TRansition paths to sUstainable legume-based systems in Europe

Ebook on the Systematic Review

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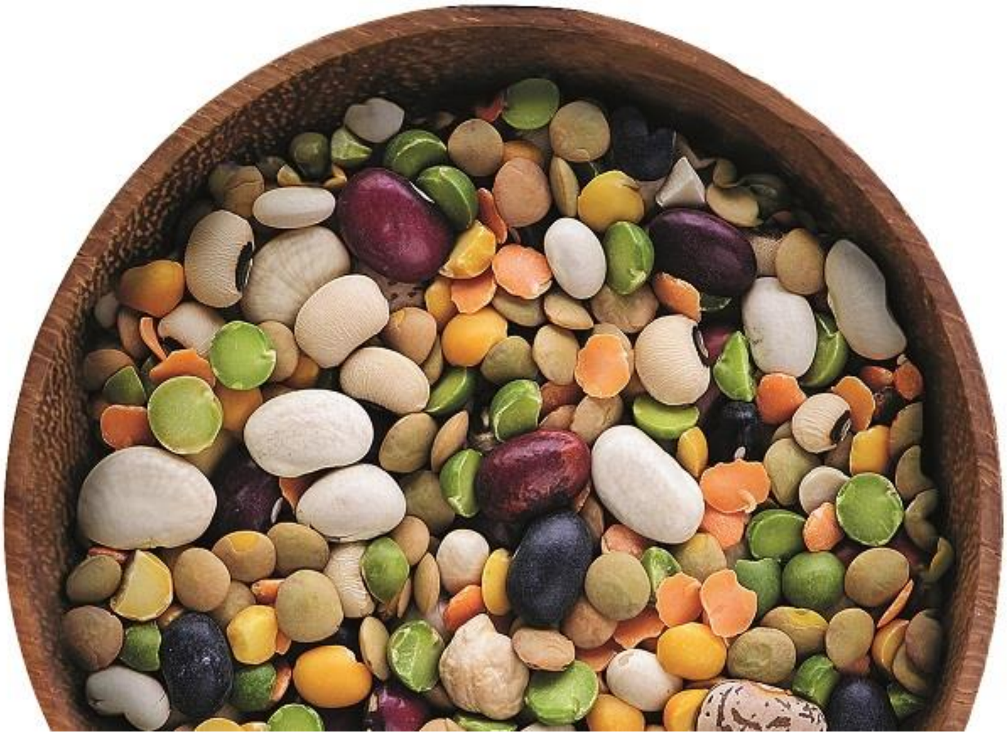

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TRansition paths to sUstainable
legume-based systems in Europe

TRUE-project Case Studies E-book

Facilitating home-grown legumes as the foundation of sustainable food- and feed-systems

The TRUE-Project has received funding from the European Commission *via* the Horizon 2020
Research and Innovation Action Programme under Grant Agreement number 727973.

Editors

Vasiliki Vougeleka, Georgia Ntatsi - Agricultural University of Athens, Greece.

Fanny Tran, Colm Duffy, Pietro Iannetta - James Hutton Institute, Scotland, UK.

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Authors

Jen Banfield-Zanin, Stockbridge Technology Centre Research Foundation, UK

Eleonora Barilli, Solintagro SL, Spain

Gábor Bertényi, Agri Kulti Kft., Hungary

Kirsty Black, Arbikie Distillery, Scotland, UK

William Burchill, Teagasc Moorepark advisory, Ireland

Imelda Casey, Waterford Institute of Technology, Department of Science, Ireland

Owen Cashman, Waterford Institute of Technology, Department of Science, Ireland

Judith Conroy, Centre for Agroecology Water and Resilience, Coventry University, England, UK

Eudoxia Efstathiadou, Agricultural University of Athens, Greece

João Ferreira, Catholic University of Portugal, Portugal

Karen Hamann, Institute for Food Studies & Agro industrial Development (IFAU), Denmark

Theresa Reif, University of Hohenheim, Germany

Sabine Zikeli, University of Hohenheim, Germany

Ana Gomes, Catholic University of Portugal, Portugal

Sabine Gruber, University of Hohenheim, Germany

Karen Hamann, Institute for Food Studies & Agro industrial Development, Denmark

Paul Hargreaves, Scotland's Rural College (SRUC), Scotland, UK

James Humphreys, Teagasc, livestock Systems Department, AGRIC, Ireland

Pietro Iannetta, The James Hutton Institute, UK

Ioannis Karavidas, Agricultural University of Athens, Greece

Attila Králl, Agri Kulti Kft., Hungary

Lars Lambertsen, Organic Denmark, Denmark

Emmanuel T. Makatiani, Kenya Forestry Research Institute, Kenya

Maggie March, Scotland's Rural College (SRUC), Scotland, UK

Adrian Newton, The James Hutton Institute, UK

Georgia Ntatsi, Agricultural University of Athens, Greece

David W. Odee, Kenya Forestry Research Institute, Kenya

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Beatriz Oliveira, Eurest -Sociedade Europeia De Restaurantes Lda., Portugal

John O. Otieno, Kenya Forestry Research Institute, Kenya

Elisabete Pinto, Catholic University of Portugal, Portugal

Francis Rayns, Centre for Agroecology Water and Resilience, Coventry University, England, UK

Robert M. Rees, Scotland's Rural College (SRUC), Scotland, UK

Costas Saitanis, Agricultural University of Athens, Greece

Carla S. Santos, Catholic University of Portugal, Portugal

Dimitrios Savvas, Agricultural University of Athens, Greece

Alfredo Sendim, Herdade do Freixo do Meio, Portugal

Ricardo Silva, Herdade do Freixo do Meio, Portugal

Matthew J. Slater, Alfred-Wegener-Institut, Germany

Barbara Smith, Centre for Agroecology Water and Resilience, Coventry University, England, UK

Marion Sorley, Teagasc, livestock Systems Department, AGRIC, Ireland

Alasdair J. Sykes, Scotland's Rural College (SRUC), Scotland, UK

Orsolya Szuromi, Agri Kulti Kft., Hungary

Anastasia Tampakaki, Agricultural University of Athens, Greece

Carla Teixeira, Catholic University of Portugal, Portugal

Magdalena Trstenjak, Public Institution for the Development of the Međimurje County, Croatia

Elisete Varandas Eurest -Sociedade Europeia De Restaurantes Lda., Portugal

Marta Vasconcelos, Catholic University of Portugal, Portugal

Vasiliki Vougeleka, Agricultural University of Athens, Greece

Monika Weiss, Alfred-Wegener-Institut, Germany

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1. Foreword

Prof. Moya Kneafsey, Chairperson, Intercontinental Scientific Advisory Board

As the winter of 2021-22 draws in, many European countries are experiencing a surge of COVID-19 infections. The pandemic has affected all aspects of our lives and had a huge impact on food systems. In the early days of the crisis, lockdowns and supply chain disruptions resulted in shortages of some foods, although these were generally temporary. The restaurant and catering sector suffered as people were confined to their homes. Many people found themselves experiencing food insecurity for the first time, due to reduced working hours or the loss of their job. Temporary food shortages prompted people to consider where their food comes from, and for some of those unable to work as usual, there was – at least for a while - more time to grow, cook, and bake. There was a noticeable increase in purchases from short food supply chains, as people sought more local sources of food.

Even more significant than COVID-19 are the threats posed to life-as-we-know-it by climate change, and declining biodiversity. These twin issues are already disrupting the lives of millions of people. Public awareness of the problems has been growing rapidly, leading to an increased motivation on the part of consumers to consider and make purchasing decisions which reduce their personal environmental footprint. We wait to see what progress the COP26 agreements will yield, but many of those representing the communities most at risk of climate change have expressed disappointment with what they have seen and heard so far. Meanwhile, successive scientific reports warn about the dangerous trajectory of environmental change that we now find ourselves seemingly locked into.

Against this backdrop, the TRUE consortium has worked for over four years to highlight and evaluate the underutilised potential of legumes in the context of transition paths to sustainable food and feed systems. In 2017 I was honoured to take up the role of Chair of the project's Intercontinental Science Advisory Board. As a social scientist working on short food supply chains and food justice I had some general knowledge about legumes, but it soon became apparent that – like many people – I did not fully appreciate their diversity and capacity to deliver social, environmental, and economic benefits. I soon learned that legumes come in many shapes and sizes including common beans, runner beans, faba (broad) beans, lima beans, cowpeas, chickpeas, lentils, clover, and lupins. They are used in many cuisines but despite this, people are often unaware of their significance both as a nutritious food for humans, and for livestock and aquaculture. What was particularly striking for me, as I followed the project's progress, was the potential for legumes to play a multifunctional role in the transition to sustainable food systems and the restoration of our threadbare environmental resources.

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The 24 case studies presented in this collection illustrate the great variety of uses and beneficial impacts of legumes, including enhancing agrobiodiversity and soil quality, reducing greenhouse gas emissions from pasture-based dairy farming, replacing environmentally damaging feed imports in livestock farming and aquaculture, through to providing ingredients for sustainable and healthy school meals, convenience snacks, climate positive alcoholic beverages and much more. The TRUE-Project has profiled, evaluated, and developed some of the impressive qualities of legumes and it has achieved this using an inter-disciplinary, multi-actor approach. This is necessary for research to achieve genuine impact and address complex issues which cannot be solved through the application of single disciplinary approaches, or knowledge systems based in universities alone. One of the project's key achievements has been to build collaborations between researchers in academic institutions, and knowledge-holders working in farms, food processing plants, breweries, kitchens, gardens, restaurants and many more spaces where insights into how to build transitions to sustainable food systems are being developed in-practice and in-place.

The transition pathways to sustainable legume-based systems are littered with obstacles, many of which are structural and require political leadership to address. For example, eating habits are shaped by the confluence of many factors, including the primacy of 'cheap' food culture. The expectation and necessity for cheap food has helped to drive farmgate prices down and contributed to unsustainable exploitation and degradation of soils, water, biodiversity, and climate. As well as squeezing the incomes of the producers, this means that the true cost of producing food is not reflected in the price of that food. Through clever branding and processing, an 'illusion of choice' is created on the supermarket shelves which disguises the limited diversity of plant and animal breeds upon with the food system depends. The global commodity food system has become increasingly concentrated, with just a few large corporate players controlling key parts of the system. Small-scale farmers have seen their farming practices and livelihoods put at risk or have disappeared. There has been a growing realisation that many people in wealthy countries have become 'disconnected' from the origins of their food. This has had negative consequences for their food skills and knowledge, which impacts on their health and wellbeing.

The research assembled in this volume illustrates that a range of approaches are needed to support the transition to sustainable legume-based systems. In some cases, invention is required for the development of new products and menus which suit contemporary tastes and lifestyles. In other cases, the renaissance of traditional knowledge and practices is needed, to help revive legume production and consumption in regions where these crops once flourished. Looking across the cases, it seems that some important ingredients for success can be identified. First, it is essential to organise learning and knowledge sharing between multiple actors who are already involved - or have a role to support - the development of markets and supply chains for legumes. Second, there needs to be space for

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meaningful, inclusive and effective dialogue between researchers, the people and communities involved in legume-based systems and the policy makers who can help to create the conditions for these systems to flourish. Third, it is vital that supply chains are transparent, in the sense that consumers can easily discover the origins and qualities of legume-based products and producers can access more reliable and detailed information on crop production, prices, supply, and demand. Shorter food chains, with fewer intermediaries between producer and consumer are one way to enhance transparency and re-distribute value back towards producers, and local communities.

We are increasingly forced to confront questions about what the future holds for humanity. Commentators have suggested that from the crisis of COVID-19, new opportunities are emerging to enable people to 'reconnect' with food and to build resilient, more regionalised food systems, supporting environmentally sustainable production and the livelihoods of smaller scale farmers in particular. The work undertaken by the TRUE-Project provides a rich array of insights into how steps towards this vision can be taken through the cultivation of legumes. Crucially, it underlines the importance of involving multiple actors in the co-design of research plus the co-production and sharing of knowledge. For just and sustainable transitions to take root and grow, 'food citizens' (producers and consumers) need to be empowered to participate in decisions about the food systems which not only deliver the food to their plates but shape the very environment that they/we all depend on. It has been a pleasure to accompany the TRUE-Project and on behalf of the Advisory Board, I am delighted to congratulate all those who have been involved, and to invite readers to enjoy this inspiring collection.

Moya Kneafsey – November 2021

Professor in Food and Local Development / Human Geography
Coventry University
England, UK

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2. Introduction

Dr. Pietro P.M. Iannetta[1], TRUE-Project Coordinator

I write this introduction whilst the 26th United Nations Climate Change Conference of the Parties (COP26) was underway, and in my home country, Scotland, and specifically Glasgow. I am saddened by the absence of discussion around agri-food systems and their central role in mitigating and adapting to climate change. While there is significant variation between countries, on average agriculture accounts for around 25% of greenhouse gas emission globally. Nevertheless, agri-food systems are well-placed to deliver critical mitigation and adaptation measures to help combat climate change, and so reverse the dysfunctions being witnessed globally in those biogeochemical cycles which determine our climate: and particularly the carbon-, nitrogen-, water-, and phosphorous-cycles. Climate change discussions over-focus on the potential of soil carbon sequestration to the exclusion of equally critical factors. Specifically, that an equal focus must be placed on the efficient use and management of nitrogen fertilisers. It may be convincingly argued that optimised management of agricultural nitrogen offers a carbon (*i.e.,* climate change) mitigation potential equivalent to that which may be sequestered by soil. Central to the foundation of 'optimised agricultural nitrogen management' is the key role of a specific crop-group known collectively as 'legumes'.

It is an unfortunate truth than while most consumers recognise beans and peas as popular foods and nutrient-dense grains, the majority are unaware that they are legumes, nor do they appreciate their ecological importance. The ecological provisions, which, when exploited in a well-managed farm, and ex-field gate processing streams (value chains), can improve the functions of society, the economy, and the environment including protecting and preservation of biodiversity.

Usually, even when the ecological significance of legumes is understood, this centres mainly around their capacity for biological nitrogen fixation. That is, the capture of 'fixing' of atmospheric nitrogen (N_2) into biologically useful forms. Legumes can therefore be cultivated with no, or greatly reduced, levels of synthetic nitrogen fertiliser. As part of a well-managed legume-supported cropped system, such provision extends far beyond the provision of natural nitrogen fertiliser and presents multiple solutions to help address the existential challenge facing society – which is that of climate change, and tied to

[1] Head of Ecological Food Systems, Agroecology, Department of Ecological Sciences, The James Hutton Institute, Scotland, UK. Email: pete.iannetta@hutton.ac.uk.

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this, biodiversity loss, and nutritional insecurity. The so-called 'climate change-biodiversity-diet nexus' (Iannetta *et al.*, 2021).

The ecological provisions are delivered by a wide range of legume types, including those yielding (high protein) grains (the 'grain legumes'), and herbaceous 'forage legumes' that are used as animal feed (fodder). Forage legumes are also used a 'cover-crop' and/or 'green manure' to protect the soil, enhance soil qualities and function, and soil fertility. The forage legumes are also deployed, often in combination with other herbaceous non-legume species, as a natural solution for pest control, and as sustenance for beneficial insects, such as pollinator.

Yet, it is also an unfortunate truth that while Europe already has food- and feed-systems[2] that are legume-dependant, these legumes, and particularly the high protein legume grains, are not 'home grown'. Also, even where legume grains are grown, too few enter the European human food chain directly.

Additionally, while Europe is largely self-sufficient in legume-based forages for animal feed, the efficiency of their production can be increased. This would diminish demand on grain used as feed, and free arable area for more and different crop species, including legume grains. Such crop diversification is also highly desired to improve the environmental and socio-economic resilience of food systems, and society more broadly (Messéan *et al.*, 2012).

Transformation towards home-grown legume-supported food- and feed-systems in Europe therefore requires significant and concentred action. Towards that end, the series of TRUE-Project Case Studies highlights necessary innovations across the value chain, from agricultural-input and -machinery suppliers, to consumers, and of course policy makers. The latter are in an especially influential position to ensure that the necessary range of facultative mechanisms are integrated and encouraged. Since only such integrated and concerted actions will see home-legume legume production increase significantly, and the necessary benefits achieved.

I therefore hope readers find this document interesting and informative. Also, this document is best assimilated in conjunction with the wealth of other popular- and peer-reviewed scientific-reports generated by the various work packages too (here) - since these are also insightful and power case studies in their own right too.

[2] Here, and for the remainder of this Deliverable text, use of the term "food" relates to crops used for food consumption only, whereas "feed" refers to crops used for animal production (including aquaculture). Though "feed" can also refer to uses as 'feedstocks', for industrial processes such as the production of 'potable neutral spirit' (for consumption), and biofuel, for example. On occasions, the term "food" can be used in general and include reference to both human- and animal-consumption (*i.e.,* food- and feed-uses). Readers should therefore be aware of these distinctions.

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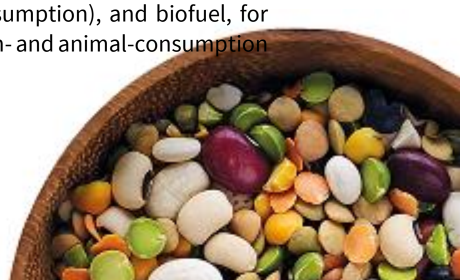

3. Legumes as agents to re-connect consumers with production environment

3.1 Do heritage varieties of legumes deliver enhanced human and beneficial insect nutrition?

Barbara Smith, Judith Conroy, and Francis Rayns
Centre for Agroecology Water and Resilience, Coventry University (CU), UK

Currently legumes only account for 1.5% of the farmed area of Europe and there are increasing calls for an expansion in acreage. Whether that is as single stand of grain legumes, strips in intercropped fields, as fields of forage legumes for animal feed or as diversification in pasture, there is a question that all farmers will face. ***Which variety shall I sow?*** This is not a new question. Humans have been selecting and breeding legumes for millennia, selecting a range of plant performance traits, especially those that achieve a high crop yield, resist pests and pathogens and manage the production of secondary metabolites (such as condensed tannins) for use in animal feed. However, there is concern that this process, focused largely on yield, has narrowed the genetic basis of our crops, resulting in the unintentional loss of some beneficial traits; we might have 'thrown the baby out with the bathwater'. That is, forfeited our future by neglecting those traits.

While research on the issue of human nutrition is underway, there are other consequences of modern crop breeding that are less frequently discussed. More generally we know that domesticating wild species, and breeding for specific traits, lead to variations in other or 'non-target' traits. Intuitively we hypothesise that, in addition to traits that impact on human nutrition, there is potential impact on the wider ecosystem, such as soil processes and functions, and provisions made to wildlife. Many beneficial insects which use floral resources may be affected by traits such as flowering time, floral volatile composition (*i.e.,* flower scent) as well as the nutritional value of the pollen and nectar. By investigating the differences between varieties in plant characteristics that impact both human health and the insects that provide ecosystem services, we open a discussion about how we should manage the links between agriculture, human health, and environment. The aim is to identify win-win scenarios for plant breeding. A key question is: *through careful selection of varieties and their associated traits, can we benefit the farmer, the consumer and contribute positively to ecosystem function?*

One approach is to breed new varieties, another is to develop the knowledge base on existing varieties, including the heritage varieties which may have fallen out of use. These approaches are not nutually exclusive, and selection of plant traits is important in both cases.

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What's the difference between modern and heritage varieties?

In line with current legislation regulating the sale of seeds, modern varieties are registered on national lists. For the purposes of this article, by modern, we mean currently commercially available. 'Heritage' is a flexible term. According to the Garden Organic Heritage Seed Library (HSL) (Warwickshire, UK), heritage seeds can be any of the following:

- rare landrace varieties, which are adapted to specific growing conditions;
- heritage varieties that have been saved over many generations; and,
- varieties that have been dropped from popular seed catalogues. This occurs for several reasons including their lack of popularity with consumers, their unsuitability for commercial scale production or simply the prohibitive cost of trialling and National Listing.

As part of work for the TRUE-Project we focussed on two commonly grown grain legumes: faba bean (*Vicia faba L.*) and French bean (*Phaseolus vulgaris L.*) and explored the varietal differences in key traits in replicated field trials. By selecting modern (five x faba bean; four x French bean) and heritage varieties obtained from HSL (five x faba bean; six x French bean), we were able to determine whether 'modern' and 'heritage' is a useful distinction to make when considering human and beneficial insect nutrition.

Human-centred Traits

Two traits are of particular interest to humans: yield and nutritional content. It might be expected that modern varieties bred for production would be higher yielding than heritage varieties, but this was not the case. There were differences in yield *per* unit area among faba bean varieties, but overall modern varieties did not perform better than heritage varieties (Figure 2A). There were also varietal differences in the nutritional content of the resulting beans. Legumes are valued for their protein content, and we found that the nitrogen content of dry beans varied significantly between 3.5% and 4.7%, which approximates to between 24 – 31% protein by dry weight (Figure 2B). In this case there was also a marginal benefit in the heritage beans, suggesting that potentially heritage varieties could provide more protein. However, only five varieties each of modern and heritage beans were tested.

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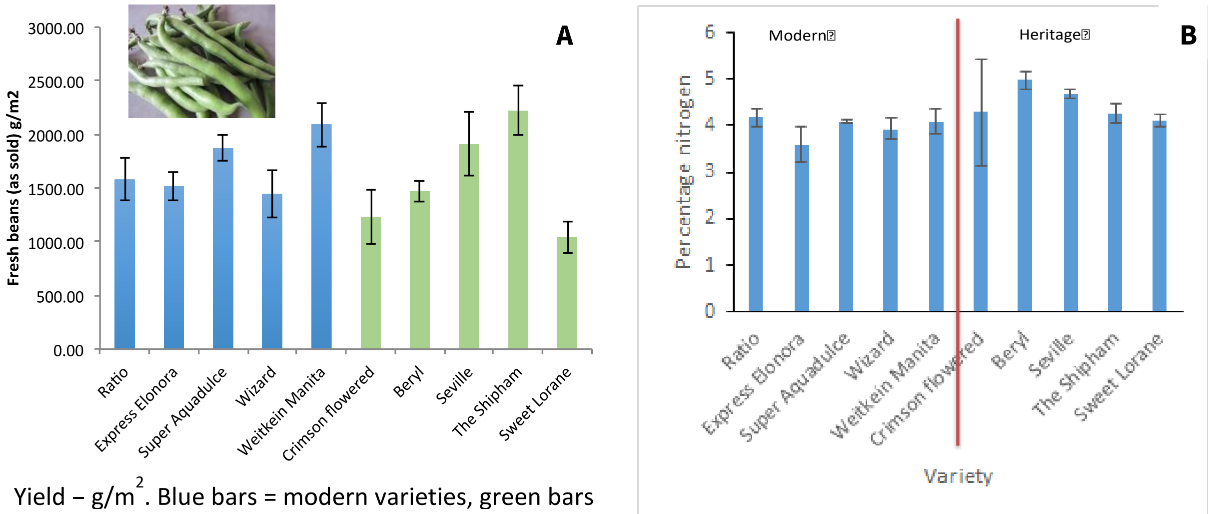

Figure 1. A, yield of fresh and air dried faba beans per m^2. B, percentage nitrogen in oven dried faba beans.

The beans were also tested for eight essential minerals: calcium, magnesium, phosphorous, zinc, iron, potassium, magnesium, and copper. Of these, calcium, magnesium, phosphorous and zinc differed between varieties and magnesium was higher in the heritage beans. This suggests that there is potential to select varieties with human health in mind and that some heritage varieties may be high in particular nutrients. However, the overall advantage lies in including heritage beans in the range of varieties that are considered for use. **Heritage varieties should not be dismissed when scanning for potential germplasm, but in general, the distinction between modern and heritage is not useful**.

There are many traits that have environmental impacts and hence, could be considered important. For example, secondary metabolites in leaves and seeds that limit pest attack, extra-floral nectaries that benefit beneficial insects such as parasitoid wasps (potentially beneficial in crop pest control), and floral resources for pollinators. In this research we have focussed on pollinators. Although neither faba nor French beans are dependent solely on insects for pollination, pollinator visitation is known to increase yield. In our studies on faba bean, we found a positive correlation between number of bee visits and yield of both fresh green beans (R^2 .481, F=35, p =<0.001) and dry beans (R^2 0.223, F=10.6, p =0.002), although we did not confirm it with exclusion trials.

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The value of legumes for insect pollinators

Legumes provide resources for a wide range of different bee species, which are beneficial in farmed environments. They support crop pollinators and can also play a part in assisting rare species and species of conservation concern in the wider landscape. As a result, legumes are included in pollinator flower mixes that farmers sow in crop margins. The value of crop legumes to bees is less well considered, although work has demonstrated that there is potential for fields of grain legumes such as faba beans to support higher numbers of pollinating insects at the landscape scale (Beyer *et al.*, 2020).

Floral characters

Bean flowers are variable in both colour and size. Figure 2 shows the differences in flower colour in the faba and French bean varieties in our experiment. Faba beans typically bear white flowers with black spots, though two of our heritage varieties were different. As its name suggests, crimson flowered faba bean is red, while a variety called 'Beryl' is pure white. The French beans varied from white through to deep pink.

There are many factors that influence whether a bee visits a flower *e.g.,* flower size and sugar content of nectar. Our results showed that bees visited some varieties more than others, and this was true for both broad beans and French beans. Interestingly, for faba beans, bees also chose to visit modern varieties more frequently than the heritage varieties; modern varieties received an average of 12 visits compared with 9 visits to heritage varieties. To try and explain this we selected floral traits that are known to influence visitation and one which is of emerging interest (the chemical composition of floral volatiles, *i.e.,* the plants scent).

Flower size varied between varieties of both faba bean and French bean but there was no difference between the modern and heritage varieties as a group. Similarly, there were varietal differences in sucrose concentration in the nectar (faba bean $F = 1.66$, $p = 0.096$; French bean $F = 2.53$, $p < 0.01$), but no difference between modern and heritage flowers. Furthermore, there was no relationship between flower size or sucrose concentration and bee visitation, which means that neither flower size nor how sweet the nectar was influenced how many visits bees made to the flowers.

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Figure 2. Colour and size variation in ten varieties of a) faba bean (*Vicia faba* L.) and b) French bean (*Phaseolus vulgaris*).

Analysis of the floral volatiles emitted by the flowers is ongoing. However early results from French bean trials indicate that there is variation in the key volatile compounds that we know are attractive to bees. Furthermore, the amount of time bees spent on flowers follows the similar pattern – indicating that the profile of floral volatile emissions may affect how long bees visit the flowers for (Figure 3).

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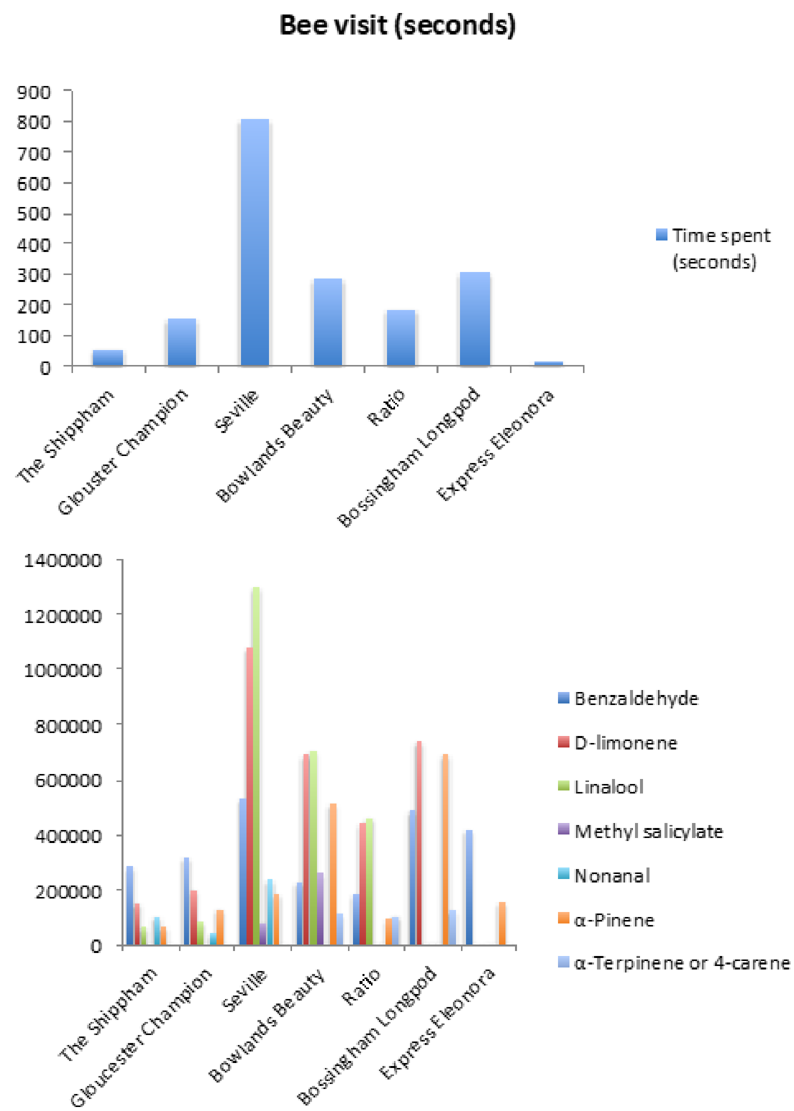

Figure 3. Bee visitation and volatile profile of faba bean varieties in a field trial.

Implications and Recommendations

Legume production in Europe is set to increase. This opens up an opportunity to consider the impact of that expansion on human health, ecosystem services and the impact on the wider landscape. This work shows that **varietal choice, both through crop breeding and though scanning our rich heritage of abandoned crops has potential to contribute to improved human nutrition**. There is also potential to include benefits for valuable insects which may have ecosystem wide impacts if crops are grown at scale. The mechanism for the latter requires more research but early results are encouraging.

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We recommend that **breeding programmes should consider traits that impact human health as well as beneficial insects, alongside agronomic characteristics**. There is emerging evidence from other studies that the benefits of legume crops spill over into the wider landscape and that legumes can play an important role in supporting ecosystem services and biodiversity in agriculture (Beyer et al., 2020). In the light of this we also recommend that **research should extend to examining the impact of varietal choice at the landscape scale**.

FAO-UN Sustainable Development Goals (SDGs) addressed

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3.2 Retailer-producer value chains and innovations

Karen Hamann

Institute for Food Studies & Agro industrial Development (IFAU), Denmark

The aim of this Case Study (CS) was to investigate the value chains for pulses, products made with pulses and fresh vegetables (peas and beans) from farm to market. The work targets the market (distribution and consumers) with some relevance for the processing and farming sectors. TheCase Study touches upon issues related to business and food marketing.

Legumes and the current EU market

In the EU market, legumes consumed for human nutrition only account for 7 % of the total legume consumption – the remaining 93 % being used for animal nutrition as feed (Development of plant proteins in the EU, 2018). The food market for pulse-based products is highly dynamic with many new products being introduced, such as plant-based meat and dairy alternatives, ready meals made with pulses, vegetarian food, or baked goods. Certification is an important tool for diversification and quality communication in the food market as demonstrated by the Vanilla Beans from Feneos Valley in Greece and the Puy lentils from France, which are marketed using the PGI/PDO scheme

Consumers that are most interested in pulses and pulse-based products are also keen on organic products, quality food, and vegetarian/flexitarian or vegan diets. This indicates that the core market for pulses in all formats is driven by quality-oriented consumers who care about their diets, the origin of their food, and the climate impact caused by food production. The results from a focus group with Danish consumers showed that if the product does not appeal to the consumer's liking, the likelihood of future purchase is very limited. Further product development is needed to encourage more consumer segments to buy pulse-based products. The contemporary market evolution shows that European food companies of all sizes and scales are introducing new products made with pulses or other plant-based ingredients from cereals. The innovations span across desserts; condiments; baked goods; meat, dairy, and seafood alternatives; alcoholic beverages and, chilled products such as ready-made salads and sandwiches.

The Importance of Marketing

For a successful market introduction of a new product, it is fundamental that the value chain is well organised and flexible. This includes a quality and food safety approach, a logistical set-up, and communication. Entrepreneurs show great creativity to organise new value chains and new business models have been developed. Consumer communication is a powerful tool for diversification of products and businesses. For example, the company Brake Foods (UK) uses local peas to make snacks

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and exploit the local dimension in the marketing of the product. The Danish company Naturli' Foods' clearly emphasises the fact that plant-based products require less water to produce than conventional meat or dairy products (Figure 4).

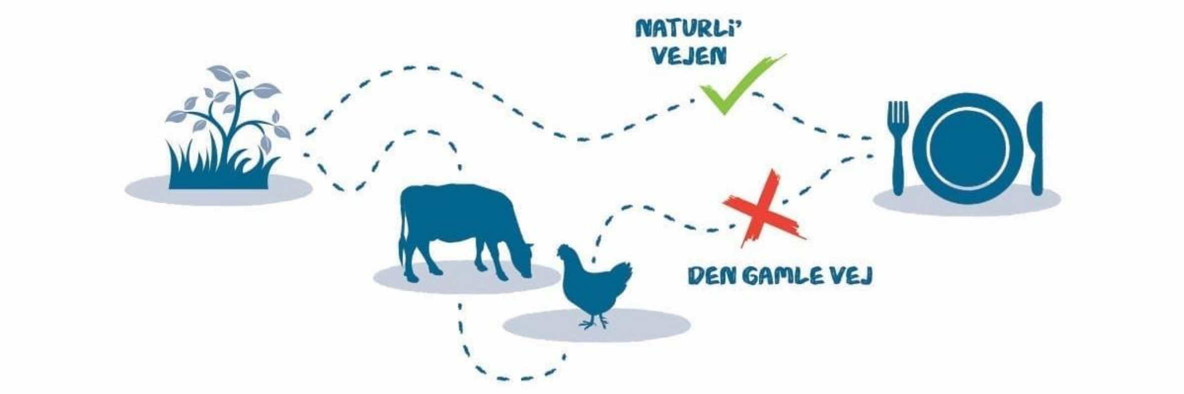

Figure 4. Example of communication to Danish consumers – Naturl' Foods. Picture retrieved from Klima & Miljø – Naturli' (naturli-foods.dk), May 2021.

Main Actors in the EU Food Market

The EU food market is a heterogeneous market where actors of all scales, business models and value chains are involved. The food market displays many examples of local and short value chains, also for marketing of fresh vegetables and pulses. Retail chains account for the majority of products traded via the food distribution system in Europe, and this makes these retailers the most important actors in the food system for the provision of products to consumers. Retailers' own brands are frequently used for introducing new products *e.g.,* organic dried pulses or processed pulse products like canned beans and lentils. Branded products from multinational companies, like Nestlé and Unilever, are important for increasing volume in the market. However, start-ups can become attractive companies to the multinationals as it was demonstrated by Unilever's acquisition in 2018 of the Dutch entrepreneur "The Vegetarian Butcher" (Netherlands: Unilever acquired De Vegetarische Slager (Figure 5). Later, in 2020, Unilever announced their strategic goals to continue to grow the plant-based segments.

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Figure 5. The Vegetarian Butcher – the entrepreneur, the brand, and the products. Picture retrieved from Holland's 'Vegetarian Butcher' Will Go Fully Vegan By 2019 (livekindly.co).

Conclusion and Recommendations

Key conclusions of theCase Study are that the European legume-based food market is:

a) innovative and continuously evolving to cater for the curious and environmentally conscious consumers' demand;
b) influenced by dynamic start-ups, multinationals, new ventures, and investors entailing new business opportunities; and,
c) full of untapped potential for further business development in all steps from farm to fork.

It is anticipated that consumer demand for food products with attributes like reduced environmental impact, organic certification, vegetarian, or vegan, or similar will remain strong in the coming years. Food processors and farmers will seek to enter the market at all scales, leading to new business models, a more diversified product assortment and, finally, to a larger market demand for pulses and vegetables. However, **it is pivotal for new entrants have excellent understanding of, and communication with, their target market(s)/consumers to devise the most effective and integrated business model(s)-where product design meets, or surpasses, expectations. Business development and facilitation services and training of legume-focused entrepreneurs could be relevant here. Since access to networks targeted at knowledge-sharing, co-innovation and business-to-business partnerships would facilitate successful market penetration.**

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FAO-UN Sustainable Development Goals (SDGs) addressed

Further Reading

D4.5 SDIs (Sustainable Development Indicators) for Quality Chains

D4.6 Best practices for the commercialisation of legumes

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3.3 Lentil (*Lens culinaris* Medik.) and soybean (*Glycine max* (L.) Merr.) cultivation: a success story from south-west Germany

Theresa Reif, Sabine Zikeli, and Sabine Gruber
University of Hohenheim (UHOH), Germany

Due to climate change and the high demand for regional, vegetarian, and vegan foods, European pulses have gained greater attention in society and via food/diet, environmental- plus biodiversity-protection oriented policies. Local pulse cultivation solves problems related to the requirements of biological nitrogen fixation in crop rotations and the farm-based protein supply of monogastric animals in sustainable farming systems (Vasconcelos *et al.*, 2019). To assess the challenges and the success factors of legume cultivation, this Case Study explores two approaches (top-down and bottom-up) as a model for stable and successful soybean (*Lens culinaris* Medik.) and Soybean (*Glycine max* (L.) Merr.) cultivation in Europe.

Soybean Cultivation in Germany

Soybean cultivation in South-West Germany was implemented through a top-down approach. Due to the breeding and availability of adapted varieties (0, 00, 000-varieties, long- to rapid-ripening types) and the demand for GMO-free food and feed, soybean cultivation has become more widespread in regions of Germany, France, Austria, and Switzerland which provide adequate climatic conditions (Bernet *et al.*, 2016; Klaiss *et al.*, 2020). With the introduction of the Protein Strategy of the Ministry of Agriculture and Food in Germany, the protein supply from local GMO-free production is to be increased, thereby conserving resources and strengthening the regional value chains (BMEL, 2021). The Ministry has been supporting soybean cultivation with a model and demonstration network (Soja-Netzwerk), as well as smaller projects. The top-down approach was complemented by bottom-up initiatives. In 1980, the association "Deutscher Sojaförderring" was founded to promote regionally produced soy in Germany (Miersch, 2017). The aim of the organisation, which include farmers, traders, processors, breeders, and universities, is to support soy-based value chains that are economically, ecologically, and socially sustainable. In addition, soy value chains are supported by retailer labels for regional production (*e.g.,* "VonHier") that require local protein feed and labels for GMO-free products (*e.g.,* for milk). Novel citizen science projects like "1000 gardens", that involve consumers in selection of soy varieties all over Germany have also helped draw the attention of society to these topics.

Lentil Cultivation

Until the middle of the 20th century, lentil was a traditional crop in many European regions, but with mechanisation and intensification of agriculture, it has disappeared from the fields (Horneburg, 2003). However, over the last decade, lentil cultivation has experienced a renaissance in Germany. Lentils are

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an important food in traditional and modern cuisine and exceptional in comparison to other pulses concerning their use. They are exclusively used for human consumption and the grains can be consumed without complex processing. Their content in nutritive compounds is very high in comparison to other pulses grown in Europe (Faris *et al.*, 2013; Santos *et al.*, 2020). The revival of mostly organic lentil growing and lentil consumption in parts of Germany is an unprecedented story of success initiated by a bottom-up approach. Though currently, lentil is still an underutilised crop throughout Europe.

Though soy and lentil offer many benefits to their agroecosystems, such as diversification of crop rotations and nitrogen-fixation, cultivation of both legumes is challenging. This is the baseline for the analysis of the successful top-down and bottom-up approach of soybean and lentil cultivation in South-West Germany, which may serve as a blueprint for the implementation and upscaling of their cultivation in other European regions. The analysis refers to agronomic, economic, and social factors. It was conducted as an on-farm survey on the current cultivation practices for both crops in South-West Germany. Moreover, the farmers' motivations as well as drivers and obstacles for lentil and soybean cultivation were identified. The study focused on both conventional and organic farming.

Soybean top-down approach

Motivation

The main reason for farmers to start soybean cultivation was the current high demand and the resulting high prices for soybeans. For the future, conventional farmers wish to have easier and less regulated access to plant protection products, as the number of pesticides that are permitted for soy cultivation is still restricted in Germany. Of farmers cropping conventionally, 33% hope for more political support to continue to grow soy. Due to the increasing number of soy-producing farmers, 55% of the farmers are afraid of declining producer prices. Overall, all farmers stressed the importance of breeding for high-yielding varieties. A soybean processor for food products (Taifun Tofu) encouraged organic farmers to start growing soybean. In contrast, conventional soybean growers were motivated by a network funded by the of Ministry of Agriculture and Food (Soja-Netzwerk) for soybean growing, as well as by neighbours.

Agronomics

Yields were slightly higher in conventional relative to organic farming, but the total range between minimum and maximum yield was higher in conventional farming. This indicates that yield stability was higher on organic farms (Figure 6). The yields in conventional farming ranged from 1.0 - 5.0 t DM ha^{-1} and in organic farming from 1.2 - 4.2 t DM ha^{-1}.

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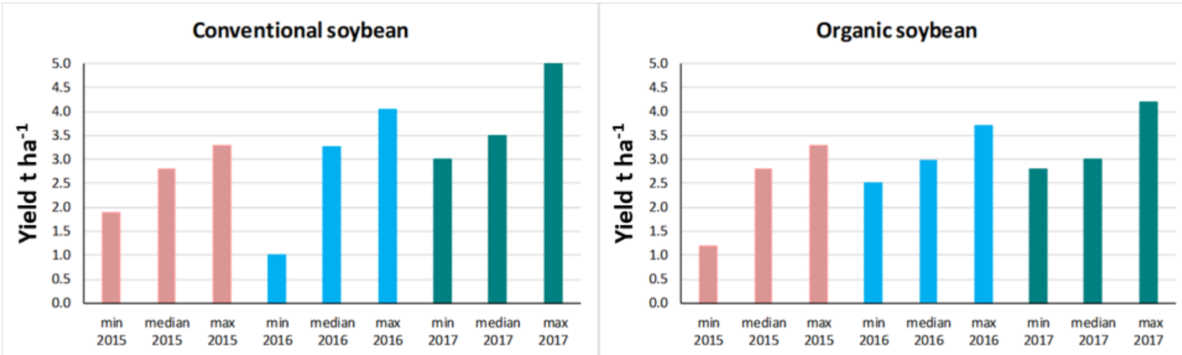

Figure 6. Min, max and median yield (t ha^{-1}) of soybean from 9 conventional and 8 organic farms, harvested in 2015-2017 in Southwest Germany.

Both organic and conventional rotations comprised a variety of crop species and lasted between three and eight years. Winter wheat (*Triticum aestivum*) was usually the preceding and following crop on organic and conventional farms (Figure 7). Generally, the proportion of cereals (winter and spring wheat, winter barley, spelt and triticale) in the rotation was high.

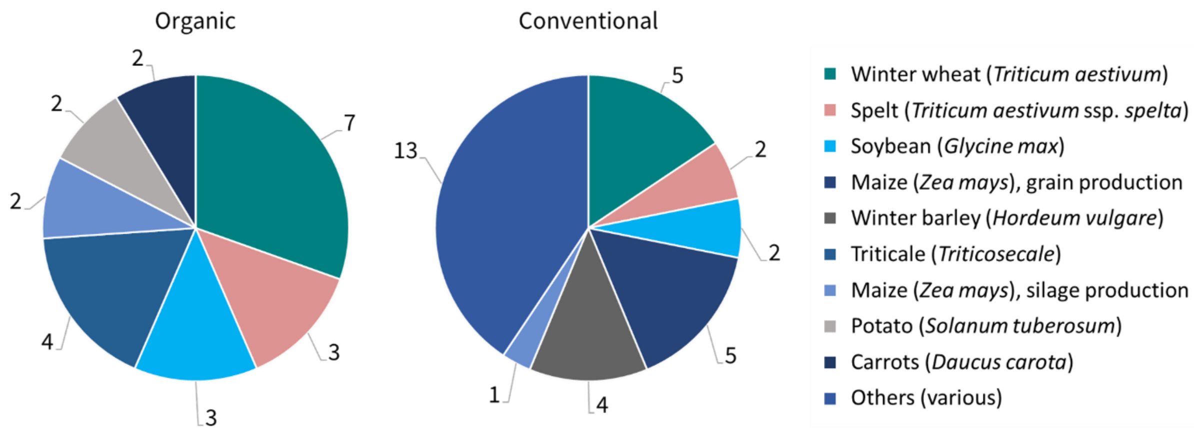

Figure 7. Frequency at which different crops preceeded soybean in organic (left) and conventional (right) farms, and for the years 2015 – 2017.

Lentil - bottom-up approach

Motivation

Nearly all organic farmers were members of a producer cooperative that was started by a charismatic and dedicated pioneer farmer more than 15 years ago. The cooperative organises processing and marketing of the lentils. According to our interviews with farmers, good marketing channels must be available to start lentil cultivation. Other strongly motivating factors for these farmers are external and socioeconomic, such as provenance or regional-identity, and the wish to continue traditions of

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ancestors. This motivation can also be observed in other regions of Germany where farmers have started to cultivate heritage varieties of lentils.

Agronomics

Average lentil yields of organic and conventional farmers were on a similar level in the three survey years (2015-2017). In organic farming, yields ranged between 0.06 - 1.3 t ha^{-1} and in conventional farming between 0.3 and 1.5 t DM ha^{-1}, across all varieties (*Anicia, Späth's Alblinse I and Späth's Alblinse II*) (Figure 6).

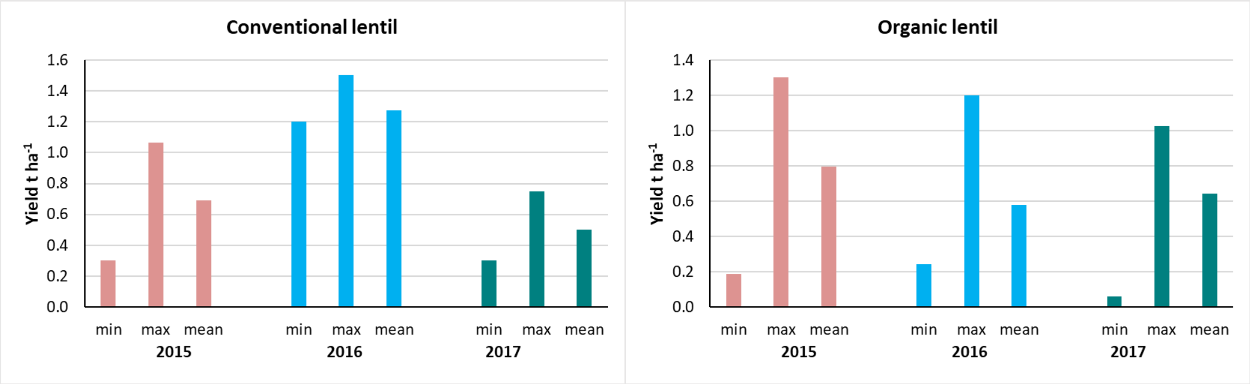

Figure 8. Min, max and mean yield (t DM ha^{-1}) of lentil from 4 conventional and 21 organic farms, harvested in 2015-2017 in Southwest Germany.

All farmers performed mixed cropping of lentil with a companion crop to support the lentil plants and to avoid lodging. Companion crops were mostly spring barley (*Hordeum vulgare*), oat (*Avena sativa*), or camelina (*Camelina sativa*). There was no evidence of correlation between yield levels and specific agronomic factor such as companion crop, seeding density of both partners, soil tillage, or crop rotation. All systems had advantages and disadvantages, and none could be identified as the optimum to gain significantly higher yields. The cropping practices were very diverse, and lentil was easy to integrate in existing structures on the farms, which helped to improve the willingness of farmers to adopt lentil growing.

Main Outcome and Recommendations

The overall outcome of the study identified factors concerning:

- agronomy for successful legume cultivation in a temperate climate;
- stabilization and improvement of soybean and lentil cultivation; and,
- upscaling of regional pulse growing and adaption of cropping systems in other regions.

We assessed the *status quo* and identified reasons for the success of increasing soy and lentil cultivation in the recent years in South-West Germany. This analysis provides important insights into the difficulties of cultivation and reveals that, in addition to economic factors, cultural background or

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special support by the government and society also play a major role. The identification of suitable regions for the expansion of European lentil or soybean cultivation should therefore not be based solely on agronomic factors, but also on socioeconomic and cultural factors. The historical or cultural connection to the region and the trend towards sustainable and regional food can lead to a high demand for lentil and soybean and the willingness on the part of the consumers to pay a higher price for the products. The motivation of farmers to grow lentils is strongly related to the consumers purchasing behaviour.

For the successful integration of the two crops in European agriculture, driving forces from two directions are needed.

- **Push: to create the interest in a promising but challenging crop, good education and trainings for farmers must be ensured. Pioneers are needed to provide farmers with information, assistance, and positive role models.**
- **Pull: the engagement of regional processors and trade offers farmers security, and a transparent value chain ensures consumer trust. The government may provide support by, for example, funding initiatives, networking, and local labels or support local processing structures.**

Once the system is established, further innovative ideas are needed to consolidate the crops in the European agricultural structures. The long-term aim is to permanently integrate soybean and lentil in farming systems in temperate climates, to stabilise these cropping systems, and thus to increase their acreage in Europe**. Focusing on new processed products made from soybean or lentil, such as lentil chips or bread spreads, would expand the range of existing products and ensures the acceptance of the crop in the agricultural sector.**

Finally, the integration of new crops for sustainable agriculture can lead to success from two different directions. In the future, both the top-down and the bottom-up approach can be applied, not only to other regions, but also to other crops such as chickpeas (*Cicereae*) and faba beans (*Vicia faba*).

FAO-UN Sustainable Development Goals (SDGs) addressed

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3.4 Pulses in short food chains

Attila Králl, Orsolya Szuromi and Gábor Bertényi
Agri Kulti Kft. (AK), Hungary

Legumes Cultivation and Consumption in Hungary

Production and consumption of legumes for food (*i.e.,* direct consumption by humans) is extremely low in Hungary, even in a European-wide comparison. There had been a steep decline in cultivation area since the 1990s, which has been further reduced by the country's accession to the EU, due mainly to CAP-related payment schemes and policies. Also, in this context, the reorganisation of markets. Consumption levels, including fresh-green and stored-dry legumes, are declining in absolute terms (Figure 9) but in a particularly dramatic way compared to the opposite trend for animal protein sources, which paints a rather gloomy picture in terms of the sustainability of our food systems.

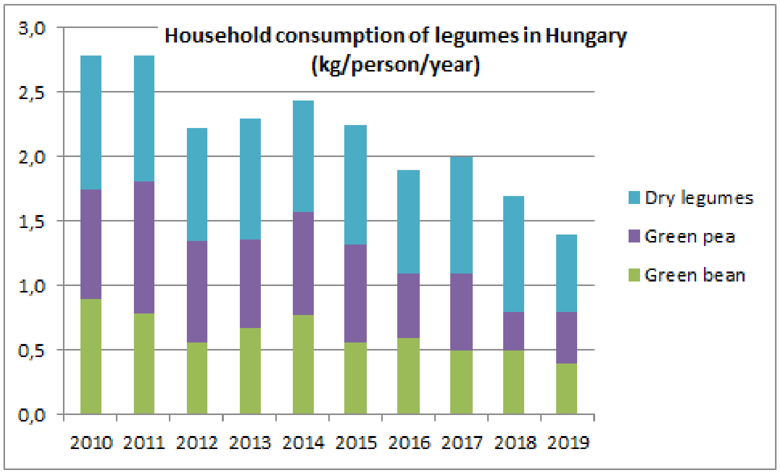

Figure 9. Household consumption of legumes in Hungary. Source: Hungarian Central Statistical Office - Household statistics.

Both cultivation and consumption of pulses have deep roots in the country; the NBGK (National Biodiversity- and Gene Conservation Centre) stores approximately 11,000 legume items, including 4.500 land races of common bean *(Phaseolus vulgaris* L.*)* of which 3,100 were collected in the Carpathian Basin. The collection is constantly updated by regular re-plantings. Although it is possible for private individuals to retrieve and plant certain cultivars from the collection, and attempts have been made in the last decade to explore the agronomic potential of this vast collection, there is still very little practical information available on these plants. How do they behave in cultivation, what are their special agro-ecological needs and sensitivity? Even less is known about the potential uses and the gastronomic value of these legumes.

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In our Case Study, we mainly sought answers to the following questions.

1. *How can these legume landraces be "freed" from gene banks and brought back into cultivation?* We were not just interested in the varieties themselves, but also wanted to model the whole process.
2. *Is it possible to sort out varieties in a few years of cultivation experiments that on one hand can be grown reliably with considerable yield and crop security, and on the other have a real perspective and provide opportunity for farmers to expand their range of cultivated varieties?*
3. *How do market players - producers and gastronomy - react to the little-known neglected and underutilised (NUC) varieties and their uses? What are the promising directions of use?*

Methodology

Cultivation

For three years between 2018 and 2020, we conducted cultivation experiments using 55 land races of a total of 9 legume species with the participation of 10 private farmers across Hungary in several parts of the country (Table 1). The original set of varieties provided by NBGK was filtered based on the experience of the years, and we also expanded the selection with new varieties. This *on-farm* experiment was carried out under the professional guidance of ÖMKI (Research Institute of Organic Agriculture), who provided cultivation guidelines.

In line with the transition goals of the project, emphasis was put on practice-oriented observations to increase applied knowledge regarding the cultivation and use of each variety and to draw farmers' attention to poorly known species, and to encourage their cultivation.

Table 1. The legume species and number of landraces used during the cultivation.

		Nr of landraces/ cultivars		
Scientific name	**Name**	**in 2018**	**in 2019**	**in 2020**
Phaseolus vulgaris	Common Bean	10	7	8
Phaseolus coccineus	Runner Bean	2	2	2
Phaseolus lunatus	Lima Bean	3	3	4
Vicia faba	Faba Bean	3	1	0
Vigna unguiculata	Cowpea	6	6	7
Vigna unguiculata ssp. Sesquipedalis	Yardlong Bean	0	2	3
Cicer arietinum	Chickpea	6	3	3
Phaseolus acutifolius	Tepary Bean	0	1	1
Lens culinaris	Lentil	3	0	0
Lablab purpureus	Lablab	0	0	1
Sum		**33**	**25**	**29**

Technological descriptions and protocols for on-farm cultivation experiments

Data and farmer opinions were collected on the following topics in particular:

- cultivation conditions and applied agrotechnology;
- observations on plant development and physiognomy;
- observations on pathogens and applied plant protection;
- experience with crop yield and yield security;
- general opinion on the variety - "Would I plant it again?" - with justification; and,
- monitoring and measurement data on the green-pod form and dry form of the crops with suggestions on its potential use in either form.

ÖMKi

TERMESZTÉSTECHNOLÓGIAI AJÁNLÁS ÉS ON-FARM JEGYZŐKÖNYV

A TRUE PROJEKTBEN KÖZREMŰKÖDŐ TERMESZTŐK SZÁMÁRA

FAJ: CSICSERIBORSÓ (BAGOLYBORSÓ) (CICER ARIETINUM)

Egy éves, lágyszárú, hüvelyes növény. Mélyen gyökerezik (1-1,5 m), ennek köszönhető szárazságtűrése. Szára 35-50 cm magas, felálló, elágazó, négyszögletes. Levelei páratlanul szárnyasan összetettek. Az egész növény mirigyszőrös. A virágok egyesével állnak, kékesfehér színűek. Önbeporzó növény, ritkán idegen megporzás is előfordulhat. Hüvelytermése csüngő, ovális, kicsi és felfújt. Hossza 2-3 cm, 1-3 magot tartalmaz. A mag fehéres, sárgás, barna vagy fekete. Ezermagtömege 200-300 g, 2-3 évig őrzi meg csíraképességét.

Humán étkezési célra és állati takarmányozásra is alkalmas, antinutritiv anyagokat nem tartalmaz. Magja zölden és szárazon is fogyasztható. A zöld növény és a szalma nem etethető a mirigyszőrei által termelt magas alma- és oxálsav tartalma miatt.

Javasolt termesztéstechnológia

A talajban visszamaradó növényvédőszer-maradványokra érzékeny.

Tavaszi vetőágy-készítés: 6-8 cm mélyen, közvetlenül vetés előtt.

Vetésidő: március vége - április első fele (8-10 °C talajhőmérséklet)

Sorba vetés: a sortávolság általában 30-36 cm, de vethető 24 és 50 cm-re is; a mechanikai művelés módjához illeszkedve válasszuk meg. Tőtáv: 3-4 cm. Vetés mélysége: 4-5 cm (barázdába). Vetéstől számítva 7-10 nap múlva kel.

Rövid tenyészidejű (80-120 nap), így elő- és utóvetemény is lehet. Nyári vetéskor szükség lehet csírázásindító öntözésre.

Szárazságtűrő, de a kelés és a kezdeti fejlődés időszakában igényli a csapadékot. Öntözés nélkül is jól terem, de terméskötés idején 1-2 öntözés növeli a termésmennyiséget.

Közepes hőigényű, melegebbet igényel, mint a borsó. Fényigényes.

Tápanyagigénye közepes, nem szükséges trágyázott talajba való vetése.

Figure 10. Example of protocols for on-farm cultivation experiments.

Exploring possible uses

Farmers were the main source of information on the use and gastronomic potential of the cultivated varieties. They gave a detailed opinion every year on what form of use and method of preparation they would consider conceivable or optimal for each variety. Information was also gathered from chefs, with the help of whom we developed and tested dozens of new recipes using cultivated species and varieties.

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Main Outcome and Recommendations

Transitions always take time and habits are key obstacles to changing systems, while information is one key leverage point. The main aim of this Case Study was to attempt to strengthen the role of food legumes in food systems - especially in short supply chains (SSCs). To achieve this, efforts to make legumes more accessible and promote them in various ways among the key actors of SSCs, and to provide meaningful, and practical information for each of the actors were made. The most important points of intervention are: (1) access to the propagating material of tried and/or unique varieties, landrace; (2) practical knowledge related to the cultivation of the species; and (3) the demonstration of the possibilities of kitchen use and the key role in sustainable gastronomy.

The most important results of our Case Study to support the desired transition are:

1. relevant, practical data on the cultivation of a number of species and varieties that are little known or neglected in Hungary were collected;
2. Several species/varieties from the initial variety list were screened, such as Lima Bean *(Phaseolus lunatus)*, Cowpea *(Vigna unguiculata)*, Yardlong bean *(Vigna unguiculata ssp. Sesquipedalis)* and several varieties of Common bean *(Phaseolus vulgaris)* - which are considered by farmers as marketable either as a raw material or in any processed form and will be integrated permanently into their cultivated crops.
3. Best varieties have been included into the community-based gene bank of the MagHáz Association, which increases the accessibility by an order of magnitude.
4. Due to the lack of diversity of home-grown legumes, there is a demand for quality, special, domestically produced ingredients among more demanding restaurants.
5. To strengthen the gastronomic role of legumes, a cookbook is being prepared that covers several aspects of sustainable and resilient gastronomy and include legume-based foods in the proportion that is recommended in human diet.

The most important overall result of the Case Study is that we have modelled and tested in practice a process through which **landscape legume varieties can be selected from gene bank collections, re-introduced successfully into cultivation, and can be integrated into gastronomy with the help of dedicated and curious farmers and restaurants.**

The operation and widespread promotion of this model could be extremely important for components of transition, such as:

1. strengthening primary food self-sufficiency by increasing opportunities for backyard production, urban farming and community gardening;

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2. **strengthening the independence from industrial varieties and reducing import dependence by favouring domestically produced raw materials;**
3. **release agro-biodiversity and associated ecosystem services from gene banks and cultivar collections.** Exploring varieties and genetic variants with special agronomic features such as disease-resistance and drought-tolerance and their introduction into breeding experiments contributes to the adaptation to changing environmental conditions.
4. **special ingredients from sustainable farming can be attractive for more demanding, specialty-sensitive restaurants and their guests, making the cultivation of these crops a breakthrough point for small to medium-sized producers.**

Gaps for further investigation

Nutrient analysis of each variety, which would provide important additional information about their kitchen uses, potential risks as well as their unique nutritional value, was not possible with the timeframe of the project.

No targeted studies were performed to explore special agro-ecological properties such as pest resistance, environmental tolerance, *etc.* These studies would provide information for longer-term climate adaptation studies, variety selection, and breeding operations.

Environmental conditions of the production site were not investigated thoroughly. Hence, a more detailed exploration of the individual farms and production sites is required, and the varieties would also be worth testing under regulated conditions.

Connecting supply and demand requires the development of a special platform that would make it easier for sustainably produced specialty raw materials (*e.g.,* legumes) to find their own markets.

FAO-UN Sustainable Development Goals (SDGs) addressed

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3.5 Ancient and heritage variety screening for higher nutritive value

Alfredo Sendim and Ricardo Silva
Herdade do Freixo do Meio (HDM), Portugal

An awareness of the failure of ‘productionism’ (the believe that ever greater levels of production, or crop yields for human use is always good), is balanced by recognition of the need for integrated and novel visions of agriculture and food systems, which recognises their multiple functions and assets for economic *plus* social and ecological sustainability and resilience. Nowadays’ production in Portuguese Montado (traditional agroforestry) systems remains largely extensive, and this approach is a critical factor for the maintenance of natural resources and biodiversity. However, activities were simplified with production unit focusing on one or a small number of markets, and farms became increasingly dependent on cork revenues and financial support *via* the EU-CAP (Common Agricultural Policy). Therefore, agriculture in Alentejo, Portugal continues to lose capacity for employment creation, and so the sustenance of regional development and vitality. The main goal of Herdade do Freixo do Meio’s Case Study is to analyse the new strategies that recreate the multifunctional Montado traditional system, and adapt it to new economic, social, and environmental challenges. Several different strategies are pursued and include the pursuit of added value products from traditional farm functions (production of food and fibre); enlargement to new functions related to new consumer demands; and the repositioning and integration of new resources. These result in improved awareness and respect for the region and facilitate a mean by which valorisation of the integrated services. The Montado ecosystem provides to human populations in terms of support and regulation for biodiversity and ecosystem functions, and in terms of greater production diversity and the enhancement of cultural services – for the local population and visitors. The dissemination of this model does not depend uniquely on farmers, although they are key players as ecosystem managers. As any economic activity, multifunctional agriculture depends on market support, and hence on society in general. Without the development of mechanisms that reward nature conservation and improve consumer awareness to value food security and environment preservation, multifunctional agriculture will lack one of its key pillars: economic sustainability.

In this Case Study, field trials were conducted to identify the best legume crops that could fit our Montado rotational system. Ideally, these crops should be local, ancient, or heritage varieties of legumes, well adapted to the region and with low water requirement. Legume crops have several advantages for agroforestry systems and for our model of food value chain: nitrogen fixation for soil fertility improvement, easy management, and sowing, and good nutritional value with high contents of protein and other nutrition, and secondary or non-nutritional components which are also conducive to

good-health and wellbeing. Three species were chosen: chickpea (*Cicer arietinum* L.), horsebean (*Vicia faba* L.) and white lupin (*Lupinus albus* L.).

Lupin (*Lupinus albus*)

Lupin is a traditional crop in Portugal known as ”tremoço“, and it is usually sold as a preserved salty snack. However, a similar species, *Lupinus luteus* (yellow lupin) is widely used as a cover crop and a natural fertiliser for the Montado. Our trials aim to include white lupin both as a crop for human food, and as a cover crop for green manure at our Montado system and rotations. This means it must be cultivated in an organic farming approach, in areas sometimes far for optimal crop performance, and without irrigation. If white lupin could be grown in such conditions, it could replace yellow lupin increasing farm production and contribute to new products, especially but not only, vegan organic products.

For the first-year trials, two fields of pure stands of White Lupin were sown with a total of 1 kg of seeds. Both trials yielded good results with excellent growth and productivity without significant differences between fields. The exception was small spots where water retention was higher and where some plants tended to wilt. Over 3 kg of seeds were collected, of which 1 kg was sold to an organic processing company partner (Agrinemus), which produces several lupin products. Year 2 trials also led to good seed production, although differences between fields were recorded with regards to plant development and germination.

The lupin grains are still being developed for production as the traditional salty snack on farm, though were also sold to a large processor who already produces this product. In addition, the grains were also processed on farm to produce a vegetarian burger which is now being sold from the farm’s restaurant.

Horsebean (*Vicia faba* L.)

Unlike lupin, horsebean (or faba bean) is commonly cultivated in Portugal with irrigation, but for our trials, horsebean was also cultivated without water. We used the two most popular local varieties: “Regional” and “Ratinha”. The first, is a tall plant with large, flattened seeds mostly used for human consumption and the second, smaller, with small and rounded seeds mostly used for animal feed.

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Three trials were performed, two sown with Regional and one with Ratinha. Regional germinated poorly in both fields and clearly suffered from lack of irrigation and heat resulting in loss of production with dried and/or burnt seeds and fruits. Ratinha variety however, even with poor results regarding grain yield, withstood the heat and therefore was chosen for the next year trials. These were conducted in irrigated agroforestry plots to produce seed for human consumption, and crop resides as green manure. Non-irrigation trials were also performed with Ratinha only, to identify if there was a better season for sowing/germination and production - with the aim of introducing this crop as an annual dry crop for animal feeding or for seed processing.

All irrigated Regional horsebeans trials produced enough seeds for commercial use through our Community Supports Agriculture vegetable basket where we provide food to around 100 families. This gained more relevance considering the impacts of COVID-19, increasing the demand for locally produced food, and especially food that can be stored, such as these legume beans.

Additionally, four fields of irrigated agroforestry were sown with horsebeans. These fields had 'irrigation lines', and horsebeans were used both along and between these lines. Along the cultivation lines, plants were cultivated to maturity and yielded grains for consumption or future sowings. These plants also provide shade and green manure. Between the lines, plants were harvested before seed formation and are used as a green manure and soil mulching. All of the fields had very good yields and horsebeans are now fully part of our agroforestry systems.

The non-irrigated fields were sown early with Ratinha at the start of the rain season (November) and produced very good results too, resulting in seeds collected mostly for sowing next year. This variety is now also part of our rotation used in the same way as lupin though we reserve it for the best soils as it is less adaptive than lupin.

Product Development

The seeds produced were used to develop novel food products highlighted our short value chain (Figure 1). In addition to the traditional pre-boiled chickpeas, an organic vegan product called "Enchido vegetal de bolota" which contains 26.5% of chickpeas, and a vegan burger with 44% of chickpeas and 8% lupin were developed. A lupin salty snack is also under development although not innovative, it is a new product made with legumes for our farm restaurants.

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Figure 11. Example of legume-based products produced by Herdade do Freixo do Meio, that are pre-boiled chickpeas, Enchido vegetal de bolota and a lupin salty snack.

FAO-UN Sustainable Development Goals (SDGs) addressed

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3.6 Legume dishes with consumer-appeal and for large-scale production

Elisete Varandas and Beatriz Oliveira
Eurest -Sociedade Europeia De Restaurantes Lda. (EUR), Portugal

Development of New Legumes Recipes

Recipes were collected from Eurest staff members who share their own experience, knowledge, and ideas associated with national gastronomic traditions, modernity, nutrition, and expectations of consumers today. All recipes were then analysed in terms of constituents and nutritional value (Figure 12). The recipes were tested and validated by Eurest's team of chefs and nutritionists. Also, the production teams involved in testing the recipes had training on the social and ecological significance of legumes, their nutritional advantages, as well as appropriate cooking methods. The process also allowed for necessary adjustments to the recipes to facilitate mass production. Recipes were also adapted to the local gastronomic traditions to ensure greater acceptance.

Figure 12. Example of recipes developed by Eurest.

Legumes Value chain to EUR sites

To introduce legume dishes on menu at Eurest's sites, the supply of legumes in sufficient quantities needed to be secured first. Currently, more than 90% of purchases of legumes by Eurest corresponded to products which originated from South America (Argentina and Brazil), with only 9% coming from the Iberian Peninsula (between Portugal and Spain), due to limited availability and market prices.

Legume	Source | Country
Pea	Spain
Chickpeas	Argentina
Bean	Argentina/ Brasil
Faba bean	Spain
Soy	Portugal
Lentils	Argentina/ Canadá

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Training of Chefs and Monitoring

All recipes include the composition of ingredients, description of the production process, presentation image and nutritional information to ensure local Eurest units could reproduce the dishes easily and effectively. To date approximately 700 Eurest sites have worked on the recipes, 1,400 Cook Chefs and more than 2,000 employees received training and information via e-learning platforms, which facilitates dissemination of information and distance monitoring. In addition, monthly meetings were held to discuss the implementation of new dishes on the menu plans and sustain involvement and participation of the project. A digital platform for all Eurest units was developed to share the monthly menu plans, facilitate access to information and promoting the creativity of the teams in adapting their ideas to their daily menus. These actions were closely monitored in terms of implementation, with regular visits to the sites and support always available to local teams.

Dissemination of the recipes

New products and suppliers, and information about legumes have been shared through the "Shopping Bulletin" (Boletim de Compras – image below), which is distributed monthly to all Eurest units. The bulletin also includes all supplier information, price negotiations and new product suggestions. This action contributed to a better dissemination of the variety of legumes available for purchase and facilitated the comparative analysis of costs between protein of animal and plant origin.

Feedback from Consumers

Each recipe was evaluated by two groups of tasters, with respect to "presentation", "flavour and seasoning", the "temperature of the dish at the time of consumption", and "overall satisfaction". Participants in the study were also offered the opportunity to provide suggestions to improve the dish under evaluation. Both groups scored most dishes between satisfied and very satisfied (the two highest evaluations).

Dissemination Campaigns

To raise consumer awareness, various forms of communication were developed and targeted both at adults and children population (Figure 13).

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Figure 13. Examples of dissemination campaigns launched by Eurest.

Consumer activities included cooking demonstration workshops in Eurest restaurants, which allowed for greater interaction with consumers and discussions about the cooking methods and advantages of legume consumption. Approximately 100 workshops were held with the participation of 10 Eurest Chefs and the local technical teams to help promote legumes as a nutrient dense and a sustainable daily food choice. More than 2,000 consumers attended these practical workshops. These initiatives were well received by Eurest customers and local teams alike, which led to the greater acceptance of dishes from daily menus.

Figure 14. Advertising for Eurest cooking demonstration workshops.

In addition, all recipes were collated into two e-books, which were distributed all EUR customers in Portugal. The second e-book was also translated into English, to ensure an even wider audience was reached.

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Main Outcomes

The current approach that includes a daily legume dish/soup/dessert/salad in EUR sites menu plan is having very positive and proven results based on total legume purchase costs. **An increase of + 21% in legumes/ beans consumption has been recorded, with 100% of EUR's restaurants now offering daily legumes options.**

FAO-UN Sustainable Development Goals (SDGs) addressed

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4 Empowering legume production for commercial and agroecosystem benefits

4.1 Intercropping for high productivity in low-input systems

Adrian Newton and Pete Iannetta
The James Hutton Institute (JHI), UK

There has always been a need for plant biomass production for animal feed but in recent years, a new market was established to fulfil the demand from the anaerobic digestion or biofermenter market too. Quality parameters tend to be less stringent than for many other crops such as wheat for bread flour, and because of its bulk, correspondingly the value of the product *per* tonne of biomass is lower. These factors drive a requirement for efficient, low-input production. Current government policies towards net zero carbon production adds a further driver and as the largest contributor to the carbon footprint is often the nitrogen-based synthetic fertiliser, reduction of this requirement can have a disproportionately large benefit. Legumes can fix nitrogen by exploiting a symbiotic relationship with rhizobial bacteria (Carranca, 2013), which means they require little or no synthetic nitrogen and could therefore be of huge value as a component of low input biomass crops.

Used alone, legumes crop species are often not the best biomass crop but used together with other compatible and complementary biomass crop species, they could have considerable potential. Here we consider only autumn-sown crops harvested the following summer to exploit the longer growing season and environmental benefits of near-continuous groundcover and active root growth.

Why use intercropping with legumes?
Intercropping with legumes could have a particular advantage. Firstly, the legume's nitrogen requirement will be lower than other components of the mixture. Secondly, legumes exude soluble nitrogen that can be taken up by other neighbouring plants. Thirdly, where mycorrhizae are active, these too transfer nitrogen (Thilakarathna *et al*., 2016). Whether in intercrops or monocrops, legumes are likely to give the same legacy effects to subsequent crops in proportion to their composition. However, intercrops give the option of introducing further species to also contribute complementary legacy effects.

Challenges
The challenge is to find optimal combinations of species that include one or more legume species and that can confer their benefits within the wholecrop truncated growth period. A further challenge is matching the agronomic treatment requirements of different crop species grown together. Different legume species and cultivars within species are likely to show varying efficacy of

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nitrogen transfer whether by soluble exudation or mycorrhizal transfer when used in different intercropping combinations. Nitrogen transfer rates recorded in literature vary from none to 73% for forage legumes to companion grasses in mixed swords with most biotic and abiotic factors affecting this rate (Thilakarathna *et al*., 2016). Commercial varieties of most crop species are bred for optimum performance in monoculture and with the implementation of specific agronomic methods, and inputs. When intercropping mixtures however, intercrop-specific agronomic factors will be required to deliver the full agronomic and commercial potential.

Transitions necessary for legume-based intercropping take-up and impact

The factors that contribute to achieving sustainable, efficient / low carbon biomass crops using intercropping in a cool temperate northern climate include:

- non-legume crop species;
- legume species;
- varieties of legume and non-legume;
- number of species/varieties in mixture;
- proportions of species/varieties;
- density of components;
- temporal and spatial distribution of components;
- nitrogen / fertiliser application;
- crop protection and herbicide treatments;
- site and season effects;
- end-use quality drivers;
- farming system factors (*e.g.,* tillage method and crop sequence considerations).

All these factors also interact, so definitive formulations will not be possible. To guide practice, the principles determining these choices must be defined and communicated effectively to growers.

Addressing the transitions necessary

The trials were grown across five growing seasons using a total of 26 cultivars of 8 crop species and 162 mixtures between 2015 and 2019 (funded by the Scottish Government). Trial mixtures contained entries with different component numbers and ratios, between 1 and 3 different nitrogen fertiliser regimes, and more than a single cultivar of each cereal and legume components were used in at least one trial. The data clearly show the benefits of pea intercrops on both yield and quality at low nitrogen fertiliser rates (Figure 15). The effects on subsequent crops are shown in Figure 16 where the wheat crops following the higher proportion legume crops show around 30% better yield than following barley, for example.

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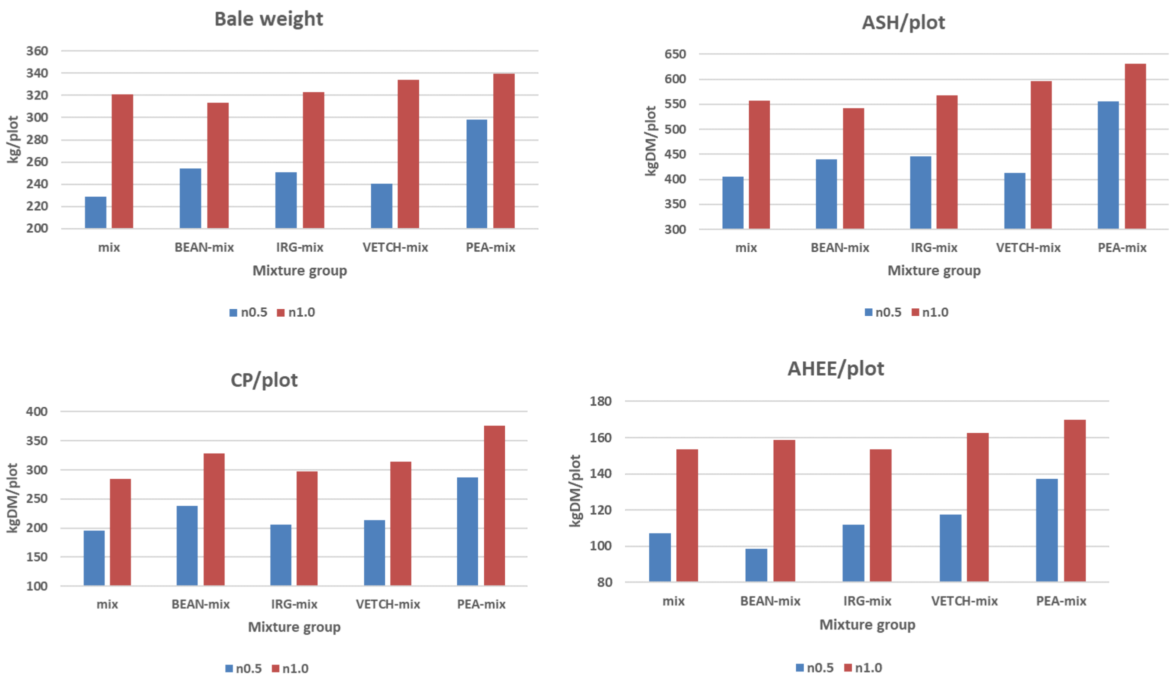

Figure 15. Quality assessments group comparisons for 2016 trial. L.S.D. values for groups*nitrogen 27.8 (bale weight), 108.5 (DM/plot), 560.2 (DOMD/plot), 8.8 (MJ/plot), 53.0 (ash/plot), 49.9 (crude protein/plot), and 20.0 (AHEE/plot). IRG =Italian Rye Grass; AHEE = Acid hydrolysed ether extract; DM = Dry Matter, DOMD = Dry Organic Matter Digestibility**.**

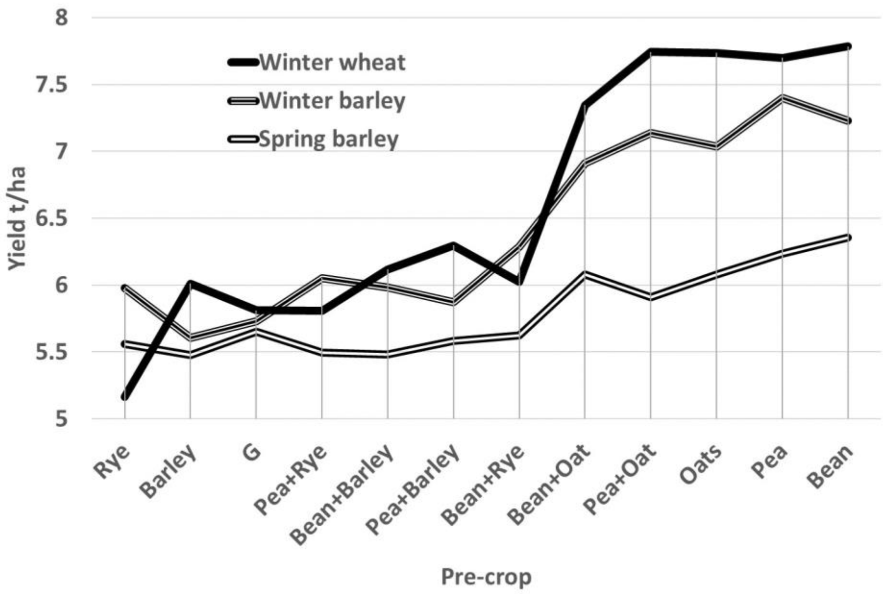

Figure 16. Effect of previous crop on subsequent winter wheat (WW), winter barley (WB) crop and spring barley (SB), ordered by the yield of the pre-crop treatment means. Pre-crop*crop l.s.d. = 0.219 (WW), 0.271 (WB), 0.198 (SB).

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Innovations and intellectual property

Normally stubble is ploughed then harrowed before sowing the next crop in conventional arable systems. **In regenerative agriculture or conservation tillage direct drilling is carried out after the previous crop has been harvested, or directly into a cover crop.** Here we cut a cereal-legume crop mixture or intercrop at or near maximum biomass but before it is ripe. It is then left for 2-3 months before direct drilling into the stubble following a herbicide treatment. This approach would inform agronomic advice to growers and crop planning. **This practice proved suitable for cooler, wetter climates such as north-west Europe.** The biomass crop with a high proportion of legumes works best with low inputs, particularly nitrogen. The subsequent cereal crop is most efficient with lower-than-normal nitrogen inputs too. Direct drilling reduces carbon and nutrient loss to the environment. **This also reduces field operations and therefore fuel and machinery resources. The cropping carbon footprint is therefore reduced throughout the crop cycle.**

Key to uptake or implementation is communication of the findings, which was achieved through peer-reviewed papers, conference presentations, field events and various other presentations. However, data from a wider range of environments is needed for more widespread implementation, although many of the principles deduced will apply broadly.

FAO-UN Sustainable Development Goals (SDGs) addressed

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4.2 Development of precision agriculture technology led agronomy for crop mixtures: strip-sown barley, or wheat with forage-legumes managed as a living-mulches

Jen Banfield-Zanin
Stockbridge Technology Centre Research Foundation (STC), UK

Leguminous living-mulches offer multifunctional positive impacts within crop productions systems. For example, with respect to the biotic and abiotic health of soils, while simultaneously helping to reduce weed, pest, and disease burdens. This in turn can help reduce reliance on agrochemical inputs, and in particular nitrogen fertiliser inputs, which would contribute to the reduction of nitrogen leaching and agricultural pollution into water courses, nitrous oxide (a powerful greenhouse gas) emissions of farming, and so improve the carbon footprint and gross margins of farming. As such, leguminous living-mulches have been considered a tool to achieving a more sustainable, resilient cropping system. Despite this, key challenges remain in terms of establishment, management, and yield stability of the main cash-crop. These must be resolved to encourage widespread uptake in industry, and particularly within “conventionally” cropped systems.

Results

This Case Study sought to investigate the role of Precision Agriculture Technology (PAT) and in-crop clover managed as a living-manure for multi-scale field production across a range of broad-acre crops, to evaluate impact and compatibility within existing agronomy. Overall, trials successfully evaluated the impact of different clover varieties on a range of broad-acre arable crops: spring barley, maize (across two years), and sugar beet, and successfully showed that PAT-assisted strip tillage in newly sown clover understories can help mitigate yield penalties in most years, where clover competition is low (Figure 17, top panel). The trials also suggested differences in suitability of clover species to different crops. For example, red clover made combine harvesting of the plots more challenging as it had climbed higher into the main-crop canopy, whereas no such considerations applied in the maize. The different clovers were also shown to have different weed suppressive potential within a growing season (Figure 17, bottom panel). Finally, trials comparing pre-drilling management of very well-established and mature clover understories showed that, in addition to use of strip tillage, knocking the clover back with a broad-spectrum herbicide prior to drilling can help mitigate yield penalties in cereal crops, which can be considerable, in some years, where no further inputs are applied (Figure 18).

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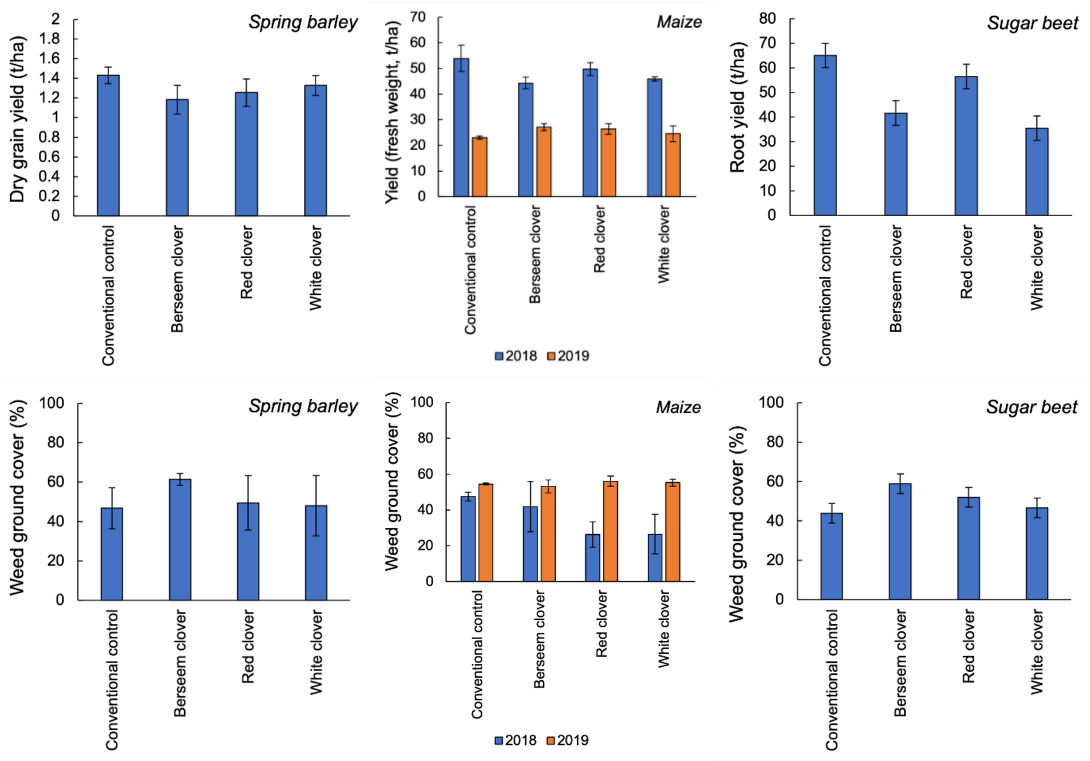

Figure 17. Top Panel: Mean yields achieved; Bottom Panel: Mean percentage weed ground cover. Trials were conducted at STC in 2018 (spring barley, maize) and 2019 (maize and sugar beet), when crops grown with different clover living-manure understories or no clover understory (conventional control), and with a minimum-input approach used across the treatments.

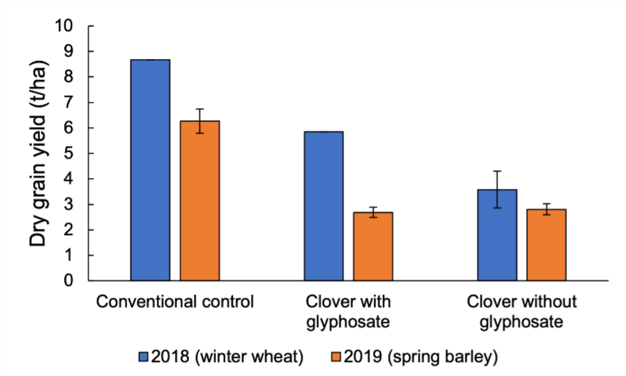

Figure 18. Mean yields achieved from cereal trials at Hessleskew Farm, in 2018 (winter wheat) and 2019 (spring barley), when crops grown with white clover living-manure understories receiving different pre-

drilling treatments (a low-rate application of glyphosate, or without the herbicide application), in comparison to that obtained from crop managed to full conventional standard programmes.

As part of the Case Study, an autonomous "prime mover" prototype, with minimal soil footprint, was developed facilitating innovative management of intercrops using techniques, including selective mowing (Figure 19). The prototype has been pilot tested and is currently undergoing in-field testing (TRL5).

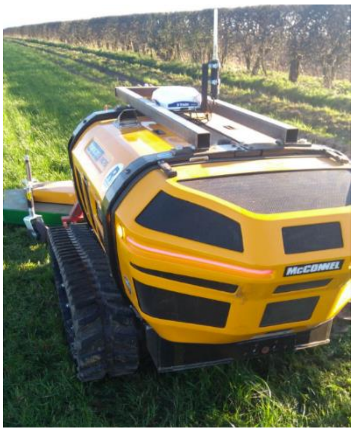

Figure 19. The autonomous prime mover prototype (TRL5) developed by Third party sub-contractor Manterra Ltd.

Conclusion and Achievements

The Case Study has successfully achieved its key aims:

- the successful innovations arising from the combination of commercially available machinery and PAT-assisted platforms with existing approaches to support resilience in cropping systems, which supported maintenance of commercial viability in terms of gross margins while supporting sustainability goals and environmental benefits.
- the development of the autonomous mover, which represents a novel PAT machinery solution to support in-crop clover living-manure solutions, and which is also applicable to other intercropped systems.

An important aspect of this work has been dissemination and demonstration of the approaches to industry stakeholders to discuss gaps in knowledge, areas for development, and to assist in supporting transitions towards implementation of clover living-mulches in the UK. To this end, findings have been demonstrated to industry stakeholders through a series of site visits and workshops, to encourage industry uptake. These have included incorporation into a series of sustainability-focused conferences and webinars, as well as inclusion in Open Days where site visits were made.

Barriers

The lack of crop varieties optimised for performance and use in combination with clover living-mulches and other green understories is a key inhibitor to uptake. Varieties developed and bred with these systems as the target would be expected to compete more strongly with the clover, leading to either improved yield relative to conventional systems, or at least mitigated yield penalty, tipping the cost-benefit in the producer's favour. Achieving good, consistent initial establishment (and subsequent ground coverage) of clover itself can be challenging, even when environmental fluctuations and challenges are accounted for in management. This has led to questions regarding forage legume seed qualities. Another key barrier to greater uptake of these approaches lies in the limited options for in-crop management of clover competition against the main cash crop, which

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can be deployed within a growing season (*i.e.,* not prior to drilling or after harvest). Limiting the clover competition in-season would further support yield outcomes, improving commercial economic viability of the growing season. Equally, there are currently limited options for in-crop management of weeds, especially where poor establishment or post-winter recovery of clover allows weeds ingress to the crop and allows them to gain a foothold. While clover has been observed to be remarkably resilient, there remain few agrochemical inputs which can be applied safely to both the clover and crop. Where the goal is to achieve control of clover competition or weeds without such agrochemical inputs, machinery availability and development targeted towards in-crop, inter-row management of clover and weeds remains necessary, particularly in terms of ground-proofing prototypes and moving these through Technology Readiness levels towards eventual accessibility for grower stakeholders. There remains also a perceived complexity in terms of establishing and managing clover green understory systems, and the associated changes required, relative to existing conventional approaches. As this coincides (at time of writing) with limited policy support for use of these approaches and techniques, this can lead to a reticence by stakeholder to exploit their potential on a wide, farm-scale, particularly where standard conventional, monocultural approaches have been the prevailing agronomic method, and where farmers are tied into existing value chains and markets.

Key transitions identified

Key transitions required for results to be taken up and have real impact **focus on the optimisation of living-manure systems to mitigate impact on farming system commercial viability, and machinery development to support use and uptake.** Necessary transitions also include the **development of ecosystem and soil function resilience-based market and policy support for legume-based cropping systems**. Another important aspect is **plant breeding**, for varietal performance optimisation for use in these cropping systems. **Farmer-led demonstration** of agronomic system at commercial scales would also be essential.

FAOUN Sustainable Development Goals (SDGs) addressed

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4.3 Using legumes as a source of fertility in protected cropping systems

Francis Rayns, Judith Conroy, and Barbara Smith
Centre for Agroecology Water and Resilience, Coventry University (CU), UK

Background

In arable and field vegetable systems, the use of legumes is most often accomplished by using rotations that include a fertility building phase of green manures followed by a period of cropping to utilise the nutrients that have been accumulated. This approach is more difficult in protected cropping situations because the financial value of the infrastructure (glasshouses and polytunnels) makes it harder to justify dedicating adequate time in the rotation to fertility building. Many intensive organic growers consequently rely on the import of fertility in the form of animal manures or by-products such as blood and horn meal. This has ethical implications, (especially for vegan consumers) and makes the system reliant on external inputs (Schmutz and Foresi, 2017).

As well as adding nitrogen from the atmosphere all green manures, including from crops which are non-legumes, contribute to soil fertility by preventing synthetic nitrogen fertiliser use and consequent losses *via* leaching and greenhouse gases. Also, green manures increase soil organic matter, improve water retention, and stimulate soil microbial activity, as well as assisting in the management of weeds, pests, and diseases. Fewer investigations have been carried out into the performance of green manures grown in protected cropping, and the potential of legumes to maintain 'contained soil' fertility. This Case Study was developed following engagement with commercial producers (e.g., members of the Organic Growers Alliance) to overcome existing technological and practical barriers, and to facilitate uptake of the findings of the research.

Experimental work

Replicated trials were set up in unheated polytunnels on a sandy loam soil in the UK midlands. The potential of eight leguminous green manures was compared: crimson clover (*Trifolium incarnatum* L.), Persian clover (*Trifolium resupinatum* L.), berseem clover, (*Trifolium alexandrium* L.), fenugreek (*Trigonella foenum-graecum*), trefoil (*Medicago lupulina* L.), winter vetch (*Vicia sativa*), forage peas (*Pisum sativum* L.) and blue lupins (*Lupinus angustifolius* L.). Additional plots contained a mixture of vetch and rye (*Secale cereale* L.). The plots were not weeded. The plants were regularly assessed (canopy height, crop cover, weed cover, growth stage, pests, disease, and frost damage) and above ground biomass was measured in mid-March and again in mid-April (Figure 20).

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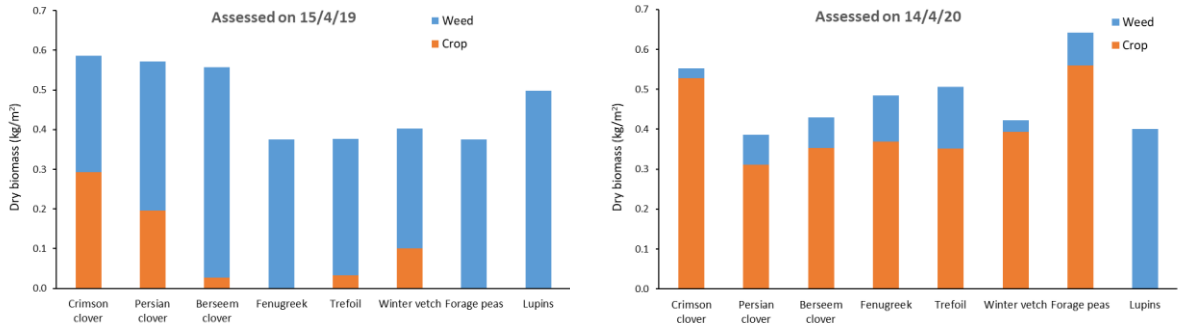

Figure 20. Final above ground biomass of the eight leguminous green manures in April 2019 and 2020.

There were clear differences between the two years (Figure 20). Overall weed pressure was much greater in 2018/19 – in 2019/20 a newly established polytunnel site was used which had been under a weed supressing mulch for several years. Weeds in a green manure are not always an issue as they will themselves add organic matter to the soil but there is a danger that some species will become established and pose a problem for the following crop. There was a spell of very cold weather in January 2020 that almost completely killed the fenugreek, the peas, and the lupins (the latter only established very poorly in both years). Warmer weather in 2020 meant that peas, in particular, did well. The most consistent green manure was crimson clover which, in the above ground biomass at the time of incorporation, contained 85 and 160kg nitrogen ha^{-1} in 2019 and 2020 respectively.

Implications

This study demonstrated that a range of leguminous green manure species can be grown overwinter in the UK in an unheated polytunnel. Some species will perform better than others under a range of conditions and so it will be best to use a mixture to spread the risk and ensure success. To be successful it is also essential that **proper attention is paid to seedbed preparation to ensure good germination and minimise weed competition**. Effective irrigation is also necessary in the absence of rainfall although deeper rooting crops may be able to utilise groundwater shed from the roofs into the spaces between tunnels; rainwater harvesting could be arranged. **All this necessitates investment in time and resources but will ultimately lead to enhanced soil fertility in successive years.**

The use of green manures in polytunnels still occupies valuable protected cropping space. Another approach could be to use **'mobile green manures'** grown in an adjacent outdoor area. These could be applied in the form of freshly cut foliage used as a mulch around growing plants, as composted material or as anaerobic digestate. The latter has several advantages; methane gas would be produced that could be used for heating and the liquid digestate could be supplied using fertigation methodology, precisely dosing the applications to the crop demand. However, there are several practical obstacles to producing it on a small scale that would need to be considered.

Other trials conducted as part of this work looked at legume meal as a source of nutrients. This relatively high value material would be most suitable for incorporation into growing media. For

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example, those used in the production of vegetable transplants prior to these being planted out in the field. This is of particular interest as an organic feed suitable for use in peat-free growing media.

FAOUN Sustainable Development Goals (SDGs) addressed

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4.4 Creating novel grain-legume types using grafting for enhanced yield

Vasiliki Vougeleka, Georgia Ntatsi, Anastasia Tampakaki, Costas Saitanis and Dimitrios Savvas

Agricultural University of Athens (AUA), Greece

Plant grafting, the joining of high performing plant-root and -shoot parts from genetically distinct individuals ("genotypes"), is an ancient technique (Figure 21). The new plant then consists of the upper vegetative component, or "scion" from one parent, and the "rootstock" which is the lower part of another parent. The grafting success depends on various factors and ultimately there must be an effective connection rootstock and scion vasculatures. Grafting affects specific vascular structures such as phloem vessels (for transportation of dissolved substances to and from the above- and below-ground plant parts) and tracheids (that transport water and mineral salts) from the roots with stems and leaves, and vice-versa. Thus, it affects the root-shoot signalling and the relevant physiological processes such as plant growth, nutrient uptake, yield, and stress tolerance.

Figure 21. Grafting is a technique to combine two different plants.

Common bean is a legume cultivated worldwide for its fresh pods or dried seeds, which are consumed by humans and animals. Domestication reduced genetic diversity (Mamidi *et al.*, 2013) but landraces still provide a valuable genetic pool. Like all legumes, its roots establish a symbiotic relationship with rhizobia bacteria forming nodules. However, common bean is a poor nitrogen fixer compared to other legumes (Kabahuma, 2013).

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The challenge

Although grafting is extensively used for vegetables (*e.g.*, eggplants, peppers, and tomatoes) to increase yield and enhance stress tolerance (Ntatsi *et al.*, 2014; Ropokis *et al.*, 2018), it is not yet an applied agronomic practice in bean cultivation. The level [rootstock x scion] compatibility cannot yet be predicted by any specific molecular markers or other plant characteristics. Thus, the compatibility can be determined only by actually grafting different combinations and then assessing the graft connection, and the development of the new plant.

Results

The aim of this Case Study was to investigate the impact of grafting on nodulation, yield, and yield stability under simple stressors: drought and salinity. Four hydroponic experiments were conducted.

- The first trial compared three nutrient solutions that provided 25%, 50% and 100% of the required nitrogen to determine the best nutrient solution for successful bacteria inoculation. It also compared the effect of the inoculation of two different bacteria cultures: *Rhizobium tropici,* or *Rhizobium vuca.* When 100% of the required nitrogen was provided to the plant, this was not compromised and formed fewer nodules. **The nutrient solution that enhanced nodulation was the one that provided the plants with 50% of the required nitrogen.** The two rhizobia tested gave no differences in nodulation.
- The second experiment screened 40 grafting combinations to identify rootstock × scion combinations that increase yield (in terms of fresh pod weight) and to evaluate the impact of the rootstocks on Biological Nitrogen Fixation (BNF). **When *Phaseolus coccineus* L. or another vigorous Greek landrace of common bean called "Pastalia" were used as rootstocks more biomass and more fresh pods compared to the self-grafted was obtained**. In contrast, *Vigna Unguiculata* (L.) Walp. (cowpea) was an unsuccessful rootstock for grafting common bean scions.
- The third and fourth experiments evaluated the four highest yielding combinations under salinity and drought stresses respectively. **These experiments showed that stress tolerance is rootstock related and can be enhanced by grafting.**

FAO-UN Sustainable Development Goals (SDGs) addressed

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4.5 Evaluating the yield and commercial potential of elite-rhizobia

Ioannis Karavidas, Eudoxia Efstathiadou, Georgia Ntatsi, Anastasia Tampakaki and Dimitrios Savvas
Agricultural University of Athens (AUA), Greece

Phaseolus vulgaris (L.), commonly known as bean or common bean, is an important legume crop that is cultivated worldwide as a grain or vegetable crop. The growth of common bean and the achievement of high yields is mainly dependent on nitrogen supply through fertilisation due to its relatively poor ability to fix nitrogen biologically. Increasingly, inorganic nitrogen fertiliser use is seen as a dependency which contributes significantly to eutrophication of water ways through leaching of reactive nitrogen compounds, and releases of volatile nitrogen containing greenhouse gases to the atmosphere. Moreover, the natural and complex solutions offered by nitrogen-based manures from organic farming systems could help us achieve more sustainable common bean cropping, and with positive environmental impacts. Ideally, this should be achieved without any yield penalty. Nitrogen (N) fertiliser supply to organic farming systems is mainly achieved through renewable organic sources such as legumes used as green manure, animal-manures, compost, and crop rotation schemes comprising N-fixing crops followed by N-utilising crops. These organic sources are capable of providing quantities of fertiliser N which is equivalent to that utilised by current conventionally cropped systems *via* synthetic, or inorganic, N fertilisers. However, nitrogen from organic fertiliser sources is unavailable to plants immediately after its application and is released gradually through mineralisation as catalysed by enzymes of soil microorganisms. Therefore, in organic cropping, the well-timed supply of nitrogen is more important than the total amount of nitrogen applied.

In addition, the use of elite or high-performing microbial inoculants such as rhizobia, and other plant growth promoting microorganisms, in organic cropping systems constitutes a practice which may minimise environmental footprint and increase agricultural productivity. *P. vulgaris* establishes symbiotic associations, forming nitrogen-fixing root nodules, with genetically diverse rhizobial species. The promiscuity of common bean is not only related to the rhizobial species but also to the symbiovar (or symbiotic species variant). Common bean can establish symbiotic relationships with a great number of rhizobial species and their symbiovars. While useful on the one hand, the crop displays reduced biological nitrogen fixation capacity compared to other legumes. For this reason, the selection of suitable varieties or landraces of common bean with high nitrogen fixation capacity in combination with efficient, competitive, and well-adapted rhizobial strains in different edaphoclimatic zones is considered the most sustainable agricultural practice for maximising nodulation and nitrogen fixation in common bean, and so achieving optimal biofertilisation, yield and yield qualities.

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Results

A 2-year crop rotation scheme was conducted to investigate the impact of the preceding winter crop on spring-summer cultivation of the common bean in organic farming systems under mild climatic conditions allowing for winter cultivation. The standard practices during the preceding winter in fields cultivated organically with the common bean in spring-summer were either left fallow or cultivation of a cold-season legume (*e.g.,* vetch or faba bean) during the winter, which is also incorporated into the soil as green manure. In the current study, the possibility to cultivate a cold-season non-legume vegetable organically during the winter as a preceding crop to a spring-summer cultivation of the common bean was also investigated. The rotation of a winter non-legume vegetable with a spring-summer common bean crop during the same year was tested under organic and conventional farming practices, the latter serving as a control or comparator treatment. Finally, in all rotation treatments, there were plots with common beans inoculated or non-inoculated with *Rhizobium tropici* strains to test whether this may also serve as a crop benefit.

The main findings indicated that the yield of common bean cultivated organically in the open field during spring-summer, following a legume crop applied as green manure during the preceding winter, resulted in similar or even higher soil mineral nitrogen levels and similar yield with those found in the conventionally cropped bean (Figure 22). **Faba bean, served as green manure crop during winter, exhibited a considerable increase in plant biomass and the total amount of biologically fixed nitrogen *per* unit cultivated area after inoculation with *Rhizobium laguerreae VFLE1* in both winter cultivation periods.** However, the greater nitrogen fixing activity in inoculated treatment did not benefit the nitrogen availability of the subsequent organic common bean crop. In addition to this, inoculation of common bean crops with *Rhizobium CIAT 899* did not substantially enhance its biological nitrogen fixing activity. Therefore, the inoculation of both legume crops did not fulfil its initial purpose as it did not contribute to greater nitrogen supply to common bean crop under organic cultivation system.

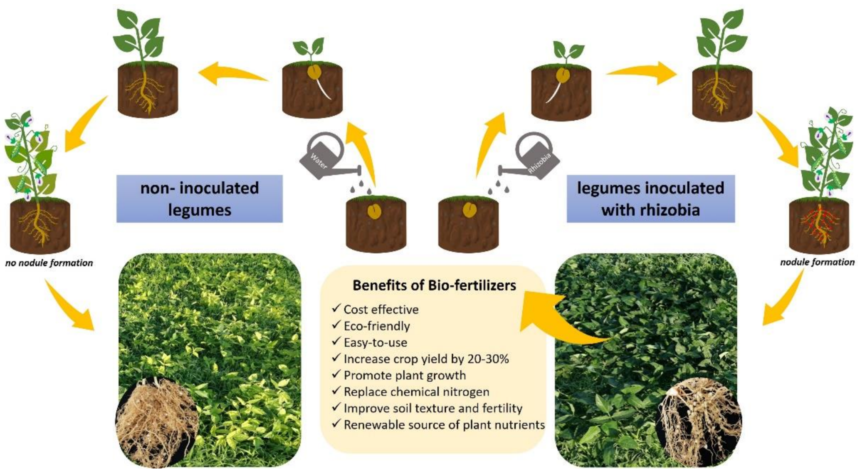

Figure 22. Effect of rhizobia-based biofertilisers on plant growth and performance. Photo credits ©: Evdoxia Efstathiadou, Anastasia P. Tampakaki.

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In addition to the above field investigation, research has also been conducted isolating and characterising, at the species and symbiovar level, rhizobia that nodulate local common bean varieties grown in five different edaphoclimatic regions of the mainland and the islands of Greece. The genetic diversity of the rhizobial isolates was assessed at the molecular level. This led to the first report on the characterisation of bean-nodulating rhizobia at the species and symbiovar level in Greece. The results showed the presence of strains that were affiliated to *R. anhuiense*, *R. azibense*, *R. hidalgonense*, *R. sophoriradicis*, and to a putative new genospecies. Most strains belonged to symbiovar phaseoli carrying the α-, γ-a and γ-b alleles of *nodC* gene, while few of them belonged to symbiovar gallicum (Figure 23). All strains formed effective symbiosis with bean plants, suggesting they are true symbionts of common bean. To the best of our knowledge, it is the first time that strains assigned to *R. sophoriradicis* and harbored the γ-b allele were found in European soils. Moreover, the results highlighted that local rhizobium may have acquired symbiosis genes via lateral gene transfer in the rhizosphere or within nodules since key gene (*nodC*) alleles were present in diverse rhizobial strains regardless of the species to which they belong. With regards to the distribution of our isolates in different regions of Greece, some isolates were predominant in certain soils while others were found in different locations. Nevertheless, the findings cannot provide conclusive evidence for the association of the rhizobial diversity with the edaphic parameters or host genotypes at our sampling sites since more isolates should be examined from each site. Hence, **the current study increases the knowledge of the diversity, geographic distribution, and evolution of common bean-nodulating rhizobia in European soils and provides a natural resource for the selection of highly efficient rhizobia that are more competitive and adapted to the local conditions.**

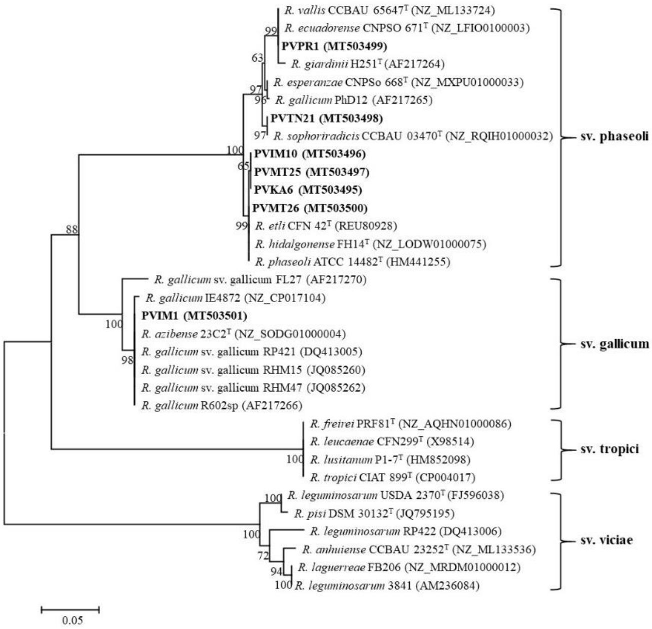

Figure 23. Definition of the symbiovar within common bean-nodulating rhizobia isolated from Greece (shown in bold) based on nodC gene sequences.

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4.6 Breeding grain legumes for improved yield and disease resistance in Mediterranean environments

Eleonora Barilli
Solintagro SL (SOL), Spain

This study explores the adaptation of new cultivars and breeding lines of a range of legume crops to Mediterranean environments. Special focus was on chickpea, lentil and faba bean as they were historically major components in Mediterranean diet, and pea, vetch, grass pea and lupin, which are important for animal feed uses. Similarly, to other Mediterranean countries, Spanish production of these legumes covers only a small proportion of the actual demand (range 20-30%) leading to high imports. This is due to legumes having been replaced in the rotations by other crops that were more readily adaptable to parallel technology introductions, such as agrichemicals, and are more profitable for farmers under current market conditions. In Spain, *circa* 5 million tonnes of grain legumes are imported yearly, out of which a large part is soybean for animal feed (95% of the total). Pea harvested as dry grains is the only legume grown in Spain in the last two decades with clear expectations for sustained expansion of its cultivatable area (Figure 24). However, even with this projected increase in pea cultivation in Spain, this remains far below requirements, and high amounts are imported annually to satisfy the demand of the food and feed industry. Hence, to meet future demand grain legume breeders must be able to provide farmers with seed of quality cultivars adapted to local environmental and market needs. Current, so-called modern elite legume cultivars are poorly adapted to Mediterranean environments, since breeding programmes have concentrated their efforts on ensuring adaptability to geographically large centres of cultivation such as parts of Canada, Central and Northern Europe. Substantial breeding efforts are therefore needed to ensure the generation of varieties adapted to Mediterranean rain-fed farming systems, and their associated biotic and abiotic stresses.

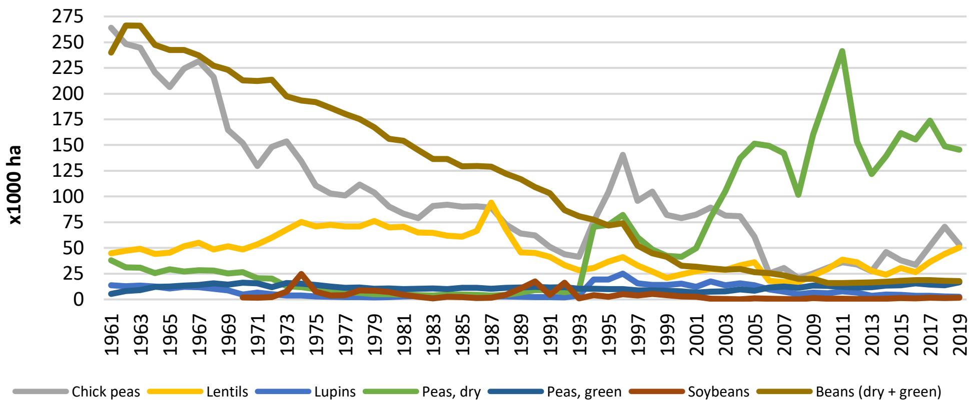

Figure 24. Historic (1961-2019) trend for grain legume cultivation in Spain (FAOSTAT data).

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Results

This Case Study assessed the adaptation of new cultivars and breeding lines to constraints typical of Mediterranean environments. A priority was resistance to broomrape (*Orobanche crenata*), as it is the main constraint to the yield of most legumes in Mediterranean areas, and this is not addressed by most breeding programmes. This broomrape resistance of any new legume type should be complemented with resistance to other diseases and offer superior standing ability plus reduced susceptibility to drought, whilst also meeting market quality expectations. This was tested through a set of cultivars and breeding lines of these crops under field conditions at three locations over two seasons.

Legumes were sown by Solintagro during seasons 2017/18 and 2018/19 at three different locations. Crops were phenotypically and agronomically evaluated to identify the most well-adapted to each location. The morpho-physiological traits of the harvested seeds were analysed (Figure 25, left panel), as well as protein and mineral contents, anti-nutritional compounds derived from the secondary metabolism) to differentiate genotypic (G), environmental (E) and G*E interactions in yield and in quality traits (Figure 25, right panel).

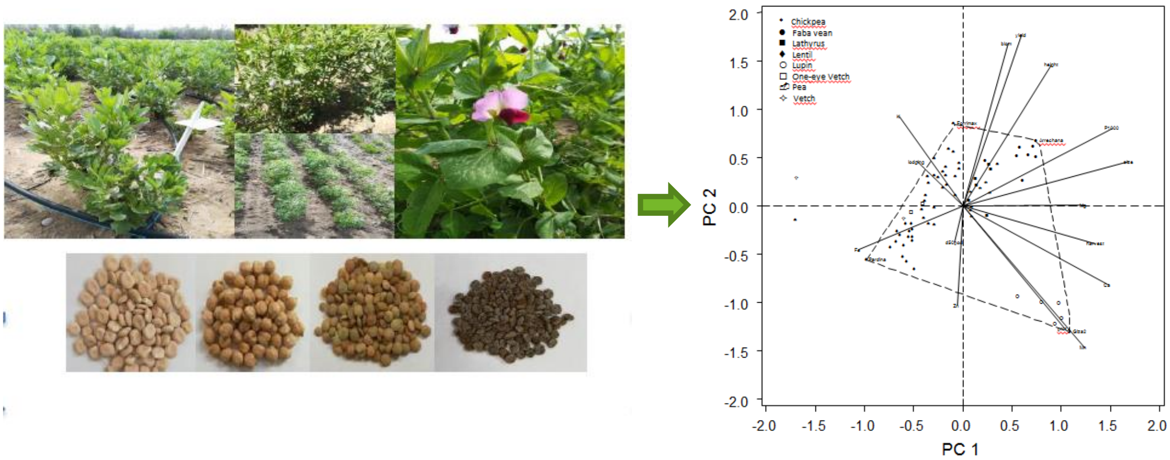

Figure 25. Left panel: Plant legumes cultivated in Spanish trials and seeds samples for analyses, Right panel: Genome-trait (GT) analysis for agronomic and nutritional parameters for season 2017-18.

Critical Appraisal/Opinion

Our study was motivated by the need to increase legume cultivation to satisfy actual and forecasted increased legume demand, which can only be achieved by selecting new cultivars more adapted to the region where they are to be introduced. Hence, **a reliable dataset on yield, adaptation, and quality of a large set of novel lines of legumes as chickpea, lentil, lupin, pea and faba bean have been collected**. In addition, **these accessions have been characterised in terms of nutritional and anti-nutritive factors**. Soon, further development of new breeding lines, fulfilment of new cultivar registration and commercialisation will still be required to reach market.

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FAO-UN Sustainable Development Goals (SDGs) addressed

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5 Optimising legume inclusion in regional cropping systems

5.1. Lowering the carbon footprint of pasture-based dairy production

James Humphreys[1], Owen Cashman[2], Marion Sorley[1] and Imelda Casey[2]
[1] Teagasc, livestock Systems Department, AGRIC, Ireland
[2] Waterford Institute of Technology, Department of Science, Ireland

At 13.2 t, the greenhouse gas (GHG) emissions *per* capita in Ireland is one of the highest in the European Union and globally. Agriculture is an important source of GHG emissions accounting for one third of national emissions, which is an exceptionally high proportion compared to other European countries. Dairy farms in Ireland are substantially more profitable, use resources more intensively than other agricultural enterprises and account for approximately 20% of agricultural land use and 45% of GHG emissions or approximately 15% of national GHG emissions in 2020. There has been a substantial increase in dairy farming in Ireland. More cows and replacement heifers mean more biogenic methane emissions from enteric fermentation and from their excreta. There are also more nitrous oxide emissions due to greater fertiliser nitrogen use and from livestock excreta. Methane and nitrous oxide are important GHG, accounting for more than 90% of GHG emissions from Irish dairy farms. This has put dairy farming in the spotlight in Ireland because while there have been reductions in GHG emissions from other sectors of the economy, energy generation for example, these have been offset to an extent by increases from agriculture and from dairy farming in particular.

Objective

The objective of this Case Study was to investigate the potential to lower GHG emissions from Irish pasture based dairy production while maintaining productivity and profitability by implementing best practices such as: (i) inclusion of legumes to supply biologically fixed nitrogen in grassland instead of fertiliser nitrogen (N); (ii) use of low emission slurry application to make more efficient use of the nutrients in slurry, particularly N; (iii) to use NBPT (N-(*n*-butyl) thiophosphoric triamide) protected urea (to reduce nitrogen losses to the environment from the action of urease) as the sole source of fertiliser nitrogen; and (iv) using high genetic dairy livestock according to the Economic Breeding Index (EBI). The first three practices were implemented primarily to lower nitrous oxide emissions, whereas the latter practice was implemented to lower biogenic methane emissions.

The experimental systems

Two experimental systems were set up and involved farm-scale systems with 24 cows on 9.6 ha *per* year. The control system was based on standard practice on intensive Irish dairy farms. In the clover+NBPT urea system, fertiliser nitrogen was applied solely as NBPT-protected urea. A third system (Clover-Zero) was added to the study in 2019 and 2020. Details of the three systems are outlined in Table 2.

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To compare the environmental and economic performance of the three systems, the results were scaled up to a farm area of 50 ha. Stocking rates of dairy cows in the scaled-up model were based on herbage production on the basis that approximately 90% of the diet of the dairy cows was home-grown grazed grass or grass silage, which is standard practice in Ireland. Environmental impact was assessed using life-cycle assessment (LCA) based on 'fat and protein corrected (by volume) milk' (FPCM) or *per* ha, and economic performance was determined using an economic model. In the economic assessment standard costs were used either from Solohead Research Farm or from the National Farm Survey as appropriate. Replacement heifers were reared under contract on a neighbouring farm, which is standard practice on many intensive dairy farms in Ireland.

Table 2. Productivity, economic performance, and environmental impact of systems of pasture-based dairy production.

	Intensive Control	Clover+NBPT urea	Clover-Zero
Fertiliser nitrogen (kg/ha)	280	110	0
Fertiliser nitrogen type	CAN and urea	NBPT urea	Not applicable
Clover content of pasture DM (%)	10	22	26
Slurry application	Splash-plate	Trailing shoe	Trailing shoe
Herd EBI (€)	165	165	195
Annual pasture DM production (t/ha)	14.48	13.80	13.50
Annual concentrates fed (kg/cow)	493	493	493
Milk yield (kg/cow)	5,886	5,931	6,166
Protein (%)	3.63	3.65	3.58
Fat (%)	4.66	4.62	4.52
Modelled results scaled up to a 50 ha farm			
Stocking rate (cows/ha)	2.50	2.40	2.35
Cows per farm	126	120	117
Total milk sold (kg)	738,276	709,754	725,544
Milk sales (€)	250,894	240,467	239,932
Total sales (€)	275,443	263,859	262,842
Fertiliser nitrogen (€)	13,300	4,276	0
Total variable costs (€)	94,997	84,166	78,370
Gross margin (€)	180,446	179,693	184,472
Labour costs (€)	50,419	48,044	47,052
Other fixed costs (€)	57,216	55,006	55,823
Net Margin (€)	72,811	76,643	81,597
Net Margin (€/ha)	1,456	1,533	1,632
GHG (kg CO_2eq./L FPCM)	0.88	0.75	0.69
GHG emissions (t CO_2eq./ha)	12.3	10.1	9.5
Ammonia (kg/t milk)	4.00	3.17	2.81

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Results

A comparison of carbon footprints, particularly across international boundaries, need to be treated with caution due to differences in methods used to make the assessments; variation in emission factors from region to region, the extent of the inventory used to assess a farm can vary, and whether the assessment is restricted to including emissions generated within a national boundary or based on their global impact and other issues. In the current assessment the carbon footprint represents the global footprint of the milk produced and sequestration of carbon dioxide (CO_2) by grasslands is not included. On this basis the average carbon footprint *per* L FPCM on intensive Irish dairy farms is 1.05 kg CO_2eq. All the systems, including the resource-intensive control in the present study had lower carbon footprint than the national average. This can be attributed to the high level of technical efficiency on this research farm; for example, the EBI of the herd is well above the national average. The national average EBI per cow was €105 in 2019.

Relative to the resource-intensive control in the present study the two clover-based systems lowered GHG emissions per ha by 18% and 23% for the Clover+NBPT and Clover-Zero systems, respectively (Table 2). Likewise, these systems lowered ammonia emissions by 21% and 30%, respectively. The volume of milk sold decreased by 4% and 2%, respectively. The higher EBI of the cows on the Clover-Zero system compensated with higher milk yield per cow to somewhat offset the lower stocking rate on this system. Nevertheless, the two clover-based systems improved profitability compared with the control.

In Ireland dairy farms are typically operated as family farms with little or no hired labour. Economic performance can be also assessed in terms of Family Farm Income (FFI), which is the combination of net margin and labour cost and typically represents a taxable income on any portion of it that is not invested back into the business. The FFI of the above three systems: €120,517; €125,629; €129,184 compare favourably with the national average FFI in Ireland (approximately €65,828 for dairy farm income in 2019) and are comparable with the top 10% of dairy farms.

Relative to the national average the two clover-based systems in the present study lowered GHG emissions by 29% and 34%. This shows that there is substantial potential to lower GHG emissions from Irish dairy farms by the adoption of best practices. Of the practices examined in this study the adoption of white clover and other pasture legumes, their capacity to biologically fix nitrogen and lower fertiliser nitrogen use and associated nitrous oxide emissions, was the single biggest contributor to lowering both GHG and ammonia emissions from the experimental systems. Legumes were historically important in Irish grassland but were largely replaced by fertiliser nitrogen during the 1970's and hence, are not used on Irish dairy farm as farmers prefer the simplicity and reliability of regular applications of fertiliser nitrogen to grow grass for their livestock. However, the agricultural sector and dairy farmers, in particular, are under increasing societal pressure to lower emissions from their farms, which has generated renewed interest in the use of legumes in grassland.

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Conclusions

Transitioning to net zero emissions by 2050 will require substantial changes in Ireland. Emissions *per* L FPCM produced in Ireland are relatively low by international standards, but agriculture is predominantly pasture-based livestock production of milk and meat products and hence, it is responsible for a large proportion of national GHG emissions. The present study demonstrates that **it is possible for farmers to substantially lower emissions and improve FFI by the adoption of best practices. Grassland legumes and white clover made the single biggest contribution to lowering emissions from the experimental dairy systems** in this study.

FAO-UN Sustainable Development Goals (SDGs) addressed

The TRUE-Project has received funding from the European Commission *via* the Horizon 2020 Research and Innovation Action Programme under Grant Agreement number 727973.

5.2. Teagasc Clover Discussion Group

William Burchill[1] and James Humphreys[2]

[1] Teagasc Moorepark advisory, Ireland

[2] Teagasc, livestock Systems Department, AGRIC, Ireland

Dairy is by far the most profitable farming enterprise in Ireland. Its profitability is driven by the production of milk from grazed pasture, which is cheaper and, in many cases, superior in nutrition to other feed types *e.g.,* conserved silage, maize. Grazed pasture on intensive Irish dairy farms requires large input of nitrogen to sustain high levels of pasture production with fertiliser nitrogen being the dominant input of nitrogen on Irish dairy farms typically accounting for >80% of nitrogen inputs. Fertiliser nitrogen usage is associated with greenhouse gas and ammonia emissions and reductions in water quality. Hence, there is an urgent need to reduce nitrogen fertiliser usage on Irish dairy farms while maintaining pasture productivity. The use of legumes such as red and white clover offers such an opportunity. Long term trials have found dairy production systems based on perennial ryegrass/white clover pasture receiving 0-90 kg fertiliser nitrogen ha^{-1} $year^{-1}$ to have similar levels of profitability and lower carbon footprint *per* litre of milk compared to dairy systems based on perennial ryegrass pasture receiving 220-250 kg nitrogen ha^{-1} $year^{-1}$. While well proven at research level there has been a low uptake of clover on Irish dairy farms stemming largely from a lack of knowledge of the benefits of clover and how to successfully establish and manage perennial ryegrass/white clover swards. There is also a barrier to adopt research findings due to a perception among some farmers that what works within the confines of a research farm may not always work within a commercial dairy farm. The use of monitor farmers and farmer discussion groups are two well proven models for knowledge transfer and adoption of research findings. Monitor farms receive extensive advice on how to adopt new technologies from research and illustrate to other farms how they can work within commercial dairy farms, while farmer discussion groups allow farmers to share their experiences and knowledge of different farm practices.

Objectives

This work aims to improve the adoption and knowledge of clover among Irish dairy farmers by: (i) establishing a farmer discussion group focusing on clover; (ii) providing the group with extensive research updates and advisory support to allow them to successfully establish and manage clover; and (iii) monitoring the progress of the group and use the learning/examples from the group to transfer knowledge to Teagasc advisors and other farmers on clover. The Clover Discussion Group members essentially acted as monitor farms to demonstrate to other farmers that grass/clover swards can be established and managed to reduce nitrogen fertiliser inputs. The knowledge transfer model employed is illustrated in Figure 26.

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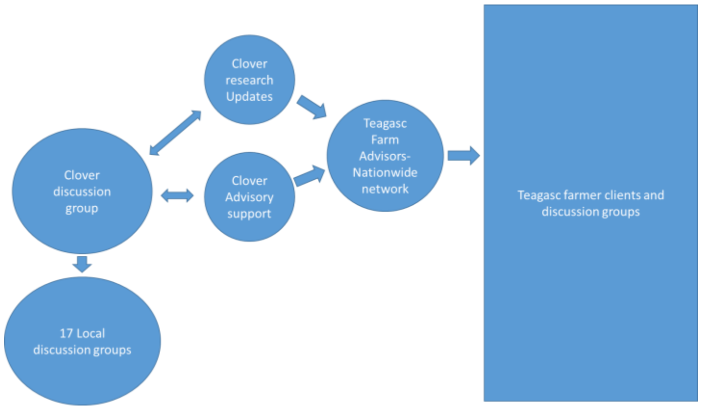

Figure 26. Knowledge transfer model used to promote the use of clover on Irish dairy farms.

The Clover Discussion Group

The Clover Discussion Group consisted of 17 dairy farmers with an interest in clover. The farms where from the southern half of Ireland (County Cork, Waterford, Tipperary, Kilkenny, Offaly, Kildare, and Wicklow). Farm size ranged from 41 ha to 172 ha (mean: 84) and whole farm stocking rate ranged from 1.72 to 2.94 livestock units[3] ha^{-1} (mean: 2.39). Fertiliser nitrogen usage at the beginning of the study ranged from 0 to 323 kg nitrogen ha^{-1} year^{-1} (mean: 175) across the farms. One of the 17 farms was farming organically. At the beginning, the experience of using clover among group members ranged from farmers with over 10 years of experience of using clover to farmers with no clover on the farm. All farmers in the group were members of their own local dairy discussion group which allowed for further transfer of knowledge from the clover group to a wider network of dairy discussion groups across the south of Ireland.

The Discussion Group met five times *per* year for 2-3 hours. Meetings were held on the group members' farms, at Teagasc research farms or online *via* 'Zoom'. A 'WhatsApp' group was established for the Clover Discussion Group to provide a platform for the group to interact and exchange knowledge & questions in between group meetings. The WhatsApp group was also used to provide clover research and advisory updates to the group on an ongoing basis.

FAO-UN Sustainable Development Goals (SDGs) addressed

[3] Livestock units facilitate the aggregation and comparative analysis of different farmed animal species, and on the basis of age via the use of specific coefficients. One livestock units (1 LSU) is the grazing equivalent of one adult dairy cow producing 3 000 kg of milk annually (without additional concentrated foodstuffs), A sheep or goat is 1/10th of this. For more information see Eurostat.

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5.3 Nutritional variation and LCA methodology effects on the carbon footprint of milk production

Maggie March, Paul Hargreaves, Alasdair J. Sykes, and Robert M. Rees
Scotland's Rural College (SRUC), UK

The science and practise of farming is changing to meet the needs of the environment. One key challenge is to reduce greenhouse gas (GHG) emissions by lowering the carbon footprint associated with dairy production. To meet mandatory emissions targets, GHG mitigation measures based on farm management type will become increasingly important as more generic options become exhausted. An improved understanding of emission sources across a range of production systems is required to lower the burden associated with livestock products. Dairy feeding system trials were carried out to assess the effects of introducing farm grown forage legumes and non-human edible co-product feeds in diets of dairy cattle. Spring beans and lucerne were grown at SRUCs Crichton Royal farm in southern Scotland and no feeds were purchased, except minerals in the novel Homegrown dairy system.

The Research
Dairy production system data were gathered from diverse breeds of Holstein Friesians managed in Langhill feeding experiments. The Langhill dataset provides a unique resource to allow life cycle assessment (LCA) and modelling of GHGs associated with the production of milk within different feeding and housing regimes. This research focused on assessing differences in GHG emission types stemming from high production Select-merit and UK-average Control merit dairy cattle managed within Low Forage and By-product housed, and High Forage and Homegrown, grazed regimes. Further investigations were carried out to determine uncertainty stemming from the variation of diet digestibility and crude protein. GHG's were calculated using SRUC's Agrecalc carbon foot-printing tool.

The Results
Control merit footprints *per* unit of milk produced across each of the management regimes were significantly higher ($p<0.001$) in comparison with high production Select merit cattle, on average by 15%. Likewise, livestock emissions (related to enteric fermentation, manure management, deposition) and embedded emissions (related to purchased feeds, fertiliser, pesticides) were significantly higher in the Control merit herds ($p<0.01$). Pairwise comparisons showed GHG's from the systems to be significantly different in total and emission types, with significant differences in mean embedded emissions found between most management systems ($p<0.05$), shown in

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Table 3. Figure 27 shows the Select merit carbon footprints expressed by emission source. Nutritional quality of the rations was investigated to determine uncertainty in the carbon footprint results stemming from natural variation of feed components. Monte Carlo simulated system footprints considering the effect of variation in feed digestibility and crude protein (CP) differed significantly ($p < 0.001$) from system footprints using average measures of CP and digestibility. Carbon accounting of purchased feed inputs using mass and economic allocation and incorporating land use led to differences in comparative performance ranking of the dairy systems according to functional units applied (Table 4).

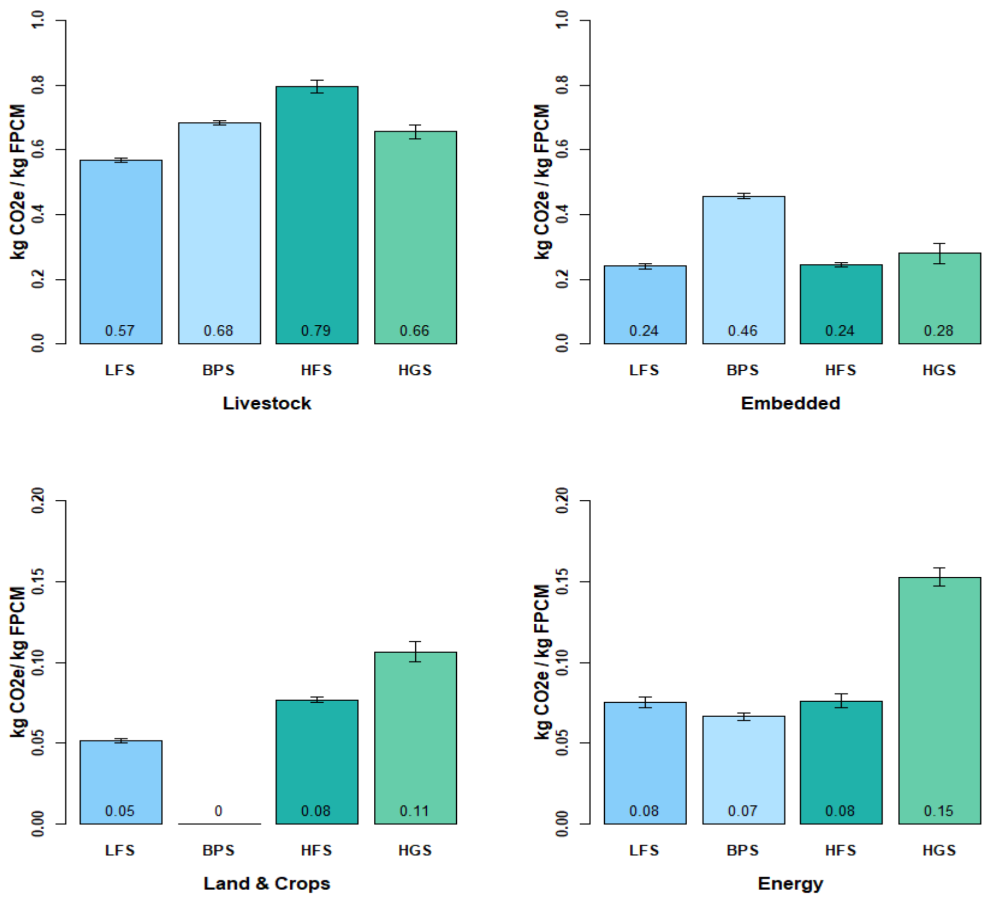

Figure 27. Dairy system average GHGs (as CO2e) associated with different emission source types (error bars denote SEs – standard errors). LFS= Low Forage Select, BPS=By-product Select, HFS= High Forage Select, HGS =Home Grown Select, FPCM = Fat and protein corrected milk.

Table 3. Least square means of dairy system GHG's by emission type.

System	Land CO_2e /kg FPCM	Livestock CO_2e /kg FPCM	Embedded CO_2e /kg FPCM	Energy CO_2e /kg FPCM
LFS	0.06^{a}	0.49^{a}	0.34^{a}	0.08
BPS	0.00	0.61^{b}	0.39^{b}	0.07
HFS	0.09^{b}	0.73	0.28^{c}	0.08
HGS	0.11^{c}	0.73	0.22^{d}	0.15^{a}
LFC	0.07^{d}	0.59^{c}	0.40^{e}	0.09
BPC	0.00	0.71^{d}	0.46^{f}	0.07^{b}
HFC	0.10^{e}	0.84^{e}	0.33^{g}	0.08
HGC	0.12^{f}	0.81^{f}	0.25^{h}	0.16^{c}

LF= Low Forage, BP=By-product, HF= High Forage, HG =Home Grown, S= Select, C=Control. Different superscripts within a column denote significant differences between levels of the same variables ($p < 0.05$). FPCM = Fat and protein corrected milk.

Table 4. Ranked comparison of dairy system performance using alternative footprinting methods and functional units.

Carbon footprinting method	Unit	Merit	LF	BP	HF	HG
Economic allocation	FPCM	Select	1	2	3	4
Mass allocation of feeds	FPCM	Select	2	4	3	1
Economic allocation	ha	Select	2	4	3	1
Economic allocation	FPCM / ha	Select	2	1	3	4
NCGD & CP Sensitivity	FPCM	Select	1	3	4	2
NCGD & CP Sensitivity	FPCM	Control	1	3	4	2

LF= Low Forage, BP=By-product, HF= High Forage, HG =Home Grown, FPCM = Fat and protein corrected milk, NCGD = Neutral Cellulase Gammanase Digestibility, CP = Crude Protein.

The Impact

Dairy system carbon footprint results should be expressed using multiple units and where possible calculations should incorporate variation in diet digestibility and crude protein content. Using an economic allocation, a localised home-grown feeding regime had the highest carbon footprint. However, this more self-sufficient system was associated with the lowest footprint using mass allocation of feeds and attracted the lowest area-based emissions, when not considering milk output. This result suggests a need for dairy system carbon footprints to be expressed in multiple units and to be mindful that methods used to allocate inputs can affect outcomes. Hence, **to achieve economy-wide reductions in agricultural GHG emissions, mass and area-based assessments of mitigation should be considered alongside methods using fat and protein corrected milk output, to guide the delivery of policy objectives.**

FAO-UN Sustainable Development Goals (SDGs) addressed

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March *et al.*, 2021. Effect of nutritional variation and LCA methodology on the carbon footprint of milk production from Holstein Friesian dairy cows, *Frontiers in Sustainable Food Systems* (Accepted provisionally). https://www.frontiersin.org/articles/10.3389/fsufs.2021.588158/full

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5.4 A market-model of legume-based feed for organic pig production

Karen Hamann[1] and Lars Lambertsen[2]

[1] Institute for Food Studies & Agro industrial Development (IFAU), Denmark

[2] Organic Denmark, Denmark

This Case Study explores the opportunities for using home-grown legumes as feed source in organic pig production mainly in Denmark. The most used protein source for organically farmed pigs in Denmark is organically grown soya. To mitigate climate impact and to better accommodate the principles of organic farming, it is important to find home-grown alternatives to imported protein feed (European Commission, 2018). In Denmark the area under organically farmed pulses has doubled from 8,705 ha in 2016 to 15,685 ha in 2018 (Lambertsen, 2019) and this area continues to increase. Mixed crops such as peas/barley or lupin/spring wheat are still regarded as novel crops in Denmark. However, the area sown with lupins is increasing. Organic farmers seek to grow more high protein legume/ and cereal grain crops in mixtures, that is by "intercropping" – sowing into the same field at the same time combination. The higher yields *per* unit area of intercropping improves feed protein self-sufficiency, and delivers additional agronomic benefits afforded by biological nitrogen-fixation, and crop residues for better soil functions generally. Organic farmers in Denmark realised that by working together, the cultivation of intercrops such as peas/barley or lupin/spring wheat could become more prosperous. Such collaborative efforts emerge in a variety of ways, including joint investments in key capacities such as: storage facilities, pooling of crops for improving logistics and better bargaining conditions for selling the crops, or working together for an improved and diversified crop rotations, and achieving a stronger circular economy for resources more generally across/between farms.

Main Findings

Danish feed mills are keen to purchase more organically grown pulse crops, such as faba beans, peas, peas/barley, and lupin. However, the feed industry identified four major hurdles to increasing organic pulse crop production and these are: current volumes are too small to justify investment; logistical challenges, (including long distances to processing centres), the higher price of Danish crops *vs.* imported protein feed, and the added costs associated with the requirement to separate organic crops from non-organic crops. Also, the amino acid content of pulses, and specifically the essential ones does not match that of the market leader – soybean. Hence, feeding rations formulated with pulses need to balance/increase the amino acid content to meet the nutritional requirement of the animal – for pigs the essential amino acids lysine and methionine are especially important. In many cases, this means adding an excess of protein to meet essential amino acid requirements. Eventually, this protein, reactive nitrogen, will be excreted by the animal impacting negatively on the environment. In praxis, feed manufacturers would add synthetically produced (essential) amino acids to adjust levels accordingly. However, this approach is not allowed for organic agriculture, value chains, and products. Consequently, diet formulation is challenging

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where home-grown pulses are used. The results from this Case Study demonstrates that feed for organically produced pigs can be formulated with Danish-produced pulses (Table 5).

Table 5. Examples of compound feed for organically produced pigs in Denmark (2019) in % of ingredients.

Ingredients	Organic compound feed for lactating sows		Organic compound feed for fattening pigs	
	With soya	Without soya	With soya	Without soya
Organic grains	69.3	68.2	67.4	35
Faba beans	13	13.2	13	23.8
Lupins		4.8		
Rapeseed cake		5.1		8.9
De-hulled oats		3.1		29.6
Fish meal		3	4	
Soy cakes, Chinese origin	15		13	
Vitamins and minerals	2.7	2.6	2.6	2.7
Protein content	15.01	15.87	16.82	17.48
Digestible protein, g/kg	123.7	129.5	141.0	146.0

(Lambertsen, 2019)

Table 5 shows that homegrown diets are possible in Danish organic agriculture but may require more ingredients to compensate for the lack of soya cakes. It is also evident that the home-grown diets tend to have a higher protein content to ensure sufficient supplies of essential amino acids, especially lysine.

Demand for organic meat from consumers in Denmark and abroad have created a market-pull situation for organic pig meat, motivating more Danish farmers to produce pigs organically. This will have a positive impact on demand for home-grown pulses for feed. The Organic Action Plan advocates for 25 % of EU agriculture being converted to organic production, and this is reflected in Danish agricultural policies.

In Denmark, most of the infrastructure for crops (storage and processing facilities) belongs to feed companies, but farmers do have some facilities for storage (European Commission, 2017). However, to encourage more farmers to grow organic pulse crops it is essential to secure investments in the agribusiness sector (on-farm and in feed companies) to facilitate the route from field to market. In addition, farmers are keen on learn more to continuously improve their farming practices. It is therefore important to continue to train the farmers in organic methods for crops and livestock production. The Organic Innovation Centre in Denmark (established April 2021 by Organic Denmark and Danish Agriculture and Food Council) underlines the importance of innovation, knowledge, and training to maintain the dynamic and growth in the organic sector. The results of this work will be made available to Danish farmers through this new Centre.

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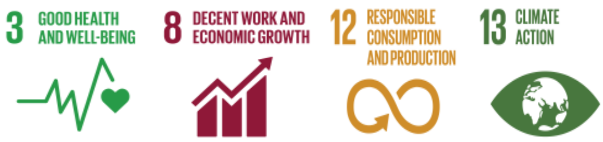
Critical Appraisal/Opinion

Denmark is among the countries where organic food account for 10 % or more of the food market. Since the early 1980s, Denmark has taken a strong interest in organic production methods and in 1987 Denmark introduced an organic certification scheme for organic food backed by legislation, which was the first legislation in the world about organic production. History shows that organic production is strongly rooted in Denmark and still developing. The challenges of finding relevant organic protein feed sources to replace imported certified organic soya cakes for the organic pig production are very important to address, not only in a Danish context. Work shows that **Danish organic pig producers could become self-sufficient with feed protein**. In a wider context, the Case Study has demonstrated **the importance of connecting the knowledge and experiences from agriculture, the value chain and, markets to achieve a goal of enhancing organic agriculture.**

FAO-UN Sustainable Development Goals (SDGs) addressed



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5.5 The role of legumes in Croatian agricultural production and economic development

Magdalena Trstenjak
Public Institution for the Development of the Međimurje County (PIRED), Croatia

Legumes are recognised to be ideal for meeting protein and energy requirement of both man and animal. Globally it is most probably the world's most valuable crop, used as feed by billions of livestock, as a source of dietary protein and oil by millions of people, and in the industrial manufacture of thousands of products. Europe is dependent on leguminous crops imports, in particular soybean used as livestock feed.

A current situation analysis in Croatian agri-food and -feed sector with a special focus on legume crops was conducted. Legumes are an essential part of Croatian traditional and modern cuisine, while fodder crops are used extensively in Croatian livestock production. Legume production in Croatia relies mainly on the activities of small-farms who use the crops as part of their rotation or for their own livestock production or consumption needs. Hence, most of these farmers produce legumes only for their own use. In addition, the commercial interest in legumes production is very low, and so only a few farm businesses are entirely focussed on cultivation, processing, and marketing. However, soya is the exception. Today, Croatia is among the larger soybean producers in the EU, with a strong growth trend, fuelled by the demand for non-GMO soya across Europe. Croatia also has a respectable soya seed development sector, reflected in the 70% market share in planted soya being sourced from locally developed cultivars.

Production, processing, consuming and policy sector overview

The work includes a comparative trend analysis for EU27+UK countries which highlights data with respect to the: number of legume producers, legume utilised agriculture area, yields, and the value of EU27+UK funded support awarded to legume producers. This analysis focussed on the production of pulses like common beans and peas. Production of faba beans, chickpeas and lentils in Croatia is more modest. Fodder protein crops like alfalfa, clovers and grass-clover mixture are traditionally grown for the purposes of animal feed. Most fodder is produced by farmers for *in-situ* consumption, while a small portion of production ends up on the farm-to-farm market, mostly as dry hay. The persistent decline in the number of livestock (especially bovine) in Croatia over the past few years is therefore constraining the growth of fodder legumes. In contrast, soya production exhibits the strongest growing trend, as Croatia benefits from European demand for home-grown non-GMO soya.

In terms of processing legumes, pulse producers are local on small farms with low acreage and yields. These units are also under strong pressure from imports, as they lack the developed infrastructure for up-scaling and suffer lock-in with few existing processors enjoying a monopoly position. These small-farm producers cannot afford modern high-tech processing equipment. Further crops such as pulses offer poor commercial returns compared to other non-legume species, such as cereals. Hence, risks for these farmers are too high. Only two or three small entrepreneurs produce soya-based vegan and vegetarian food such as tofu and tempeh *etc*. Since this is a strongly growing niche market, an annual “ZeGeVege” festival is organised annually, which attracts over 50,000 visitors. Nevertheless, whilst promising this market pull is currently insufficient to justify the high-cost investment necessary on an individual farmer basis.

In terms of the sector, a huge paradox exists. Croatia’s policy emphasises support for the small family farms on one side, but large private corporates on the other. This has resulted in an investment of over € 4,8 billion into agriculture sector from 2005 to 2014 through various programme measures, but in the same period production of agriculture goods and services fell by 27%. Agriculture imports have increased dramatically, and with a fully open market economy, many agriculture sectors have become increasingly uncompetitive, which has negatively impacted legume production in Croatia. However, after Croatia joined the EU, and especially after the introduction of so-called “Green” payments in 2016, production of fodder protein crops, which include clover, grass-legume mixtures, fodder beans and peas, sainfoin and others, marked significant growth (Figure 28).

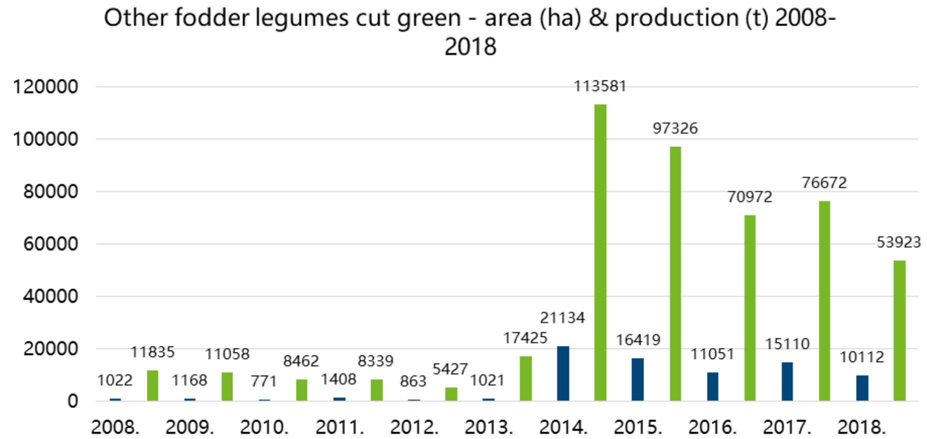

Figure 28. Other fodder legume cultivation area (green bars) increased dramatically due to “Green” payments introduced in 2016. Blue bars = production (yield; t). Other fodder legumes include clover, grass-legume mixtures, fodder beans and peas, sainfoin amongst others.

This analysis has highlighted many negative aspects which characterise Croatian agriculture positioning and development. These relate to the relatively weak and even negative impact of current governance measures, including inefficient payment mechanisms. Also, there is inadequate protection for farmers from unfair trading practices, outdated land use policy, insufficient quality of farm support mechanisms (including advisory services), lack of knowledge transfers, and lack of adequate agriculture financing.

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Main Recommendations

Focus must be to **actively engaging farmers and value chain stakeholders in more meaningful and effective dialogue with policy makers**. Such cooperation would facilitate the creation of more effective, integrated, and successful policy strategies. Ongoing consultations provides a valuable opportunity to shape a comprehensive, relevant, applicable, and informed set of policy measures. In addition, **a wide and inclusive stakeholder dialogue should be encouraged to ensure a common understanding and acceptance amongst all interested parties – across the value chain - and participation in successful policy recommendations**. This should allow legumes to play a bigger and more significant part of Croatian policy and agriculture sector. Within the research performed in this Case Study, there is: an overview of the proposed policy and value chain group measures and initiatives to bridge existing gaps, and to leverage existing strengths in legume production sub-sectors in Croatia. These insights and recommendations are segmented and outlined according to the sub-sectors, level of relevance/importance according to relevance to stakeholder groups – including supply and demand sectors.

Croatia must create conditions to capitalize on demand for locally produced plant protein by investing in processing capacities to ensure that value is added (and retained) locally, thereby creating stronger market pull for farmers, traders, and processors. Also, local varieties should be developed further, *via* investments in R&D capacity to protect and enhance their genetic potential. For farmers focused on in-house production of soya as feed protein for their livestock, education, and assistance in development of in-house capacity for processing should be made available. These recommendations are being shared with our local decision makers and will subsequently be discussed with the Croatian Ministry of Agriculture to help inform a comprehensive, relevant, applicable, and informed set of policy measures in a new and effective strategy for agricultural development – economically and environmentally.

FAO-UN Sustainable Development Goals (SDGs) addressed

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5.6 Agroforestry in Kenya: increasing production, and developing up- and down-stream value chains

David W. Odee, Emmanuel T. Makatiani, and John O. Otieno
Kenya Forestry Research Institute (KEFRI), Kenya

This Case Study is in western Kenya region of the Lake Victoria Basin. The region has a longstanding history in applying soil fertility management strategies using agroforestry technologies to enhance crop production and food security in mainly smallholder farming systems. Legumes are major components of these systems, with common beans, cowpeas cultivated both as staple and cash crops. The most common legumes are common beans (*Phaseolus vulgaris* L.), cowpea (*Vigna unguiculata* (L.) Walp.) and peanuts (*Arachis hypogaea* L.). They are cultivated as monocrops or intercrops, which may include other non-nitrogen-fixing crops such as the staple –maize (*Zea mays*), and N_2-fixing trees and shrubs for soil fertility management as a source of organic manure in the form of nitrogen-rich green biomass production.

The specific challenges and motivation

The main challenges are low productivity due to small farm sizes (< 2 ha), unaffordable or unavailability of basic agricultural inputs and lack of optimal inputs (fertilisers, quality seeds, pesticides, *etc.*). In many instances, grain yield production is too low to support household consumption within smallholder communities. Common beans are the most important legume staple food in Kenya, and together with maize, are the main sources of plant-based protein and energy for most families.

Demonstration of new improved fallows and rhizobial inoculation with farmers

A demonstration trial co-designed with the local farmers was established to evaluate the new improved fallow agroforestry system. Also, legume inoculation with locally selected elite rhizobial inoculants for common beans. The term 'new improved fallow' means the integration of the N_2-fixing tree species, tephrosia (*Tephrosia candida*) grown for a short duration lasting no more than a season (normally during the short rains) and established as either a monocrop or intercrop with the target companion crops (*e.g.,* beans, maize or beans and maize) in the first season. Thereafter, the leafy biomass is removed and

Figure 29. Six-month old tephrosia leafy biomass spread on plots in readiness of cropping with common bean and maize. Tephrosia woody material can be used as firewood or stakes for runner crops.

applied as green manure to replenish soil for the next cropping season (during the long rains, Figure 29).

The trial showed that rhizobial inoculation significantly increased the leafy biomass of tephrosia (Figure 30) – especially where yields were low (in short rain season). As expected, grain yields were generally lower in the first season (short rains) than the second season (long rains). In common bean, treatment with tephrosia green manure attained greatest grain yield of 3.9 t ha^{-1} (Odee et al. 2021), which was higher than the range of yields (0.63 – 3.0 t ha^{-1}) reported for the region (MoALF, 2016). Maize grain yields (8.8 t ha^{-1}) were higher (Munialo et al. 2019). These encouraging findings are based on two consecutive cropping seasons (short and long rains), and hence will need to be repeated for several seasons to provide sound conclusions and robust advisories to farmers.

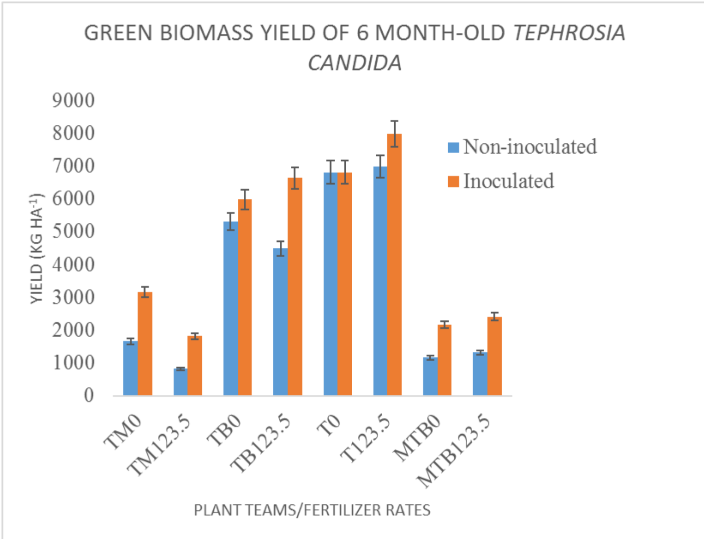

Figure 30. Effect of rhizobial inoculation on biomass production of tephrosia. Treatments were either sole tephrosia or mixed with maize and beans. Plant/mixtures: T = tephrosia, M= maize, B = common beans; inorganic fertiliser treatments, 0, no fertiliser or applied at the rate of 123.5 kg/ha). Bars represent standard error means.

It is envisaged to team up with a commercial agri-business in future to upscale production and distribution should the rhizobial inoculants demonstrate effectiveness across a wide range of pedoclimatic conditions.

Barriers to greater uptake

Major barriers to uptake of these approaches include: small production unit areas, lack of high yielding varieties, the prevalence of diseases and pests, inadequate markets and value chain capacities (especially after a good season and surplus yield production), shortage of extension services, and the general unaffordability and inaccessibility of agriproducts. **Success will require the development of national policies to enhance infrastructural support systems for supply and accessibility of agriproducts, and value chain capacities systems, from rural area input suppliers to consumers.**

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Recommendations and way forward

This Case Study was undertaken at a village level, with direct involvement of >20 local farmers in. **Our plan is to support these farmers as practitioners of the new technologies to share the knowledge among the > 500 farming households in the village through peer-to-peer learning**. Beyond the village and county level, we plan to disseminate the technologies through farmer field and open days, national agricultural shows, as well as information leaflets and brochures.

As the uptake of these approaches and technologies increase, it is expected that self-sufficiency will be attained, and consequently, the surplus yield feeding into the supply local and international value chains.

FAO-UN Sustainable Development Goals (SDGs) addressed

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6 New and lucrative legume-based market opportunities

6.1 Intercrops for food and feed

Kirsty Black
Arbikie Distillery (ADL), UK

The commercial success and environmental potential of pulses will not be assured if sold at a low premium for animal feed. Faba bean protein, for example, is an excellent high value aquaculture feed and its commercial success could be greater were the generation of a faba bean protein concentrates possible during processing. Processing must also maximise the commercial potential of the bean starch (ca. 60% by weight).

Additionally, legumes may be used to support the production (where there is high demand) for more traditional beverage alcohol raw materials, and with a reduced carbon footprint. Sufficient nitrogen fertiliser is essential for high crop yields, and spring cereals such as barley (*Hordeum vulgare* L., the common and main raw material in the brewing and distilling industries) receive around 110 kg nitrogen ha^{-1}. However, '*intercropping*', cultivating two or more crops in the same field at the same time, can allow cereal production without added man-made nitrogen fertiliser. For example, barley can be sown with a legume crop such as peas (*Pisum sativum* L.). The legume can meet its entire nitrogen demand using a natural process called "*biological nitrogen fixation*". The legume can also deliver nitrogen to its companion non-legume crop (barley), which cannot fix nitrogen biologically. The average carbon footprint (carbon dioxide equivalents, CO_2e), for applied nitrogen (as ammonium nitrate, AN), is 5.6 kg CO_2e kg AN^{-1}. So, for every hectare of AN (110 kg) application avoided, 616 kg CO_2e ha^{-1} is also offset. In the UK, the spring barley area was 682 kha (2016), and so approximately 75 kt of nitrogen would have been applied. If the same area was sown with a pea-barley intercrop without nitrogen fertiliser application, 420 kt CO_2e would be saved. To put this into a tangible context, this is equivalent to removing 176,000 cars from the road annually. Financially, and without accounting application costs and pesticide savings accrued by intercropping, the AN fertiliser cost saving would be a £13.5 million, at the current low prices of around £180/t.

While the intercropped barley will be processed for malting, the creation of high value markets for legumes is necessary in promoting the adoption of such an approach and developing them as a commercially attractive crop when grown both as a sole- and as an inter-crop. Here we used traditional brewing and distilling industries as a fractionation step, the starch removed by saccharification and fermentation to produce high value beer and distilled spirits, leaving the protein rich by-products for use in aquaculture feed or, following further purification, in human nutrition.

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Brewing Process Optimisation

In the production of beer, the processing step known as 'mashing' involves the gelatinisation of the raw materials' starch, its enzymatic degradation into simple sugars, and the separation and removal of solid material. The efficiency of this step is critical in the production of beer as the amount of fermentable sugar produced directly impacts the alcohol content of the end beer. The addition of commercial enzymes is an established practice to increase levels of fermentable sugars, nitrogen availability and wort run off rate. Using a stepped temperature mashing regime and exogenous enzyme additions, the faba bean wort was comparable in processability and fermentability to that of 100% malted barley wort. In addition, the use of faba bean positively impacts necessary 'Free Amino Nitrogen' (FAN) levels with no detrimental effect on yeast growth and fermentation performance. The results of this study have been published in the Journal of the Institute of Brewing (Black *et al.* 2020).

A microbrewery in Edinburgh (barneysbeer.co.uk) has demonstrate the feasibility of this by successfully brewing a number of faba bean ales; replacing up to 50% of the malted barley with milled beans with the most recent release being sold under the brand 'Cool Beans', Figure 31A. Product tests showed that consumers could not discern between the faba bean base beer, and the equivalent barley-only brand (Black *et al.* 2019).

Figure 31. A. 'Cool Beans' - an environmentally sustainable, gluten-free, and vegan beer made with faba beans at Barney's Beer. Made with 40% faba beans and 60% barley and B. NÀDAR GIN AND VODKA MARKETING MATERIALS - the world's first climate positive spirits produced from 100% Peas at Arbikie Distillery.

Distillery Processing

The knowledge obtained from the brewery-based studies can also be applied to a distillery environment. Laboratory scale mashing and fermentation trials were successfully transferred to a commercial scale distillery. Peas (*Pisum sativum*) were used to produce a neutral base spirit which was then further processed to produce Nàdar Vodka and redistilled, in the presence of botanicals, to produce Nàdar Gin (Figure 31B). The high product quality was allied to an effective marketing campaign made possible by key Life Cycle Analysis (LCA) data published in the peer-reviewed literature by Lienhardt *et al.* (2019a, and 2019b).

Work has continued to maximise alcohol yields whilst also investigating the use of pea processing co-products. Co-products include pea starch from the food pea protein industry and coarse flour from the pea kibbling process. Both present a more economical raw material when compared to fine pea kernel flour. Figure 32 shows the alcohol yield improvements made with the introduction of pea starch to the mashing process.

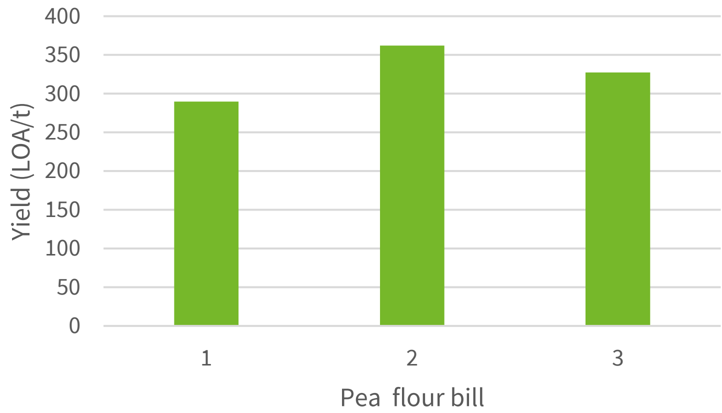

Figure 32. Alcohol yields (Litres of alcohol (LOA) per tonne) obtained from different pea flour options. 1) fine pea kernel flour, 2) fine pea kernel flour + peas starch, 3) coarse pea kernel flour + starch.

By-products

The reduced starch content of pulses, compared to traditional neutral spirit raw materials, has a direct impact on alcohol yield and processing quantities required to produce equivalent alcohol yields but also on the protein content, and potential value, of the related by-products. An initial assessment of the co-product has shown very promising results with the faba bean distilling by-product with supplementary methionine can replace soy concentrate in aquaculture feed. The level of protein in the co-products is also of interest as a poultry or pig feed and both routes into aquaculture and poultry farming are being investigated.

Summary

For pulses to be considered as a viable starch source to the beverage alcohol industries the raw material cost *per* litre of alcohol must be comparable to conventionally used raw materials. With current market prices this is not the case with, for example, whole peas currently demanding a 127 %, and pea starch a 222 %, premium compared to the average market values for maize, wheat, or potatoes commonly used in the production of neutral spirit. These numbers, however, consider neutral spirit purely as a commodity with no consideration to its environmental impact nor the marketing potential for products made from pulse-based spirit, or high-protein by-products. The LCA undertaken quantified and compared the environmental footprint of gin produced from either wheat- or pea-based spirit (Lienhardt *et al*., 2019a and b). **Pea-based gin was found to have a smaller environmental footprint in twelve of the fourteen categories considered.** Through avoidance of fertiliser use and distillery co-products being used as a soybean animal feed alternative, each litre of packaged gin avoids 2.2 kg CO_2e. These findings, accompanied by the research reported here, has informed industry and the realisation of commercially available pulse-based spirits. Nàdar Gin and Nàdar Vodka are produced entirely from green peas and, as such, are

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marketed as 'climate positive'. Consumers are moving towards more premium distilled spirits (Scotland Food & Drink, 2019) and are increasingly climate conscious, considering sustainability and environmental impacts when making purchases (White *et al.*, 2019; Mavrokefalidis, 2020). Such consumers should be accepting of a price increase, offsetting the increased raw material costs, whilst supporting the associated environmental gains. Furthermore, **because of the elevated protein content of pulses, the distillery co-products will also be protein enriched therefore have the potential to demand a higher price, further offsetting the elevated raw material costs**.

FAO-UN Sustainable Development Goals (SDGs) addressed

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6.2 Legumes in public and private food services

Karen Hamann
Institute for Food Studies & Agro industrial Development (IFAU), Denmark

This Case Study addresses the challenges and opportunities for having more legumes in public and private food service markets, with segments assessed with respect to their potential as being focus areas for policies which encourage the cultivation and use of home-grown legumes. It is highlighted that the **food service market** is a growing segment in the food market and constitutes 25 % of the food consumed in the EU. Provisions of food services are undertaken by public entities such as hospitals and schools, also private entities such as restaurants and cafes. Across the EU, it is estimated that public food services account for 25 % of the food service market, the remaining share being held by private actors.

There is a growing and significant interest in the food service market to provide menus which ensure environmental sustainability, so-called, "green menus". This trend materialises as an increasing demand for alternatives to meat and dairy products, or to have more plant-based product options including peas, beans, and dried pulses. In recent years, more vegetarian and vegan food options have found their way into everyday menus of entities in public and private food services. In the **canteen segment and among premium restaurants,** it has become a customer service- and food-quality indicator to offer comprehensive vegetarian options, or present fresh vegetables from local growers. Chefs in such restaurants are regarded as being at the forefront industry development menu creation. This is important for stimulating consumers' interest in trying vegetarian or pulse-based meals. **Fast food chains** in the burger segment have also introduced plant-based fast- or convenience-food, such as burgers, and the offer of plant-based menus keeps on widening. The trend for greener menus is clearly paving the way for a **growing demand** for vegetables and pulses.

In food service, vegetables such as fresh frozen peas and beans are most frequently used, whereas pulses come as canned and often pre-cooked products. The use of processed legume-based products is developing rapidly, and the assortment has recently widened significantly to include meat alternatives, non-dairy drinks, ready-made soups cooked with pulses and, many other products. New cooking trends, new menu items or new raw materials can spur the need for **education** with kitchen professionals, the partners in trade, or even with procurement authorities. Some contract caterers have already implemented internal educational measures to increase the skills of the kitchen personnel to cook with pulses. It is also clear from the Case Study that new structures for collaboration may be needed to support the entry of growers or smaller food processors into the food service market, particularly to answer to demands for consistent supplies or for compliance with public procurement procedures.

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Procurement of food for public food service entities is subject to compliance with the EU Green Public Procurement (GPP) Criteria for food, catering services and vending machines. This framework aims to reduce the environmental impact of the food system by providing public procurement authorities with the tools for pushing suppliers (*e.g.,* wholesalers, food companies, farmers, and other suppliers) towards a reduced environmental footprint. Given its volumes, public procurement plays an important role for pushing the European food system towards a more sustainable system. The recently updated EU GPP criteria specifically mention **plant-based diets and organic food** as two criteria to include in tenders issued for procurement of food and catering services for public services. The extent to which this recommendation is met by such agencies, remains to be seen with respect to legumes.

Public and private entities in the food service market mainly buy their supplies from wholesalers. Large **wholesalers** have national coverage, some even international, and as such, these companies hold a strong market position due to their buying power and distribution range. For food producers, the wholesalers are the most important business partner in the food service market – particularly for supplying chained restaurants and public entities. Since, they are centralised purchasers demanding large volumes, and these are key competitive parameters. However, food value chains are based on a system of product categories such as “meat products”, “dairy products”, “frozen foods” *etc*. As legume-based products appear as fresh vegetables, dried grocery products, canned or frozen products, or as ready meals it requires a huge effort from the personnel selecting the products to buy from the wholesalers. **Despite their unique national density and environmental benefits, there is no category framing legumes and pulse-based products at the wholesaler level.**

Recommendations to realise transition in practice

It is fundamental that public procurement personnel recognise the value of the GPP criteria and, how these criteria could be implemented in calls for tenders. One issue is to include criteria on *e.g.,* share of organic food in calls for tenders for food and catering services, another is to evaluate the bids and monitor the implementation of the green criteria in the contract. This is partly addressed in the GPP training toolkit provided by the EU. However, the connection from the toolkit, the GPP criteria and a strategic approach to sustainability around the public meal still needs attention. It is important to identify best practices in public procurement and organise a learning and knowledge sharing approach in local as well as European contexts.

To facilitate the selection of pulse-based products, it is strongly recommended to **create a home-grown legume or legume-based category in the value chain**. This new category would include pulses in all formats (fresh, frozen, dried, processed) and could be expanded to become a plant-based category. This would be well in line with the GPP criteria on plant-based menus. Major value chain actors would need to come together to agree on the new category as this would imply significant changes in existing IT systems.

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Cooking appealing meals with pulses for restaurant menus or in large scale for hospitals or schools may require upskilling of the kitchen staffs. **A dedicated approach that targets vocational education for chefs-to-be as well as providing current staffs with more skills is recommended**. This issue is that the meals provided in food service must be to the liking of the consumers if the intake of pulses and vegetables is to be increased. Both public and private providers of meals can act as educators and motivate an increased intake of plant-based foods.

Products, that match the way food is prepared in professional kitchens are always high in demand, which is also relevant for pulses. Only few professional kitchens allocate time and resources to cook dried pulses, and this paves the way for innovative pulse-based or plant-based products. Such innovations come from entrepreneurial companies as well as large businesses, and wholesalers, who carry the products for distribution. **It is essential that SMEs and large businesses have knowledge of the working routines and demands of the professional kitchens to develop attractive products, and that the wholesalers are geared to work with suppliers of all sizes to underpin a widening of the assortment and include more suppliers into the food service market.**

FAO-UN Sustainable Development Goals (SDGs) addressed

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6.3 Overview of breath and diversity for peas

Karen Hamann
Institute for Food Studies & Agro-industrial Development (IFAU), Denmark

This Case Study aimed to provide an overview of the breadth and diversity of use for peas, which acts as a model for how legumes could be used and to identify opportunities for processing and trade in local as well as international contexts.

Peas can be used for many different purposes within feed and food. This work focussed on the diversity and opportunities in relation to food. Peas are a crop that has been cultivated for centuries in the Nordic and Baltic countries. Today, peas are available to consumers through retail stores as fresh in season produce, or as frozen or canned products year-round. The assortment of products where peas are used as an ingredient is rapidly expanding. New products include meat alternatives, ice cream, pea drinks, bread enriched with pea protein, and a range of products destined for the nutritional supplements market. Innovation is important to develop unique selling points, which draw the attention consumers, and of course their spending power. New products in the Nordic markets include pea sprout from Denmark, for salads or decorating meals. Also, a pea-based "soy sauce" from Sweden (Figure 33).

Figure 33. A. Pea sprouts (organic) marketed through an online supermarket in Denmark, 2021 (Ærteskud øko. fra Yding Grønt – køb online hos nemlig.com); B. Pea-based "soy sauce", Sweden, 2017(Liuras ärtsoja - Liura).

The food processing industry is dependent on proper ingredients to make processed foods. Consumer demand for plant-based products has fuelled demand for pea-based ingredients to make plant-based burgers, sausages, nuggets, and similar products. The range of pea-based ingredients is centred round extruded pea protein and pea protein isolates. A large share of these ingredients is made with yellow peas from Canada and processed at a handful of European companies. In Nordic countries, you also find companies producing pea-based ingredients including a company

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specialised in organic pea protein. The growing demand for pea-based ingredients has a direct impact on agriculture as the ingredient companies want to buy local crops. Demand for peas for processing exceeds for example the Danish crop volume, so processors are currently buying peas from Lithuania or sourcing semi-processed pea ingredients from a Norwegian company. In Sweden, you also find examples of how companies have collaborated with farmers to provide innovative pea-based products in the domestic food market. Homegrown peas used for plant-based nuggets is such an example. It is marketed under the organic brand Änglamark belonging to the retailer COOP (Figure 34). It is therefore relevant to consider retailers in the assessment of how to have more plant-based products in the food market.

Figure 34. Änglamark pea-nuggets, organic certification and made in Sweden, 2020. (Änglamark ärtprodukter i samarbete mellan Jannelunds gård, Slätte gård och Coop - Rådet for Grøn Omstilling (rgo.dk)).

These examples demonstrate a regional and highly dynamic market where local value chains go hand in hand with international value chains. Farmers in the region are keen on growing more pulses and farmers' motivation is closely linked with prospects for selling the crop. These trends are also common across the EU. Innovative products and good marketing play a pivotal role in stimulating consumer demand. The structure of the value chain and the location of different processing steps are generally of less importance to consumers. This points to food processors and retailers being important actors for driving demand for pea crops in local and international scales.

Recommendations to realise transition in practice

For a value chain to be recognised as sustainable, it is necessary that actors of the chain make a profit. Business conditions that enable actors like farmers, distributors, processors, or retailers, to make a profit from producing or trading pulses or pea-based products is a fundamental requirement. Therefore, **policies need to be shaped to promote entrepreneurship as well as fair and transparent market conditions.** If the aim is to have more pea crops in the fields, policies should be shaped to encourage farmers to grow this crop, for example by promoting crops that do not require synthetic fertiliser or promote the use of natural fertilisation effects and soil improvement capabilities of leguminous crops. However, farmers are influenced by a range of policies, so policy (mis)alignment must not be overlooked.

Market transparency is important for any economic actor in connection with decision making. **Having more reliant and detailed information about crop production, prices, supply, and demand would be important. More reliant and detailed market information is also crucial for actors making decisions about expanding their activities into the plant-based food market at**

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all scales. It is therefore recommended for local, national and EU contexts to work towards solutions for more transparency in the market.

Critical Appraisal/Opinion

Following the push from the EU to have more legumes in the agri-food system it was obvious that changes in agriculture, value chains, food markets and consumption patterns would occur. However, identifying and understanding the dynamics of the plant-based food market has always been challenging as this market segment is highly competitive with limited access to information.

FAO-UN Sustainable Development Goals (SDGs) addressed

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6.4 Novel feed formulation for aquaculture

Matthew J. Slater and Monika Weiss
Alfred-Wegener-Institut (AWI), Germany

Fish is the world's most important animal protein source, and most of the fish humans eat now comes for aquaculture (FAO 2016). Fish are extremely efficient protein converters, yet large amounts of feedd is needed to grow aquaculture fish. This Case Study investigates the use of legumes in formulated diets ('fish feed' or 'fish pellets') for feeding fish and shrimps in large recirculating aquaculture (fish farming) systems in northern Germany. Legumes such as lupins, faba bean or pea meal are particularly promising as ingredients for diets for aquatic animals grown in fish farms. They generally provide the right mixture of amino acids for good growth, and if treated correctly can be very efficiently absorbed by fish and other aquaculture animals (Glencross et al. 2005). One of the advantages of using legumes in fish feeds is that they can replace fish meal. Fish meal is made from small fish like sardines and anchovies, and from waste fish, offcuts from fish processing etc. One of the problems of using fish meal, even though it makes fish grow very well, is that it seems inefficient to feed perfectly good fish to other fish (with some loss in total protein) just because humans prefer to eat the cultured fish (rather than the anchovies). In addition to this concern, fish meal is now extremely expensive (approx. €2000 *per* tonne – as opposed to lupin approx. €300 *per* tonne) making it the most expensive element in many standard fish diets. Thus cheaper, more environmentally friendly alternatives are desperately needed. Locally produced legumes, which are suitable for inclusion in fish and shrimp diets, are high, and lupin is one of the most obvious choices in Germany, as it is a traditional crop, particularly in the north.

White leg shrimp feed

Ultimately, this Case Study results in highly price-competitive diets containing locally produced legumes to grow fish and crustaceans in Europe. The results contribute to increased use of sustainable legume alternatives to fishmeal, bringing a strong positive environmental balance, and can significantly increase protein efficiency for European aquaculture production. Aquafeeds containing lupin kernel meal were successfully tested for the White leg shrimp (*Litopenaeus vannamei*). Four experimental diets with increasing lupin kernel meal content were formulated to meet the requirements of *L. vannamei* in the grow out phase (Gonzáles-Félix and Perez-Veazques 2002, Li, Wang *et al.* 2017, Shao, Liu *et al.* 2017). Where necessary, single amino acids (Methionin and Lysin) were added to balance the amino acid profile. All diets were isonitrogenous and isocaloric. Results show that growth of the shrimp did not differ significantly from the commercial feed up to a replacement of 20% of fish meal with lupin kernel meal (Figure 35). Shrimp fed with the high lupin content L30 diet showed reduced growth. Analyses of the haemolymph metabolites showed that glucose (a stress parameter) and triglycerides (parameter for nutritional status) is reduced in shrimp fed L30, while the total haemolymph protein did not differ between the feeds. The total haemocyte count, which gives us an insight on the capacity of the immune system, shows elevated values for

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the L10 feed, which may indicate a positive enhancement of the immune defence. To get a more detailed view of the effect of lupine on the haemocytes, flow cytometric analyses were conducted, that allowed the differentiation between haemocyte types. No significant differences between the treatments occurred, although there is a tendency that semi-granular cells are promoted in animals fed the L10 diet but are reduced with increasing lupine content in the feed. Additionally, the analysis of the phenoloxidase (PO) activity and capacity shows that PO is significantly higher in shrimps fed with the L10 diet. These results indicate a positive response of the immune system to the L 10 diet, which might reflect an immune-stimulating effect of the lupin.

Atlantic salmon feed

Aquafeeds containing lupin and faba bean products were successfully tested in controlled feeding experiments with the Atlantic salmon (*Salmo salar*). A literature review was conducted, and industry advice was sought to formulate diets to accurately meet all optimum nutritional and physical requirements of Atlantic salmon. Nine experimental diets with high and low inclusion of different lupine and faba bean products were formulated to meet the requirements of *S. salar* in the grow out phase. Where necessary, single amino acids (threonine, methionine, and lysine) were added to balance the amino acid profile. All diets (except the L diet) were isonitrogenous and isocaloric. Results show that growth of salmon was significantly reduced (when compared to commercial diets) in two diets (L and LC+BC) and did not differ significantly in the other tested diets (Figure 36). The L diet was designed containing lupin kernel meal, which is comparably low in protein. Therefore, the recommended level of crude protein of 45% could not be reached in this diet but was only 33%. The LC+BC diet is designed without fishmeal. Although all considered nutritional requirements were met, it is known that diets without any fishmeal content can result in reduced growth.

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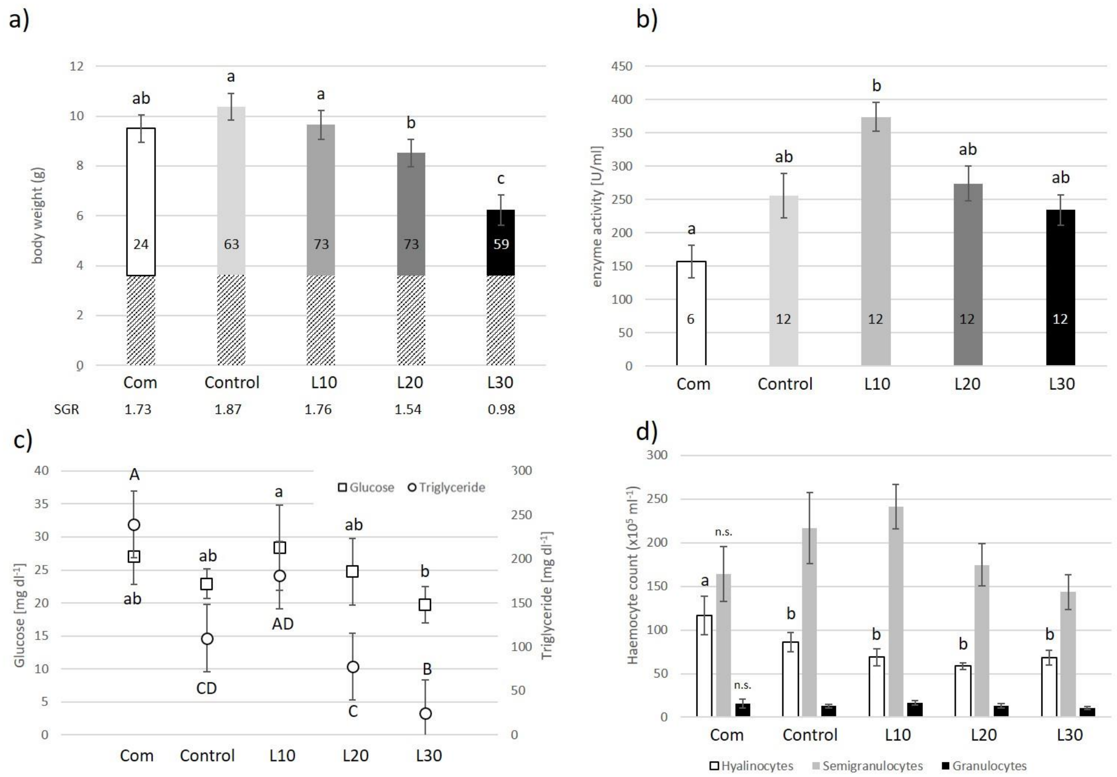

Figure 35. Litopenaeus vannamei (White leg shrimp). Results of feeding experiment. Com—commercial feed, Control—control feed, L10—10% of the feed is lupin meal, L20—20% of the feed is lupin meal, L30—30% of the feed is lupin meal. Significant differences are indicated by different letters. Replicate numbers are indicated in the bars for a) and b), for c) is Com = 6 individuals (ind.), Control, L10, L20 and L30 = 12 ind., each ind. measured in 3 technical replicates. (a) growth performance based on weight. SGR – specific growth rate. Dashed area shows start weight. (b) Phenoloxidase activity in shrimp haemolymph given as mean ± SE. Data were ln transformed to reach normality. (c) Glucose and acylglyceride levels measured in shrimp haemolymph given as mean ± SD. (d) Differential haemocyte count.

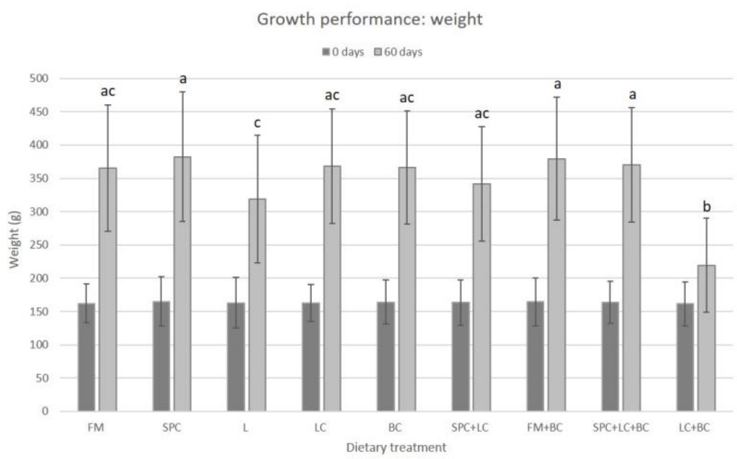

Figure 36. The growth performance based on weight of Atlantic salmon fed with experimental diets for 60 days. Each value (X ± SD) is the average performance of 60 to 64 fish/treatment. Values with the same

superscripts within the same column are not significantly different (P < 0.05). FM = Fishmeal, SPC = soya protein conc., L = Lupin (raw flour), LC = Lupin Protein Concentrate, BC = Faba Bean Protein Concentrate.

Key industry leaders, including two of the main agricultural services companies in Europe and aquaculture diet producers in Europe, have identified the need to increase reliable production of legumes in European agriculture and have undertaken some efforts to encourage contract farming of selected legumes for their own production purposes. **These industry partners see a certain level of competition with the direct human food market but argue that if relatively low-price production of legumes continues to expand, or if there are legumes unsuited to human use, these could be included in aquaculture diets.** It is clear, that acceptance is limited primarily by financial and supply concerns on the side of the processes and the fish farmers themselves. Plans are to continue working closely with feed producers to create suitable commercial feeds.

FAO-UN Sustainable Development Goals (SDGs) addressed

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6.5 Processors: snack and convenience foods

Marta Vasconcelos, Carla S. Santos, Ana Gomes, Elisabete Pinto, João Ferreira, and Carla Teixeira
Catholic University of Portugal (UCP), Portugal

Currently, consumers have different expectations in terms of what they want to find on the supermarket shelves. Generally, they look for good nutrition, a 'clean' label[4], and potential well-being attributes (Mehlhose *et al.*, 2021), among the convenience associated with availability, product consistency, utility/flexibility, pricing, and packaging. Current legume consumption in Portugal was analysed to specifically identify drivers and barriers with respect to the transition to greater consumption of home-grown legumes, and legume-based products (Duarte *et al.*, 2020). The main barriers identified were: lack of recognition of legumes' nutritional value; long cooking times; and the potential effects of the anti- (or non-) nutritional factors. Studies show that consumers have a positive response to sustainable food products (Yang *et al.*, 2020). It is therefore important to increase education and awareness as to the value of legumes and legume-based products that improve health, well-being, and their positive impacts regarding the environment. A clear education, marketing, and awareness strategy showing their positive potential will increase home-grown legume inclusion in diets by targeting consumer concerned with low environmental footprint diets (as well as optimised nutritional densities).

At the beginning of the TRUE-Project, in 2017, the availability of new pulse-based products was increasing in many industrialised countries across the world. Interestingly, the 'Meat Substitutes' sub-category registered a considerable increase when compared to previous years. The 'Pasta' sub-category also had an impactful growth rate over the years. Finally, the 'Snacks' sub-categories registered a 38% increase over the period analysed.

The use of claims in pulse-based products

With the increased demand for plant-based alternatives, one of the major trends that emerged in the market was the expansion of vegan and vegetarian products, driven by the growing consumers' preference for natural, healthier, simple, and flexible diets. As a response, more food manufacturers started developing products focusing on plant ingredients, and the attractive flavours and functional properties that these can grant to the product. In the labelling and claims for new product launches, this trend was evident, with the vegan and vegetarian claims registering major growth, together with environmental friendliness related claims.

[4] A "clean label" food product is made using as a few ingredients as possible. The term is accepted by food industry stakeholders of all forms, including consumers, academics, and food regulatory agencies.

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Novel legume-based foods development

Although legumes intake can be key to responding to most of the consumers demands identified in the previous market analysis, their consumption is still below the recommended intake for most countries (Herforth *et al.*, 2019). In this Case Study, we have successfully developed different food products, using legumes as key ingredients.

We first developed 'PlantCakes', a dry mix for sweet pancakes preparation with lentil flour as its main component. Lentil is a legume grain with high production levels in Europe (in Spain and Germany, for example) and there are numerous studies linking its consumption with cardiovascular diseases and diabetes prevention (Rochfort *et al.*, 2019; Ferreira *et al.*, 2021). 'PlantCakes' can be a healthier alternative to this sweet, high in sugar and carbohydrates content snack, since it has low sugar, low saturated fat and low salt content; and is enriched with plant-based protein and fibre. All the ingredients used in the prototype development were certified organic, so the product can also be inserted in the 'Bio' food segment. Current body of knowledge associate these foods with the development of several diseases in children, adolescents and adults and current dietary guidelines are showcasing the importance of reducing their intake (Elizabeth *et al.*, 2020).

Additionally, 'BBdonuts' were developed, which stands for 'Broad Bean donuts'. This product is a donut-shaped cake, made with faba bean flour. In addition to faba flour, BBdonuts also includes in its composition, other typically Mediterranean ingredients, such as almond flour, honey, and olive oil. The appreciation of local ingredients, quality and nutritional and functional adequacy were aspects considered in the elaboration of the product, not only to promote healthy diets but also increase awareness about the sustainability of our local value chains and the need to increase local production of legume grains.

We also developed a faba bean-based drink, inspired in a typical beverage from Guatemala. Besides having a rich nutritional profile, the flavouring of the drink was adapted to different tastes, with three main flavours being generally accepted after sensorial analysis testing: chai tea, pumpkin spice, plus orange and chocolate flavours.

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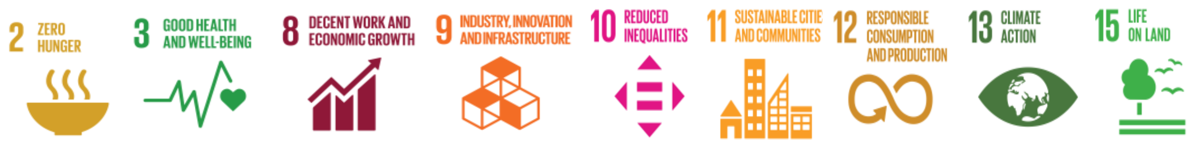
Main Findings

To overcome the barriers previously mentioned, we have increased the dissemination of legumes importance to citizens through the release of communications to national media, actions developed with schools and through the application for national projects with the aim of disseminating the role of legumes in the value chain.

During our work in this project, we also understood that **changing food habits is not an easy or fast process**, and that food habits developed at a young age are often sustained throughout adulthood (Małachowska and Jeżewska-Zychowicz, 2021). Hence, it is important **to target children and include legumes in meals, from a young age** (Vasconcelos *et al.*, 2020). With this in mind: a yogurt enriched with lupin flour was developed, especially for the children's market. The lupin flour replaces the regular thickening products used in yogurt processing, resulting in a product denser in nutrients. It is being analysed with a life cycle assessment analysis, as this simple substitution could represent lower environmental impact. In addition, a Legume cookbook for children is now available in multiple languages. These recipes, collected from different European countries, are easy to prepare and are accompanied with useful nutritional facts, to break the barriers hindering legumes consumption in a fun and educational way, and fostering time between parents and children. We consider that all these new food products can be up-scaled to the market with success, considering their acceptability in a lab scale, in the first sensory tests.

FAO-UN Sustainable Development Goals (SDGs) addressed



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Concluding Remarks

The insight provided by the 24 TRUE-Project Case studies here provides only a brief summary of research and innovation effort. Nevertheless, they provide a representative suite of example legume-based approaches which should be undertaken collectively across the value chain, and the very wide range of stakeholders concerned.

Despite such potential, legumes remain an underutilised crop across Europe and there is confusion as to why this paradigm, or paradox, persists, which is: that European food- and feed-systems are legume-supported, just not home-grown legume supported. Consequently. environmental benefits are forfeited. Equally, that most legumes are grown mainly for feed, not food, so human health benefits are also largely forfeited, and environmental damage encouraged.

Despite this, there is some indication in some European countries show a slow upward trend for the cultivation and consumption of home-grown legumes, both of grain and forage legume types. Also, there appears to be two distinct market types emerging - generally speaking. One drives home-grown legumes cultivation and at small and artisanal scales. These efforts can for example include farmers who are increasing on-farm legume-based feed self-sufficiency, and cooperative or community-based legume growing and breeding initiatives - to help develop short-value chains for local- or bioregionalised-markets. Such food system transitions tend to become embedded slowly. On the other hand, the potential of rapid upscaling of home-grown legume-production could be offered by larger-scale business frameworks, particularly animal- and aquaculture-feed producers. Where there is large-scale use of grain legumes, this is for specific legume types such as 'yellow pea', and the extent to which this encourages widespread legume-cultivation and value-addition locally and across Europe is not clear. Consequently, ex-farmgate national *i.e.,* large-scale capacities for legume processing and value addition appear to remain largely fragmented and stereotyped by a lack of co-innovative sustainable-business partnerships.

Caution should also perhaps be exercised with respect to what appears as an over-focus on grain-legume production, and even productionism generally. Since, high quality grains for human food markets command significantly higher premiums that lower quality grains for animal feed markets, which offer high volume markets instead. Moreover, there is increasing awareness and recognition for the importance of forage legumes, which now feature as an essential component of crop mixtures for animal forage, green-manure, and critically preservation of soil functions. This includes their pivotal importance for delivery of promising regenerative agriculture (including soil carbon capture) based approaches, and more recently biorefining to provide protein concentrates, and high fibre biomass. These advantages also place forage legume-types as critical to help ensure optimised ecosystem functions. Their effective use also helps ensure highest gross margins and profits, whilst also minimising greenhouse gas footprints - even if there is lower levels of production. Increasingly, there is a realisation among producers that commercial resilience and profitability relates not to

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increasing yields, but lowering input costs and optimising ecosystem functions, and especially soil qualities.

At the other end of the value chain, and considering the role of consumers, sustainability is becoming the battleground for new marketing approaches, and the rhetoric of policy makers. Yet, market forces continue to determine what is grown and consumed, and the environmental- and societal (dietary)-costs of our current food system is not reflected in the structure of our foods system, food labelling, or indeed the food purchase prices. Equally, and where environmental and health benefits are achieved using legumes, these are not accounted in products either.

Added to this, the persistent neglect of home-grown legumes is compounded by the widescale "green washing" of our current food system. That is, the increasing use of spurious facts regarding the benefits of a particular product or approach as "environmentally friendly", perhaps with deceptive purpose or perhaps through ignorance, to capture the considerable spending power of consumers. It is therefore imperative that robust accounting tools, monitoring mechanisms, labelling and or certification systems are established to provide the necessary clarity, specificity, validity and certainty around any environmental-, biodiversity-, or health-benefits which are made - including for legume-based innovations. Also, that advancements are realised for all food-producing localities, such that socio-ecological and -economic development is achieved on an inclusive bioregionalised basis. In parallel, national education and awareness building initiatives on 'food system literacy', and the central role of home-grown legumes in environmentally sustainable consumption is also required.

Towards these collective goals or transition-paths the insights of the 24 TRUE-Project Case studies highlighted here present a range of legume-focused innovations and interventions which should be integrated. Since, it is the collective implementation of such approaches that will help realise real sustainability for the environment and society, and not just short-term economic satisfaction.

Dr. Pietro P.M. Iannetta, TRUE-Project Coordinator - November 2021

Head of Ecological Food Systems,
The James Hutton Institute
Scotland, UK

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Appendix I: Background to the TRUE-Project

TRUE-Project Executive Summary

TRUE's perspective is that the scientific knowledge, capacities and societal desire for legume supported systems exist, but that practical co-innovation to realise transition paths have yet to be achieved. TRUE presents 9 Work Packages (WPs), supported by an *Intercontinental Scientific Advisory Board*. Collectively, these elements present a strategic and gender balanced work-plan through which the role of legumes in determining '*three pillars of sustainabilit*y' – '*environment'*, '*economics'* and '*society'* - may be best resolved.

TRUE realises a genuine multi-actor approach, the basis for which are three *Regional Clusters* managed by WP1 ('*Knowledge Exchange and Communication',* University of Hohenheim, Germany), that span the main pedo-climatic regions of Europe, designated here as: *Continental*, *Mediterranean* and *Atlantic,* and facilitate the alignment of stakeholders' knowledge across a suite of 24 Case Studies. The Case Studies are managed by partners within WPs 2-4 comprising '*Case Studies'* (incorporating the project database and *Data Management Plan*), '*Nutrition and Product Development'*, and '*Markets and Consumers'.* These are led by the Agricultural University of Athens (Greece), Universidade Catolica Portuguesa (Portugal) and the Institute for Food Studies & Agro Industrial Development (Denmark), respectively. This combination of reflective dialogue (WP1), and novel legume-based approaches (WP2-4) will supply hitherto unparalleled datasets for the '*sustainability WPs*', WPs 5-7 for '*Environment'*, '*Economics'* and '*Policy and Governance'.* These are led by greenhouse gas specialists at Trinity College Dublin (Ireland; in close partnership with Life Cycle Analysis specialists at Bangor University, UK), Scotland's Rural College (in close partnership with University of Hohenheim), and the Environmental and Social Science Research Group (Hungary), in association with Coventry University, UK), respectively. These *Pillar WPs* use progressive statistical, mathematical and policy modelling approaches to characterise current legume supported systems and identify those management strategies which may achieve sustainable states. *A key feature* is that TRUE will identify key *Sustainable Development Indicators* (SDIs) for legume-supported systems, and thresholds (or goals) to which each SDI should aim. Data from the *foundation WPs* (1-4), to and between the *Pillar WPs* (5-7), will be resolved by WP8, '*Transition Design',* using machine-learning approaches (*e.g. Knowledge Discovery in Databases*), allied with *DEX* (*Decision Expert*) methodology to enable the mapping of existing knowledge and experiences. Co-ordination is managed by a team of highly experienced senior staff and project managers based in The Agroecology Group, a Sub-group of Ecological Sciences within The James Hutton Institute.

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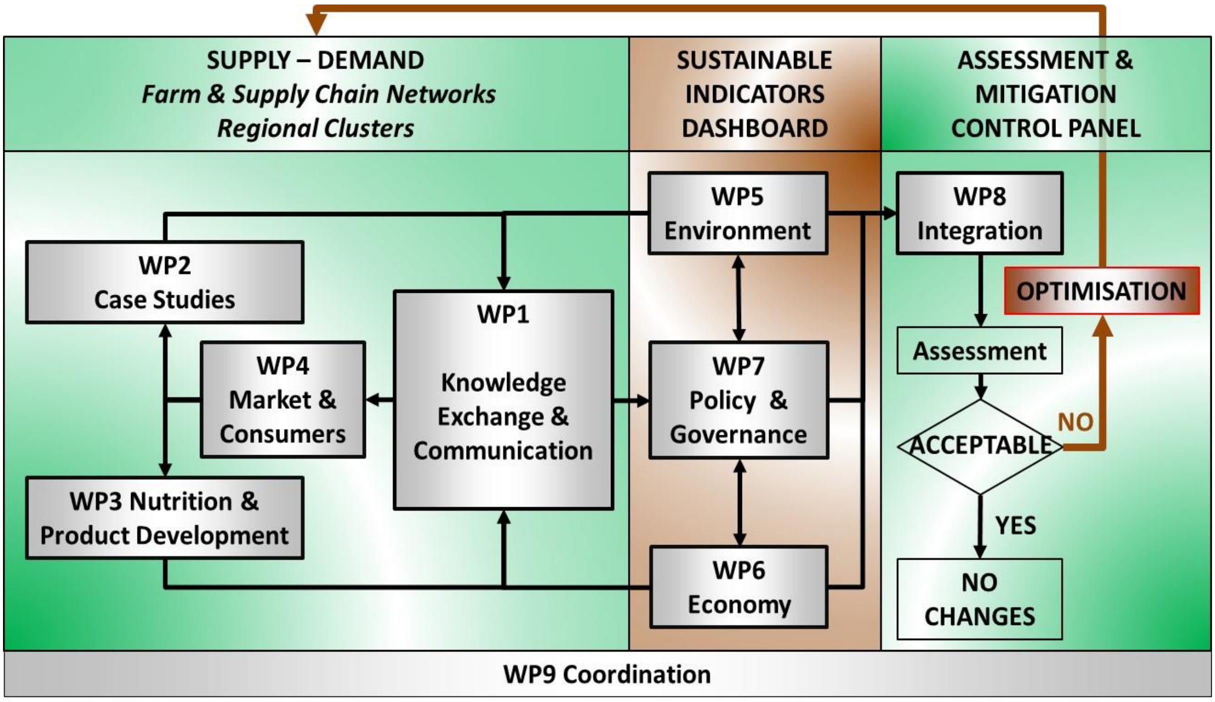
Work Package Structure

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) (Figure 1).



Work package structure and flow of information and knowledge between work packages.

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Project Partners

Nº.	Participant organisation name (and acronym)	Country	Organisation Type
1 (C*)	The James Hutton Institute (JHI)	UK	RTO
2	Coventry University (CU)	UK	University
3	Stockbridge Technology Centre (STC)	UK	SME
4	Scotland's Rural College (SRUC)	UK	HEI
5	Kenya Forestry Research Institute (KEFRI)	Kenya	RTO
6	Universidade Catolica Portuguesa (UCP)	Portugal	University
7	Universitaet Hohenheim (UHOH)	Germany	University
8	Agricultural University of Athens (AUA)	Greece	University
9	IFAU APS (IFAU)	Denmark	SME
10	Regionalna Razvojna Agencija Medimurje (REDEA)	Croatia	Development Agency
11	Bangor University (BU)	UK	University
12	Trinity College Dublin (TCD)	Ireland	University
13	Processors and Growers Research Organisation (PGRO)	UK	SME
14	Institut Jozef Stefan (JSI)	Slovenia	HEI
15	IGV Institut Fur Getreideverarbeitung Gmbh (IGV)	Germany	Commercial SME
16	ESSRG Kft (ESSRG)	Hungary	SME
17	Agri Kulti Kft (AK)	Hungary	SME
18	Alfred-Wegener-Institut (AWI)	Germany	RTO
19	Slow Food Deutschland e.V. (SF)	Germany	Social Enterprise
20	Arbikie Distilling Ltd (ADL)	UK	SME
21	Agriculture And Food Development Authority (TEAG)	Ireland	RTO
22	Sociedade Agrícola do Freixo do Meio, Lda (FDM)	Portugal	SME
23	Eurest -Sociedade Europeia De Restaurantes Lda (EUR)	Portugal	Commercial Enterprise
24	Solintagro SL (SOL)	Spain	SME
25	Public Institution for Development of Međimurje REDEA (PIRED)	Croatia	Development Agency

*Coordinating institution

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Objectives

Objective 1: Facilitate knowledge exchange (UHOH, WP1)
- *Develop a blue-print for co-production of knowledge*

Objective 2: Identify factors that contribute to successful transitions (AUA, WP2)
- *Relevant and meaningful Sustainable Development Indicators (SDIs)*

Objective 3: Develop novel food and non-food uses (UCP, WP3)
- *Develop appropriate food and feed products for regions/cropping systems*

Objective 4: Investigate international markets and trade (IFAU, WP4)
- *Publish guidelines of legume consumption for employment and economic growth*
- *EU infrastructure-map for processing and trading*

Objective 5: Inventory data on environmental intensity of production (TCD, WP5)
- Life Cycle Analyses (LCA) -novel legumes rotations and diet change

Objective 6: Economic performance - different cropping systems (SRUC & UHOH, WP6)
- *Accounting yield and price risks of legume-based cropping systems*

Objective 7: Enable policies, legislation and regulatory systems (ESSRG, WP7)
- *EU-policy linkages (on nutrition) to inform product development/uptake*

Objective 8: Develop decision support tools: growers to policy makers (JSI, WP8)
- *User friendly decision support tools to harmonise sustainability pillars*

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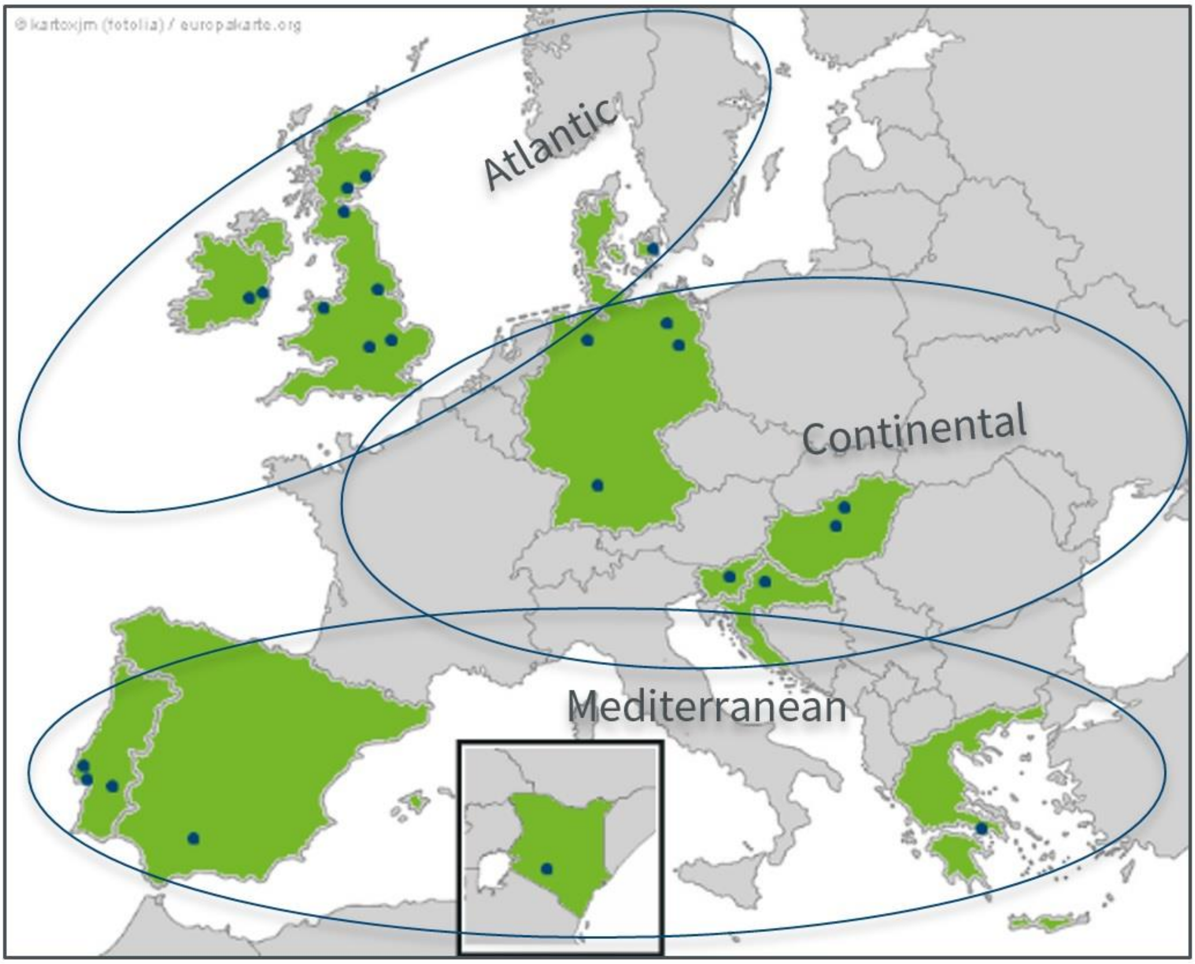
Legume Innovation Networks & Case Studies

Knowledge Exchange and Communication (WP1) events include three TRUE European Legume Innovation Networks (ELINs) and these engage multi-stakeholders in a series of focused workshops. The ELINs span three major pedoclimatic regions of Europe, illustrated above within the ellipsoids for Continental, Mediterranean and Atlantic zones (Figure 2).



Three TRUE European Legume Innovation Networks (ELINs).

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