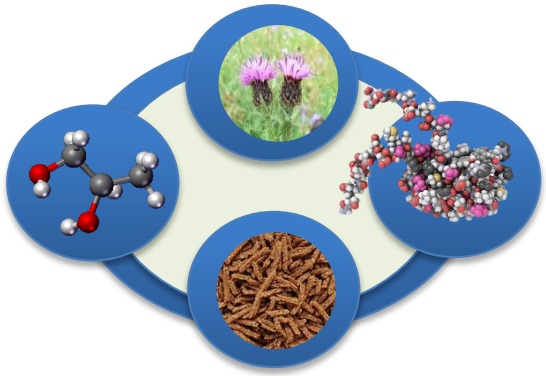
- grow on marginal lands (urban areas too)
- Minimal / no inputs
- natural bioactives (flavours, pesticides)





Species selection informed by SEFARI think tank

Circular Bio-refinary Approach



Developing novel processing technologies

Full characterisation to realise potential

Stakeholder engagement barriers/opportunities

Aligns with global projects (Moringa)

BBSRC bioscience for the future

GCRF Global Challenges Research Fund

NASFAM

LUANAR

ENVIRONMENT AFRICA

NABW National Association of Business Women

THE HUNGER PROJECT

Some acknowledgements

(a snap-shot)

MANTERRA LTD
LEADERS IN THE FIELD

THE BRITISH QUINOA COMPANY

SEFARI

Limagrain
United Kingdom

Genomia Fund

Plant Works

EWOS

Innovate UK
Technology Strategy Board

BioMar

marineharvest
excellence in seafood

ARBIKIE
HIGHLAND ESTATE

Harbro
QUALITY LIVESTOCK NUTRITION

LEGUME
Technology Ltd

PGRO

Legume Futures

Scottish Government
Riaghaltas na h-Alba
gov.scot

Faba bean official ales

- Edin.Inter.Sci.Fest. 2015 & ’17
- Limagrain (Cereals 2017)

SEFARI

- **Examples given are not simply novel academic products or approaches**
- **There is high commercial potential in the high protein co-products too**
- **Effort aims to ensure efficient, green and profitable food systems**

Lead Contributors

SEFARI

RD2.1.7

- Hutton, George & White *et al.,*

The James Hutton Institute

RD2.1.8

- RINH, Russell *et al.,*
- SRUC Walker *et al.,*
- Hutton, Newton *et al.,*
- BioSS, Hackett *et al.,*
- *RBGE, Hollingsworth et al.,*
- *Hutton, Stewart et al.,*

The Rowett Institute

SRUC

BioSS

Royal Botanic Garden Edinburgh