Legumes supported food- and feed change in Scotland as a case-study

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Twitter: AgroEcoAtJHI

The James Hutton Institute
Science connecting land and people
The James Hutton Institute has 5 main sites

- **Balruddery Farm, Angus**
  - Arable farm 350 ha
  - Site of the Centre for Sustainable Cropping

- **Hartwood Research Station, Lanarkshire**
  - 350ha rotational and permanent grassland, moor and woodland

- **Craigiebuckler, Aberdeen**
  - Laboratories

- **Invergowrie, Dundee**
  - Laboratories, glasshouses and arable land (300 ha)

- **Glensaugh, Kincardineshire**
  - 865ha rotational grassland, permanent pasture, heather moor and peat
The institute is named after James Hutton (1726-1797)  
Geologist - Naturalist - Experimental Farmer

ca. ~600 staff, turnover ~£30m  
http://www.hutton.ac.uk

‘An Investigation of the Principles of Knowledge and of the Progress of Reason, from Sense to Science and Philosophy’
I work with the Hutton’s “agroecology” group

The aim of the agroecology group is to:

*Devise, test and promote sustainable agricultural systems,*
*(and these systems should be profitable)*
Welcome to the ANTHROPOCENE

- An epoch proposed by Prof. Paul Jozef Crutzen
- Atmospheric chemist, Nobel Prize Winner
- Based on negative impact of humans on the Earth's geology, including
  - biodiversity loss and species extinction
  - biogeography (species distributions/evolution)
  - climate change
  - geomorphology (drainage patterns)
  - stratigraphy (sedimentological record)
    - fossil record (techno-fossils)
    - trace elements

- Suggested periods for initiation include
  - the industrial revolution / Haber-Bosch 1909
  - neolithic times and rise of agriculture

The impacts of discouraging natural chemical cycling

“Planetary Boundaries” are exceeded

Production challenges

- Output static
- Declining efficiency
- Growing farmer concerns of yield instability

![Graph showing grain yield (t/ha) over years from 1995 to 2020 for different crops like wheat, spring barley, and oilseed rape.]

Geoff Squire. Source: SG national statistics
National yields have stopped increasing

Crops are receiving an increasing array of pesticides formulations (winter crops > spring crops)

Crops receiving more mineral nitrogen receive more pesticides too
The nitrate “time-bomb”
The nitrogen crisis is an protein consumption crisis

Un-healthy EU28 dependencies
- High N fertiliser use = 10m t y⁻¹
- 23% of N fertiliser is imported
- Imported gas = 62% (2006-10)
- Imported feed protein = 70% (42Mt, ’09)

Yet there are solutions
- **LEGUME** supported cropped systems
- on near pH neutral soils
- organic production (legumes)
- 5% less productive than conventional

---


Is natural nitrogen cycling, using BNF by legumes, a solution?

**LEGUME FACTS**
nitrogen fixation in legumes is carried out by rhizobia and so legumes need no nitrogen fertiliser

Legumes also:
- improve soil qualities
- gift nitrogen to non-legumes
- liberate soil phosphorous
- can be biocontrol agents
- support pollinators & beneficial insects
- high protein, resistant starches, essential minerals

BNF = biological nitrogen fixation

**RHIZOBIA** in root nodules fix di-nitrogen gas from air into biologically useful nitrogen

**AM fungi infected roots enhance biological nitrogen fixation**
How much legume cover is best for a crop rotation?

When legumes are present for 50% of the rotation-time

A, Nitrogen input was highest
B, Man-made fertiliser use was lowest
C, Overall nitrogen input was greatest
D, Nitrogen (protein) yield was most

MAIN POINT: Legume supported production need not compromise yield

Proportion of whole-rotation with legumes

Examining scale of legume cultivation across EU countries

Why is the % of legume cultivation so low in Europe?
Which policies would help increase production?

- Beus et al 2013:
  - Integrated farming
  - Greening measures, CAP
  - Investment in suitable research
  - Constraints N fertiliser use

- Funding to develop capacities?
  - Precision ag. technology
  - Small-/medium-scale processing machinery

- Helming et al. & Topp et al. 2014
  - www.legumefutures.eu (reports)
  - International trade /control imports
Policy supporting legume production has failed to increase legume consumption

- But - legumes promote debate of food system policy
  - Meat analogues (e.g. www.impossiblefoods.com)
  - #IYP2016 (http://www.fao.org/pulses-2016/en/)
  - The ‘Protein Transition’ movement (away from meat)
  - www.forumforthefuture.org/project/protein-challenge-2040/overview (affordable & healthy)
  - Green Protein Alliance (www.greenproteinalliance.nl/)
  - FOOD2030 Policy Framework

- Policy Paradox & Protein Puzzle
  - Soya Declaration (July 17, 2017 – boost soy in EU)
TRransition paths to sUstainable legume-based systems in Europe (TRUE)

- An H2020-Sustainable Food Security (SFS), Research & Innovation Action
- 24 partner project, €5m
- Started on April 1st 2017, for 4y

www.true-project.eu
# The Partners

<table>
<thead>
<tr>
<th>No</th>
<th>Participant organisation name (and acronym)</th>
<th>Country</th>
<th>Organisation Type</th>
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<tbody>
<tr>
<td>1 (C)</td>
<td>The James Hutton Institute (JHI)</td>
<td>UK</td>
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<td>Coventry University (CU)</td>
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<td>Stockbridge Technology Centre (STC)</td>
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<td>Scotland’s Rural College (SRUC)</td>
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<td>HEI</td>
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<td>Agricultural University of Athens (AUA)</td>
<td>Greece</td>
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<td>Bangor University (BU)</td>
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<td>University</td>
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<td>Trinity College Dublin (TCD)</td>
<td>Ireland</td>
<td>University</td>
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<td>Processors and Growers Research Organisation (PGRO)</td>
<td>UK</td>
<td>SME</td>
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<td>14</td>
<td>Institut Jozef Stefan (JSI)</td>
<td>Slovenia</td>
<td>HEI</td>
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<td>15</td>
<td>IGV Institut Fur Getreideverarbeitung GmbH (IGV)</td>
<td>Germany</td>
<td>Commercial SME</td>
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<tr>
<td>16</td>
<td>ESSRG Kft (ESSRG)</td>
<td>Hungary</td>
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<td>Sociedade Agrícola do Freixo do Meio, Lda (FDM)</td>
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<td>23</td>
<td>Eurest -Sociedade Europeia De Restaurantes Lda (EUR)</td>
<td>Portugal</td>
<td>Commercial Enterprise</td>
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<td>24</td>
<td>Solintagro SL (SOL)</td>
<td>Spain</td>
<td>SME</td>
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# Primary Impacts

## Main Impacts

1. Enable sustainable legume-based cropping systems and agri-food and feed chains
2. Increase the commercial competitiveness of legume crops across agri-food/-feed chains
3. Reduce the environmental impact of food- & feed-production and processing
4. Integrated support for EU policies: CAP, Water Framework, IPCC, etc
5. Strengthen co-innovation: help build multi-stakeholders (transdisciplinary) community

## Additional Impacts

6. Optimise water and nutrient use efficiency - reducing the environmental impact
7. Enhance innovation capacity: for EU, local and global markets
8. Create new market opportunities: strengthen competitiveness and growth of SMEs
9. Wider benefits for society (more than GDP): culture, positive behavioural change
10. Legacy: evidence and resources (database, decision tools, media), ‘Pulse Europe’
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<td>Coventry University (CU, UK)</td>
<td>Nutritional profiling of heritage faba beans. Vegan production systems.</td>
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<td>Stockbridge Technology Centre (STC, UK)</td>
<td>Use of clover-based living mulches (direct &amp; strip tillage, Manterra Ltd.)</td>
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<td>4</td>
<td>Scotland’s Rural College (SRUC, UK)</td>
<td>Dairy system design. Farm &amp; behaviour modelling. Life Cycle Analysis</td>
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<td>Kenya Forestry Research Institute (KEFRI, KE)</td>
<td>Agroforestry based production and processing of cowpea</td>
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<td>Nutritional analysis of novel cropping &amp; legume based food and feed products</td>
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<td>Universitaet Hohenheim (UHOH, DE)</td>
<td>Spatial analysis of legume cropping in the UK. Lentil &amp; soybean field studies</td>
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<td>Developing a LIN and linked example Case Studies in Croatia</td>
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<td>Bangor University (BU, UK)</td>
<td>Life Cycle Analysis methods and tools for legume-based value chains (Food Print)</td>
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<td>Trinity College Dublin (TCD, IR)</td>
<td>Sustainable diet indicators: nutrient density x envir.- impact indices</td>
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<td>Critical appraisal of policies and development of new governance-based solutions</td>
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<td>Novel legumes food production - short supply-chain case study</td>
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<td>Pulses for aquaculture bass &amp; shrimps (e.g. lupin and faba bean coproducts)</td>
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<td>TRUE Food Print: legume recipes to encourage sustainable diets</td>
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<td>Intercropping and novel processing to improving profitability of short supply-chain</td>
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<td>Agriculture And Food Development Authority (TEAG, IR)</td>
<td>Low carbon system of dairy production. TEAGASC Clover discussion group.</td>
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<td>Sociedade Agricola do Freixo do Meio, Lda (FDM, PT)</td>
<td>The economics of self-sufficient production, processing and retailing</td>
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<td>23</td>
<td>Eurest - Sociedade Europeia De Restaurantes Lda (EUR, PT)</td>
<td>Expanding “Choose beans” &amp; development and testing novel legume foods</td>
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<tr>
<td>24</td>
<td>Solintagro SL (SOL, ES)</td>
<td>Screening for breeding: heritage varieties disease resistance &amp; stress tolerance</td>
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</tbody>
</table>
Robert Boddey, Professor Soil Science & Biological Nitrogen Fixation, Embrapa Agrobiologia, Rio de Janeiro, Brazil.  
- Also offers a case studies perspective on studies in Ghana.

Laurence Carmichael, Dr. Coordinator WHO-Centre Healthy Urban Environments, Uni. West England, Bristol, UK.
Michael A. Grusak, Prof., Pediatrics-Nutrition, Baylor College of Medicine, Houston, TX, USA.
Valentina Hažić, Head Rural Development, EiP Expert - Short Food Supply Chain Management, Čakovec, Croatia.
Parthib Basu, Head of the Centre for Pollination Studies, University of Kolkata, India.
Albert Vandenberg, Prof. & NSERC Industrial Research Chair, Uni. Saskatchewan, Canada.
David O’Dee, Dr, Kenya Forestry Research Institute (KEFRI), Kenya, Africa.

IAB Chairperson - Moya Kneafsey, Prof. Food & Local Development / Human Geography, Uni. Coventry, UK.
IAB Vice-chair. - Vice - Bob Rees, Prof. Agriculture & Climate Change, Head Carbon Management Centre, UK.
TRUE multi-stakeholder networks

European Legume Innovation Networks (ELINs)

ELINs embody legume focused Case Studies which span food- and feed-chains across a wide range of pedoclimates.
The ‘Three Pillars of Sustainability’

- **Environmental**
  - A Viable Natural Environment

- **Social**
  - Nurturing Community

- **Economic**
  - Sustainable Development
  - Sustainable Economic Development

- **Equitable**
  - Sufficient Economy

Bearable

Viable

Equitable
TRUE has developing a mechanistic framework to help understand and manage the three pillars:

Food policies are rarely effective on a national level
Does this approach need applied on a regional basis?

- The workings of the inner wheel for Society-Environment can be determined

- Harmonising society-economy is challenging as these aspects are recalcitrant:
  - history/tradition;
  - local palate culinary preferences; and,
  - social values.
WP Data-management and -flow

Flow of information and knowledge in TRUE, from definition of the 24 case studies (left), quantification of sustainability (centre) and synthesis and decision support (right).
TRUE activities span the supply chain:
and show a high TRL (technology readiness level)
Legumes as agents to help resolve critical issues: the environment- and human- health crises

The simple emphasis on production (sustainable intensification) is not acceptable

Society must increase its focus on sustainable consumption

- Major health issues prevalent:
  - 1980 – 2017 obesity doubled (30% of global population)
  - 30% of global population suffer nutrient deficiencies (≠ same 30% obese)
- Global agriculture ~25 % of GHGs: nitrogen pollution
- ~9 billion people by 2050
- Lack of diversity (polarisation) in production, operations, crops and biodiversity
  - excessive use of N and pesticides etc (for a low number of commodities)
- Polarisation of production encourages polarised food- and feed chains
  - Polarised food- and feed-chains encourages polarised use or consumption

5th Assessment Report IPCC highlighted potential of consumption shifts to combat GHG (https://ipcc.ch/report/ar5/)
TRUE: new metrics to inform sustainable dietary guidelines (NDEI)

Nutrient density (ND) analysis $\times$ environmental impact (E) index (I; standardised by weight) for commodities across their production and processing pathways and (NDEI, LOG 13:3)

This approach will be developed: NDEI/ha, also for meals.
What is intercropping?
the practice of cropping two or more crops in close proximity

Intercropping takes many forms and all forms exploit

- biodiversity and ecological interactions
- the interaction of diverse crop types
  - often the approach combines legumes and non-legumes
    - very often a cereal (non-legume) and a legumes

- The main function of intercropping is to:
  - provide greater yield more efficiently than a monocrop
  - achieve that higher yield with minimum dependency on inputs

Can we mainstream intercropping on Scotland?

- **Barley in Scotland as a case study**

  - Beer and whisky production contribute **£10 billion** to UK annual tax revenue

  - 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 (whisky mainly)
    - ½ is used for animal feed or meat production
    - While animal feed offers a large market, profits are low
    - Very little legumes currently used in Scotland (3% of rc

  - What about **INTERCROPPING barley with pea**?
    - Avoid nitrogen and reduce pesticide dependency and costs
      - lower environmental pollution
      - higher gross margins possible
Barley-pea as a model for Scotland

Plot-scale study carried out at the James Hutton Institute
- different variety combinations of pea and barley were assessed
Barley yields under conditions of **no added man-made nitrogen**?

- **Intercropped-barley (50% sowing rate) = monocrop (100% sowing rate)**

**2015 data**

- Average yield with fertiliser (monocrop) ~5 t/ha
- Average total intercropped yield ~6 t/ha (4.5 barley + 1/5 pea)
  - intercropped barley develops 2x more stems (tillers)

- **ALSO, protein content of intercropped pea & barley 5 to 20 % higher than monocrops**
  - depending on variety combination
<table>
<thead>
<tr>
<th>Crop</th>
<th>Crude Protein (%)</th>
<th>%N</th>
<th>Est. yield (t/ha) 2016 (uk avg)</th>
<th>Moncrop (kg N/ha)</th>
<th>Fertiliser Use (kg/ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Barley only</td>
<td>Pea only</td>
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<tr>
<td><strong>Monocrop</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Barley</td>
<td>12.8</td>
<td>2.0</td>
<td>7.2</td>
<td>141.8</td>
<td></td>
</tr>
<tr>
<td>Pea</td>
<td>22.6</td>
<td>3.5</td>
<td>4.8</td>
<td>166.9</td>
<td></td>
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<tr>
<td><strong>Intercrop</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Barley</td>
<td>12.8</td>
<td>2.0</td>
<td>5.4</td>
<td>106.3</td>
<td>117.0</td>
</tr>
<tr>
<td>Pea</td>
<td>22.6</td>
<td>3.5</td>
<td>1.4</td>
<td>50.1</td>
<td>55.1</td>
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</table>

**Assuming LER 1.2, intercrop barley yield at 75% of con.**

<table>
<thead>
<tr>
<th>Intercrop (kg N/ha)</th>
<th>Inc. 10%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Barley</td>
<td>106.3</td>
</tr>
<tr>
<td>Pea</td>
<td>50.1</td>
</tr>
<tr>
<td><strong>Total intercrop N yield (kg/ha)</strong></td>
<td>156.4</td>
</tr>
</tbody>
</table>

**% N yield difference of intercrop relative to monocrop barley and monocropped pea.**

<table>
<thead>
<tr>
<th>% (kg N [intercrop - monocrop])</th>
</tr>
</thead>
<tbody>
<tr>
<td>monocropped barley</td>
</tr>
<tr>
<td>monocropped pea</td>
</tr>
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</table>

**10-20% more N with intercrop, no mineral N added**
Intercropping can help mitigate the carbon footprint of agriculture

If all barley in all UK was intercropped,....

<table>
<thead>
<tr>
<th>Potential kg CO₂ e removed from the road / year</th>
<th>Equivalent cars offset</th>
<th>Cost Saving (M£) Fertiliser Offset (fertiliser at 18p kg⁻¹)</th>
<th>Intercropping barley contribution to total CO₂ e of UK Agric.</th>
</tr>
</thead>
<tbody>
<tr>
<td>420,112</td>
<td>176,000</td>
<td>13.5</td>
<td>Reduced ~1%</td>
</tr>
</tbody>
</table>

*UK agriculture - total UK emissions 54 Mt CO₂ e*

**The savings listed here probably underestimated**

- Fertiliser price is low (saving would be higher in future)
- Profitability (gross margins) could also be increased
- Reduced pesticide applications of intercropping are not accounted
- Increased yield and yield qualities of intercropping are not accounted
- Financial benefit of improved soil qualities are not accounted
Salmon farming in the Scotland: the potential of field beans (faba beans)

- Scotland’s second largest export
- £600m at farm gate
  - *Salmon feed now containing 70% vegetable protein*
  - *Very efficient feed Conversion (1.25)*
- To serve only Scottish aquaculture demand
  - beans need grown 1 crop in 12
- Bean protein concentrates of 50%+ are required
  - currently commercial faba bean = ~28% protein

https://beans4feeds.hutton.ac.uk/
Lines for field trials 2018

- 4 high protein lines
- 1 early harvesting line “The Scottish Bean”
RiL ‘Molecular Breeding’ Population (150 lines)
- ssp *paucijuga* (Afghan landrace) x cv Optica

- Screened over 2 y including in-field
- Map genes of agroecological potential (biological nitrogen fixation, individual grain %N)
Vicia faba L. genetic mapping - of key traits

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
- KASPTM assay - robust clean data
- 150 SNPs identified for genome wide markers
- Mapped against model legume Medicago truncatula
We also genetically characterise the rhizobia - to understand the genetics of elite strains.

Isolated rhizobia on Petri dish

Rhizobium leguminosarum bv. viciae KHD9.5 (KM591239.1) Vicia faba Tunisia

- Nodulate crop legumes (mainly)
- Nodulated wild legumes (mainly)

nod A gene sequencing
Searching for elite rhizobia

- in a collaboration with commercial rhizobia and AMF suppliers
- over 150 rhizobia isolates screened in glasshouse growth trials
Normally peas and beans are not inoculated with rhizobia but farmer complain of yield instability

Greenhouse screen for elite rhizobia (pea cv. Corus biomass monitored after 60d)

Field trials of elite rhizobia strains are underway
Novel crops (for Scotland): soybean & seed inoculation

Inoculating soybean seed with AM fungi & elite rhizobia increased biomass yield over 30%

Can the bradyrhizobia + AMfungi effect be translated into grain yields?

**Potential dry biomass (t/ha)**

- **Control**: 6 t/ha
- **AMF only Treatment**: 8.9 t/ha (39% yield inc.)
- **Rhizobia only Treatment**: 8.9 t/ha (39% yield inc.)
- **AMF & Rhizobia**: 12.3 t/ha (93% yield inc.)
FAO-UN Sustainable Development Goals (SDGs): other metrics to monitor food-system sustainability

- 17 SDGs
- 167 sustainable development indicators (SDIs)
- SDIs for legume supported food- and feed-networks remain to be defined
Food system trends: countries with high relative GDP

Impact of dietary change: facilitated by crop & diet diversification


- Healthy Global Diet (including red meat): 35% GHG Reduction
- Lacto-ovo-vegetarian: 38% GHG Reduction
- Vegan: 40% GHG Reduction

Fish (farmed) can alleviate low B12, Se. High folate, Mg, Vit C - due to high fruit & veg.

% Blue Water Use Reduction

% Greenhouse Gas Reduction
Other underpinning funding for legume research

**EU-DIVERSify** *(informing the breeding of intercrops)*
- *Designing InnoVative plant teams for Ecosystem Resilience and agricultural Sustainability* (€5m)
- JHI-Agroecology Coordinating, *Dr. Ali Karley*
- [www.plant-teams.eu](http://www.plant-teams.eu)

**EU-TomRes** *(understand combined stress tolerance)*
- Uni. Turin, Coordinator, *Prof. Andrea Schubert*
- Work-package, Nutrient and Water Use Efficiency, *Pete Iannetta*
- *Breeding crops for nitrogen and water stress tolerance* (€6m)
  - using tomato as a genetic model (organic forage-legume systems)
  - [www.tomres.eu](http://www.tomres.eu)
Science contributors (26)

Post-Doctoral Scientists (5)
Carolyn Mitchell, Plant-insect interactions
Gaynor Malloch, Mol. biologist
Gillian Banks, Agronomist
Marta Maluk, Mol. biologist
Nora Quesada, Landscape modeller
Richard Dye, Ecological modelling

Research Assistants (6)
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“Top 12” rhizobial strains

Dry weight above ground biomass (g) pea cv. Kareni
Why are legumes not more profitable?

Grown well, legumes can be the most profitable crop in the rotation
- Good growth = good biological nitrogen fixation = good yield
- Legumes are more environmentally dependant than high-input cereal crops
- Legumes need
  o the right soil attributes
  o best rhizobia & AM-fungi (and other soil microbes)
  o low soil nitrogen
  o sufficient phosphorous, essential minerals and water

Production and supply-chain restrictions
- Lack of crop diversity in production - lack of diversity in supply chain capacities
  o Need a consistent supply of legume grains esp. to large processors
    ▪ Who is contract growing / aggregating?
  o Lack of processing capacities (small- and large-scale)
  o Lack of investment in food technology and development of food culture

▪ Investment in high quality provenanced (local/regional) food cultures improves Gross Domestic Product, and well-being (life quality)