Legume-supported cropping systems for Europe

Legume Futures Report 5.3

Outlook for knowledge and technology for legume-supported cropping systems

Compiled by:

Donal Murphy-Bokern (Germany)

Christine Watson (Scotland's Rural College, UK)

Fred L. Stoddard and Kristina Lindström (University of Helsinki, Finland)

Peter Zander, Moritz Reckling, Sara Preissel and Andrea Bues, (ZALF, Germany);

with a contribution from outside the consortium from

Ana Torres (Andalusian Institute of Agrarian, Fishing Research and Training, Spain IFAPA).

January 2014

Legume Futures

Legume-supported cropping systems for Europe (Legume Futures) is an international research project funded from the European Union's Seventh Programme for research, technological development and demonstration under grant agreement number 245216. The Legume Futures research consortium comprises 20 partners in 13 countries.

Disclaimer

The information presented here has been thoroughly researched and is believed to be accurate and correct. However, the authors cannot be held legally responsible for any errors. There are no warranties, expressed or implied, made with respect to the information provided. The authors will not be liable for any direct, indirect, special, incidental or consequential damages arising out of the use or inability to use the content of this publication.

Citation

Please cite this report as follows:

Murphy-Bokern, D., Watson, C.A. Stoddard, F., Lindström, K., Zander, P., Reckling, M., Preisel, S., Bues, A., and Torres, A. 2014. Outlook for knowledge and technology for legume-supported cropping systems. Legume Futures Report 5.3. Available from www.legumehub.eu

2

Legume Futures Report 5.3:
Outlook for knowledge and technology for legume-supported cropping systems
www.legumehub.eu

CONTENTS

3

Legume Futures Report 5.3:
Outlook for knowledge and technology for legume-supported cropping systems
www.legumehub.eu

Legume Futures Report 5.3:
Outlook for knowledge and technology for legume-supported cropping systems
www.legumehub.eu

FOREWORD

The Legume Futures project was conducted at a time of widespread public debate about the future of cropping systems, particularly in relation to the potential role of legume species in contributing to the sustainable development of European agricultural and food systems. Being the only European major project on legume cropping at the time, the Legume Futures consortium contributed extensively to these debates and provided supporting information. These processes included participation by Donal Murphy-Bokern, Herwart Boehm (vTI) and Johann Bachinger (ZALF) in the Legume Expert Forum set up by the German Agricultural Research Alliance (DAFA). This fed in to wider debate across Europe about the future of legume crops and the knowledge and technology required to support them. Our work also included contributions to the European Innovation Partnership Focus Group on protein crops which includes two members from the Legume Futures consortium.

Based partly on the results of these intensive stakeholder engagement activities and on review of the literature, this report sets out thoughts from the consortium on the challenges of increasing the production of legume crops in Europe and the potential approaches to research and development that might be taken. Much of the review of the literature presented draws heavily on work many of the authors did for the European Parliament in 2012 and 2013.[1] In preparing this report for Legume Futures from that and the other work we have done, it is not our intention to present an exhaustive review of all the issues or possible approaches to developing legume-supported cropping systems. Rather, this report brings together information on the context of Legume Futures and the results of the forward-looking activities that were a particularly strong feature of the consortium's work.

Donal Murphy-Bokern

February 2014

---

[1] Bues, A., Kuhlmann, T., Lindstrom, K., Murphy-Bokern, D., Preissel, S., Reckling, M., Stoddard, F.L., Topp, K., Watson, C. and Zander, P. (2013) The environmental role of protein crops in the new common agricultural policy. The European Parliament
(http://www.europarl.europa.eu/delegations/en/studiesdownload.html?languageDocument=EN&file=93370)

Legume Futures Report 5.3:
Outlook for knowledge and technology for legume-supported cropping systems
www.legumehub.eu

STATUS OF LEGUME CROPS AND FUNDAMENTAL CHALLENGES

Introduction

Despite their potential advantages in agricultural systems, the use of legumes as crops and in pasture has declined in the EU. The pulse crop area as a proportion of all arable land has declined from 4.7% in 1961 to 1.8% today (Fig. 1). This compares with 8% in Australia and western Canada. Furthermore the distribution of legume crops across Europe is uneven with 86% of the EU grain legume production in 2005 in only 5 countries. The low use of legumes in European cropping systems is compensated for by a large import of soya beans and soya bean meal, particularly from South America. The EU imports the equivalent of 37 M t of soya bean, about 14% of the worldwide soya production. Imported soya accounts for about 15 M ha of land outside the EU and is the largest cause of the EU's net 'virtual' land import.[2] This dependence on imported protein has stimulated discussions about Europe's approach to plant protein provision and the consideration of possible options to replace imported soya by protein crops grown in Europe.

Within Europe, the low contribution made by legumes to crop production means that Europe forfeits any environmental and resource conservation effects legume crops provide. The effects of legumes are only fully evident and optimised when whole farming system-wide effects are considered. This includes the very important pre-crop and break-crop effects of legumes. Grain legumes are grown as components of crop rotations, often providing a 'break' from pests and diseases of the dominant crops (usually cereals) as well as supplying nitrogen to the following crop. Yields of subsequent crops are higher than would otherwise be the case (even when they are fertilised). A recent analysis of trends in wheat yields in France suggests that the decline in the use of legumes has adversely affected the yield of wheat crops.[3] Legumes play a particularly important role in farming systems that are valued by consumers, including organic and low-input systems, certified quality meat production, and traditional systems that characterise certain regions, such as in the Alps.

---

[2] von Wirzke H, Noleppa S (2010) EU agricultural production and trade: can more efficiency prevent increasing 'land-grabbing' outside of Europe. Humbolt Univ., Berlin, Germany http://www.agrar.hu-berlin.de/fakultaet/departments/daoe/ihe/Veroeff/opera-final_report_100505.pdf

[3] Brisson, N., Gate, P., Gouache, D., Charmet, G., Oury, F.X., Huard, F. (2010). Why are wheat yields stagnating in Europe? A comprehensive data analysis for France. Field Crops Research 119:201-212

Legume Futures Report 5.3:
Outlook for knowledge and technology for legume-supported cropping systems
www.legumehub.eu

The consumption driver

The current public debate about supporting legume production in Europe is often driven by the unease felt at the reliance on imported soya.[4] The growth in the deficit is sometimes attributed to declining production of protein crops. However, any consideration of developing protein crops to reduce the European protein deficit needs to consider the main driver behind growth in Europe's deficit in plant protein: the growth in meat production. The consumption and production of livestock products are closely linked in the EU. The combined production of beef, pig and poultry meat in the EU has increased from 17 to 43 M t from 1961 to 2011 (Fig. 2), and demand for protein-rich feed has grown accordingly.

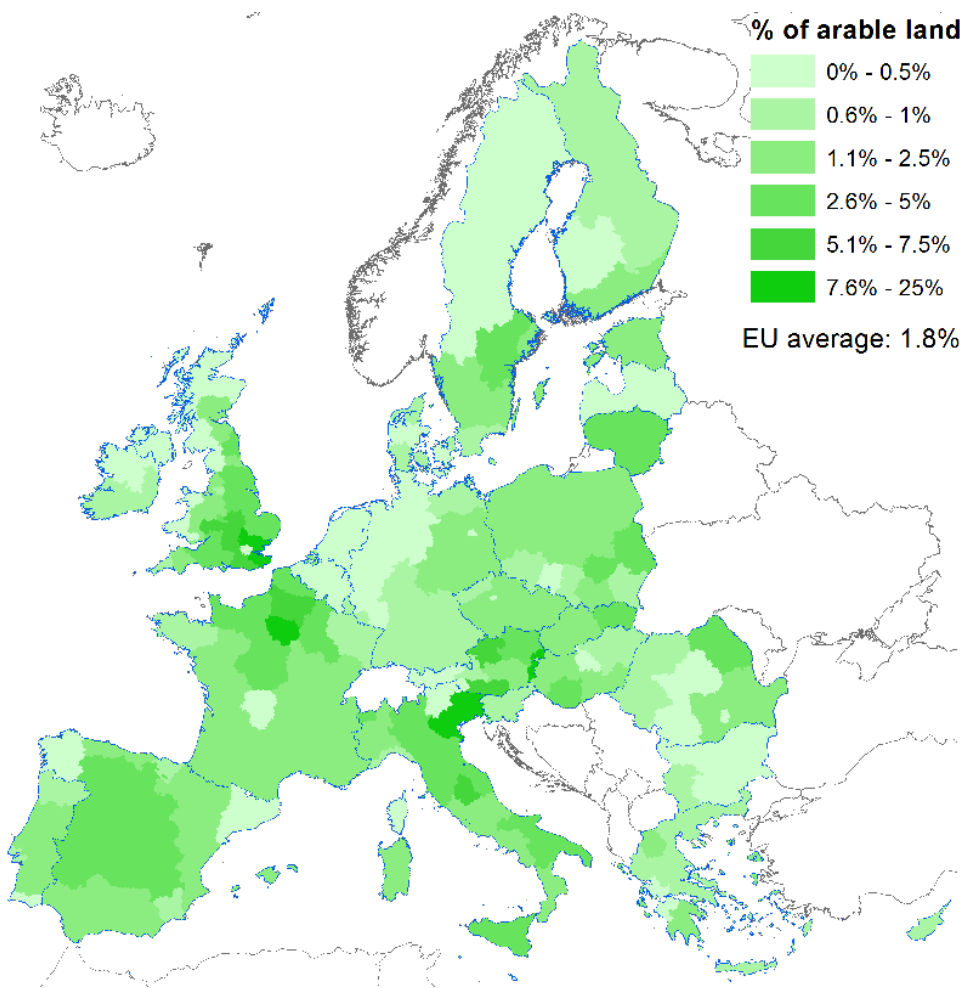Figure 1 Proportion of EU-27 arable land used for protein crops in 2010 (%). Source: calculations based on data from EUROSTAT accessed in 2013.

---

[4] Beste, A., Boeddinghaus, R. (2011). Der Eiweissmangel in der EU: wie lässt sich das seit langem bestehende Problem lösen? Martin Häusling/Die Grünen

Legume Futures Report 5.3:
Outlook for knowledge and technology for legume-supported cropping systems
www.legumehub.eu

This demand has been met by a higher production of grain legumes (an increase from 3.3 M t in 1961 to 4.3 M t in 2011 and a larger share being used as animal feed) and greatly increased import of soya bean (increase from 2.7 to 37 M t). The higher consumption of meat has been met by increased production of pig and poultry meat rather than by beef. Pig and poultry diets are cereal-based and approximately two-thirds of Europe's cereal harvest is now used to feed livestock. This scale of production based on European-grown cereals is made possible by the complementary qualities of soya bean meal that provides the necessary protein enrichment for cereal-based feeds. It is also made possible by the particularly high yields of cereals in Europe.
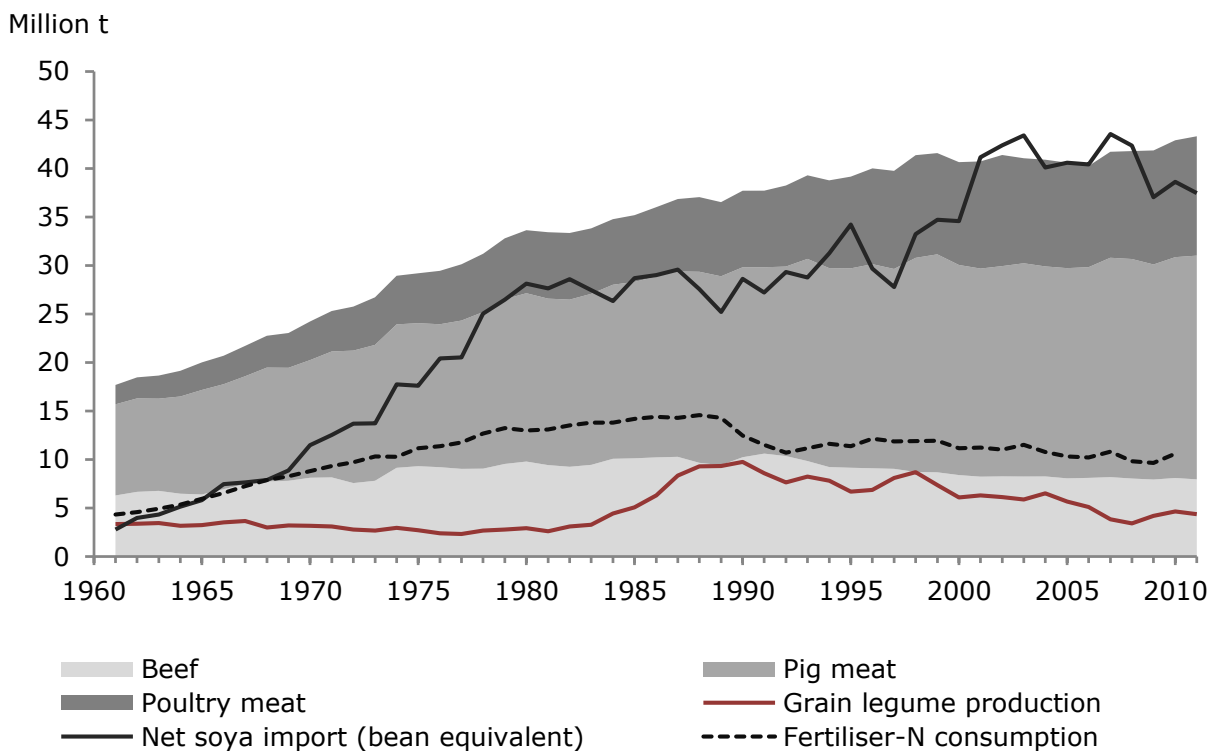
Figure 1. Changes in the production of meat and corresponding changes in fertiliser N use, protein crop production and net soya import for the EU-27 (1961 – 2011). Source: Calculations based on data from FAOSTAT accessed in 2013.

History of protein crop production and consumption
The increase in the reliance on imported protein-rich commodities is sometimes attributed to the decline in the area of legumes grown and the expansion of cereal production. However, since 1961, the production of pulse crops has increased in terms of quantity harvested.   The major changes in terms of the proportion of land allocated to crops have been in the decline in potatoes and sugar beet (due to productivity growth), the growth in the production of oilseeds. Grain legumes (protein crops) declined from 5.8 M ha in 1961 (4.7% of the arable area) to 1.9 M ha in 2011 (1.8% of the arable area). The area of 8

Legume Futures Report 5.3:
Outlook for knowledge and technology for legume-supported cropping systems
www.legumehub.eu

cereals as a proportion of the area devoted to the major annual arable crops has remained remarkable stable over the 50 years 1961 to 2011, at about 65% of the area allocated to the major arable crops (Fig. 3). At this European scale, the decline in the area of grain and forage legumes is associated with an increase in the area of maize and oilseed rape in cropping systems that remain dominated by carbohydrate-rich small-grain cereals and maize. This dominance has persisted through the development and reform of the CAP over the last 50 years.

Figure 2. Change in areas of production of key arable crops in the EU-27 (1961 – 2011). Data source: FAOstat (2013). Pre-1992 data do not include data on crops grown in the Czech Republic, Estonia, Latvia, Lithuania, Slovakia, and Slovenia.

The comparative advantage of growing cereals in Europe

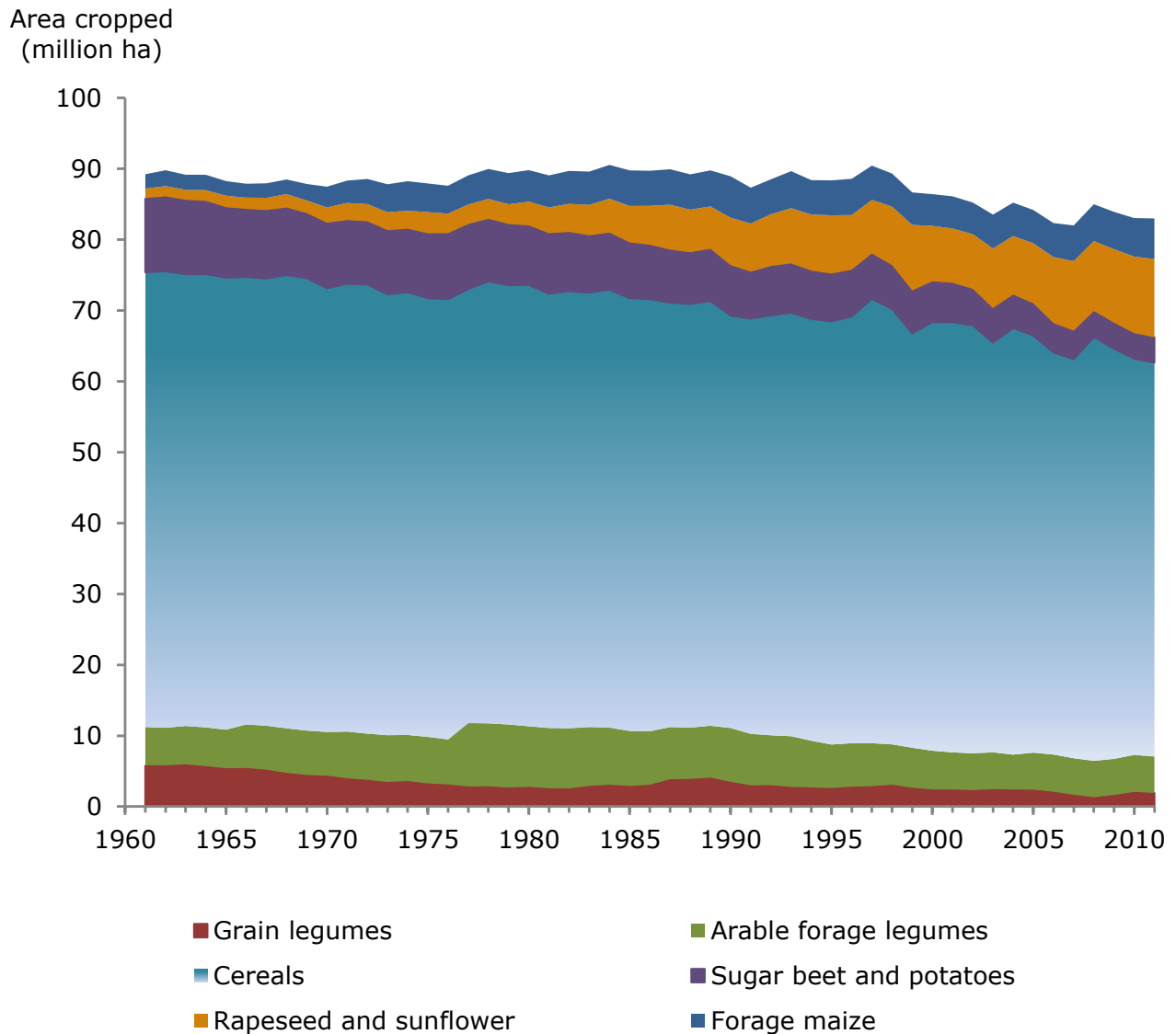A major underlying driver behind the reduction in the proportion of arable land used for protein crops is the increased comparative advantage in the production of starch-rich cereals in Europe over the production of protein-rich grain legumes. Between the 1970s and the 1990s, wheat production in north-western Europe benefited from an annual yield increase of about 0.15 t/ha/yr facilitated by the switch to autumn sowing, the availability of inexpensive nitrogen fertilisers, investment in plant breeding, and a wide range of pesticides from a well-established European pesticides sector. [5]

In the same period, the yields of soya bean and other protein crops which are closely aligned in Europe, grew at a slower rate so that between 1960 the yield gap between the average yield of wheat over faba bean, pea and soya grew from 40% in 1961 to almost 100% in 2011 (Fig. 4). To examine the effect of this on trade, data for soya and wheat from France and the USA can be used. Soya bean yields in France have been similar to soya bean grown in the USA since 1971. While US wheat yields are similar to US soya bean yields, wheat out-yields soya in France by a factor of 2.7. The comparative advantage of using French land to grow wheat instead of protein crops has increased. This pattern can be found across much of Europe's major cropping areas with different cereal and legume crop combinations (See Legume Futures Report 1.3: Agronomic Case Studies). An implication of this is that the prospects for legume-supported cropping systems are better in regions where the major cereals do not grow well, and where there is not already a large quantity of organic manures available.

In addition to higher yield potential of cereals in Europe, farmers who grow grain legumes are confronted with a range of agronomic challenges. Grain legume yields are considered unstable, as pointed out in many studies.[6][7][8] Some are not as competitive as cereals against weeds.[9] Pea in particular is susceptible to lodging (collapse of stems so the crop

---

[5] Supit, I. (1997). Predicting national wheat yields using a crop simulation and trend models. Agricultural and Forest Meteorology 88(1-4):199–214

[6] Von Richthofen, J.-S., Pahl, H., Bouttet, D., Casta, P., Cartrysse, C., Charles, R., Lafarga, A. (2006a). What do European farmers think about grain legumes? Grain Legumes 45:14–15

[7] Sass, O. (2009). Marktsituation und züchterische Aktivitäten bei Ackerbohnen und Körnererbsen in der EU (Market situation and breeding input in faba bean and field pea in the EU). Journal für Kulturpflanzen 61:306–308

[8] Flores, F., Nadal, S., Solis, I., Winkler, J., Sass, O., Stoddard, F.L., Link, W., Raffiot, B., Muel, F., Rubiales, D. (2012). Faba bean adaptation to autumn sowing under European climates. Agronomy for Sustainable Development 32(3):727–734

[9] Corre-Hellou, G., Crozat, Y. (2005). N2 fixation and N supply in organic pea (Pisum sativum L.) cropping systems as affected by weeds and pea weevil (Sitona lineatus L.). European Journal of Agronomy 22:449–458

10

Legume Futures Report 5.3:
Outlook for knowledge and technology for legume-supported cropping systems
www.legumehub.eu

lies on the soil), drought stress, and pests and diseases.[10] Where pea has been grown intensively, build-up of aphanomyces root rot, which is a serious soil borne disease, has reduced yields. Yield instability is partly due to the indeterminate or continuous growth of most legume stems, which allows them to take advantage of good mid-season growing conditions, but delays their ripening and harvesting periods. Cereal crops, in contrast, are determinate and flower and ripen much more uniformly due to synchronised development.[11] Determinate faba bean and non-branching lupin cultivars have been developed to circumvent this problem, and have gained some market share in regions with short seasons.

---

[10] Gueguen, J., Duc, G., Boutin, J. P., Dronne, Y., Munier-Jolain, N., Sève, B., Tivoli, B. (2008). La filière protéagineuse, quels défis pour la recherche? Rencontre au Salon International de l'Agriculture. INRA, Paris, France. February 2nd 2008. 6pp. In: Mahmood, F. (2011). Analysis of the conditions for the development of grain legumes in the Midi-Pyrénées region (France), using the APES-FSSIM-Indicators modelling chain. PhD Thesis, SupAgro Montpellier, Ministère de l'Agriculture, IAM Monpellier
http://www.iamm.fr/ressources/opac_css/doc_num.php?explnum_id=5957 (2013-05-07)
[11] Hay, R.K.M. and Kirby, E.J.M. (1991). Convergence and synchrony – a review of the coordination of development in wheat. Aust. J. Agric. Res. 42:661-700

11

Legume Futures Report 5.3:
Outlook for knowledge and technology for legume-supported cropping systems
www.legumehub.eu

Yield (t/ha)
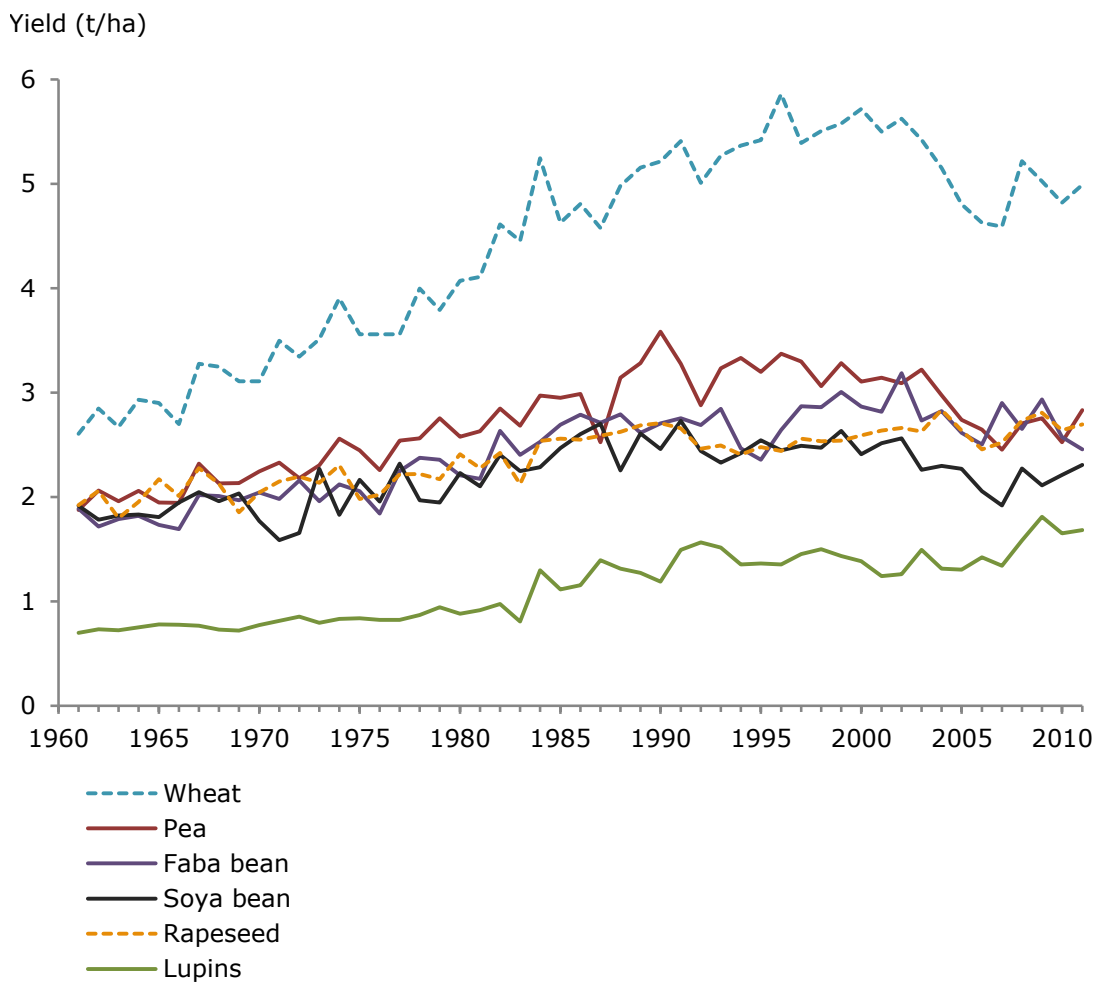
Figure 3. Average yields of wheat and the main grain legumes in the EU-27 (1961 – 2011).
Data source: FAOSTAT (2013)

12

Legume Futures Report 5.3:
Outlook for knowledge and technology for legume-supported cropping systems
www.legumehub.eu
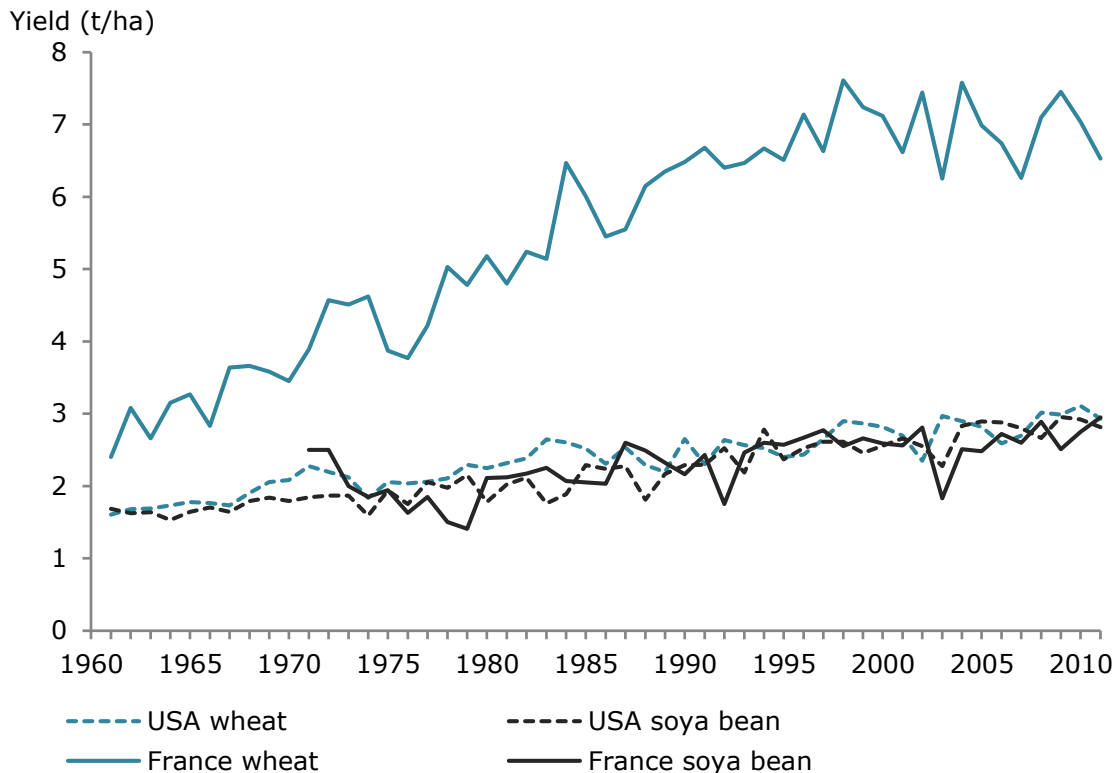
Figure 4:   Yields of wheat and soya bean in the USA and France (1961 – 2011). Data source: USDA National Agricultural Statistics Service and EUROSTAT accessed in 2013.

Profitability of cropping systems

Estimates that per hectare gross margins of different protein crops were shown to be between 55 and 622 €/ha less than those of cereals and oilcrops in several case studies across Europe. However these estimates generally do not take account of savings of nitrogen fertilisers and pesticides used in subsequent crops, and the higher yields of those crops. These cropping system level benefits from legume crop realised in the subsequent crop can be the equivalent to more than 100 €/ha. Therefore, on a rotational basis, the average gross margins of legume-supported rotations are reported in case studies to be about 40 €/ha less per year compared with the dominant cropping systems without legumes. In considering these data, it must be remembered that small reductions in rotation gross margin may arise from a large reduction at the legume crop level, as the crop level reduction is averaged over the other crops in the system.

13

Legume Futures Report 5.3:
Outlook for knowledge and technology for legume-supported cropping systems
www.legumehub.eu

Specialisation and intensification are driven by comparative advantage resulted in more concentrated production and more homogeneous farming systems. The combination of availability and low costs of synthetic nitrogen fertilisers relative to farm product prices (e.g. cereals, milk, beef) and imported feed protein has been another major enabler of this process. Consequently, increases in the price of nitrogen fertiliser and soy in particular increase the incentive to include legumes in cropping systems.

Nitrogen price
Nitrogen fertiliser prices have doubled since 2000 (Fig. 6) and OECD data indicate that the costs of fertiliser N relative to farm prices for wheat and milk have increased by 78% and 63%, respectively. Thus, the economic benefit of nitrogen provision through legumes is increasing.
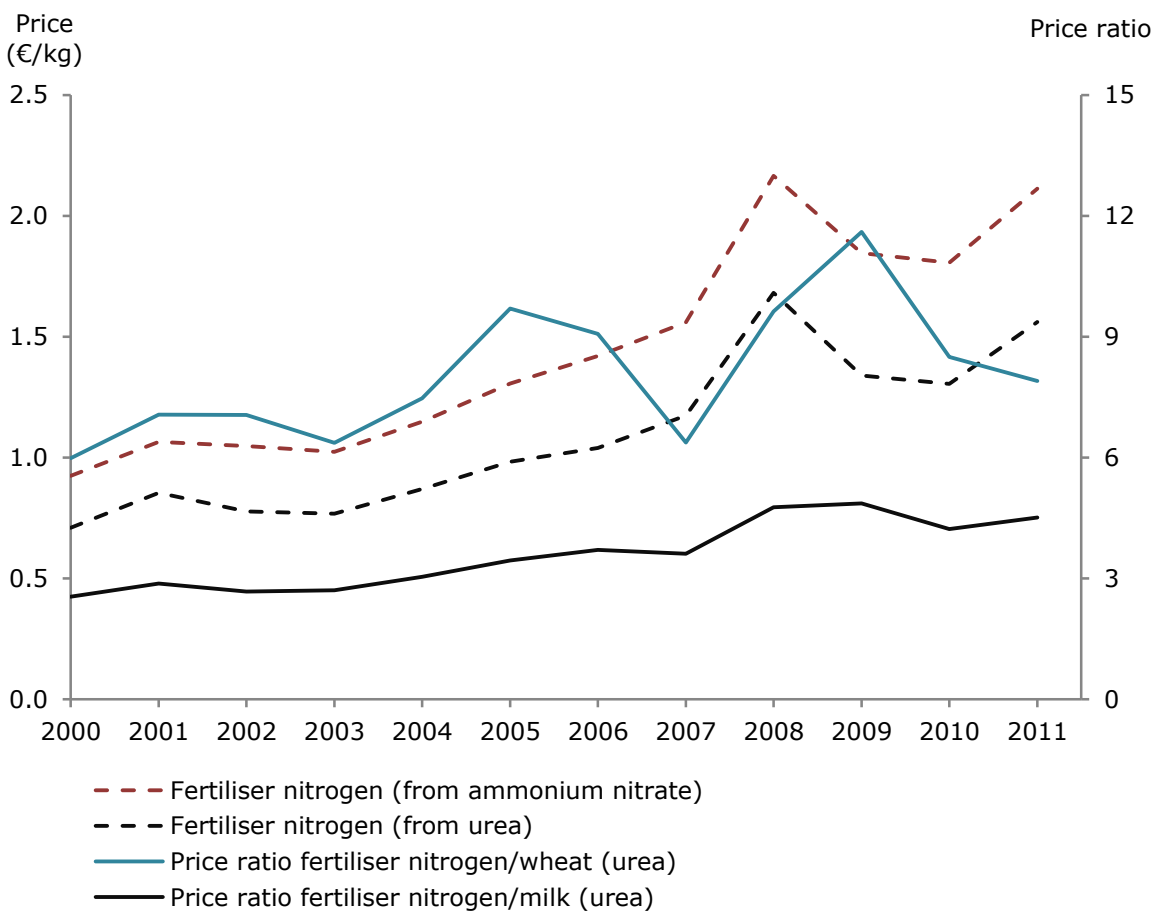
Figure 5. Changes in the price of mineral nitrogen fertilisers, wheat and milk in the EU-27, and the associated fertiliser/product price ratios (2000-2011). Source: Calculations based on data from EUROSTAT (2013). The urea-N/wheat-milk price ratio is the amount (kg) wheat or milk required to pay for one kg of nitrogen in urea fertiliser.

14

Legume Futures Report 5.3:
Outlook for knowledge and technology for legume-supported cropping systems
www.legumehub.eu

Rising nitrogen fertiliser prices have two main effects on the cropping decisions. Higher prices increase the cost of production of non-legume crop which reduces the competitiveness of them unless produce prices rise, and the value of the pre-crop effect increases. Research in Ireland on the use of white clover in grassland for milk production has identified a tipping point in the relationship between milk and nitrogen fertiliser prices beyond which milk production systems based on clover-grass swards are economically competitive.[12] There is also evidence of increasing interest in the use of white clover on farms, for example, in the west part of France where in 2009 50% of sown pastures are mixed grasses and WC compared with less than 10% in 1985.[13] Overall, this means that the use of white clover in grassland-based systems is competitive when the ratio of fertiliser nitrogen to milk prices (per kg) exceeds 3.

Soya price

The relationship between soy and wheat prices is fundamental to the competitiveness of grain legumes in European cropping systems. The price of wheat and other cereals, including grain maize, are linked. The value of all grain legumes used for animal feed is also linked to the price of soya. Based on these assumptions, the micro-economic effect of introducing soya into cereal dominated rotations was studied intensively in Bavaria.[14] That study estimated that if a rotational (pre-crop) benefit of introducing soya into cereal dominated rotations is not considered, the price of soya needs to be 2.0 to 2.4 times that of the price of wheat using average yields of soya and wheat in Bavaria (2.8 and 7.0 t/ha respectively). If a pre-crop benefit of 150 Euros/ha is allocated to the soya crop, the price ratio required to make soya competitive with wheat drops to between 1.5 to 2.2. The study concluded that there is a potential to produce 16,000 ha soya in Bavaria (total arable area is 2 million ha) competitively within Bavarian cropping systems at current prices.

The price paid for imported soya has increased steadily since 2007 and the import quantities have fallen (Fig. 7). If the EU were to have one quarter of its soya imports GM-free, the increased demand would raise the price of GM free soya by 55 €/t.[15]

The prices of European-grown protein crops used for animal feed are closely correlated with the price of imported soya bean. Accordingly, the producer prices of European-grown

[12] Humphreys J., Mihailescu E. and Casey I.A. (2012) An economic comparison of systems of dairy production based on N fertilised grass and grass-white clover grassland in a moist maritime environment. Grass and Forage Science, 67: 519-525

[13] Peyraud J.L., Le Gall A. and Lüscher A. (2009) Potential food production from forage legume-based systems in Europe: an overview Irish Journal of Agricultural and Food Research, 48, 1-22

[14] Schätzl, R. and Halama, M. (2013). Micro-economics of soya production. Second International Danube Soya Congress. 25-26 November 2013. http://www.donausoja.org/tag-1-forum-i

[15] Aramyan, L.H., van Wagenberg, C.P.A., Backus, G.B.C. (2009). EU policy on GM soy; Impact of tolerance threshold and asynchronic approval for GM soy on the EU feed industry. Report 2009-052. The Hague: LEI Wageningen UR. (http://edepot.wur.nl/7856, 2013-03-03)

15

Legume Futures Report 5.3:
Outlook for knowledge and technology for legume-supported cropping systems
www.legumehub.eu

soya bean, pea and faba bean have increased in line with the increase in international soya prices (Fig. 8). Most importantly, the price advantage of protein crops over wheat has increased slightly, reducing the comparative advantage of wheat (and cereals in general) over protein crops in competition for European land.

However, there should be caution in developing cropping systems on the assumption that recent trends in prices will continue. Different rates of increase in the prices of protein and carbohydrate rich materials do not translate into similar differences between cereals and protein crop materials. This is because the grain legumes have components in common with the competing crops and therefore changes in the value of components change the value of all crops, albeit to differing degrees. Focusing on this, recent analysis for the European Innovation Partnerships for Protein Crops has shown that significant changes in the ratio of cereal and protein crops may be short lived and cannot be relied upon to sustain a growth in legume crop production. Therefore efforts to increase the yield of legumes relative to cereals and oilseed rape is a more robust way forward.

Aquaculture represents a significant potential market for legumes. Aquacultural developments are likely to play a central role in the sustainable development of food systems presenting special opportunities for legume crops. At the present time around 45% of fish consumed by humans is produced in aquaculture. The FAO forecasts a doubling in the demand for farmed fish by 2030. Non-sustainable feeds such as fishmeal and fish oil will not meet the demand and the responses required include a shift to more herbivorous fish species such as carp and tilapia along with greater use of processed legume proteins to produce sustainable fish feeds. There is also a small but important market for grain legumes for human consumption which may increase in significance if meat and dairy production consumption stabilises or reduces in Europe. Grain legumes and products derived from them can help in managing or preventing cardiovascular disease, type 2 diabetes, cholesterol uptake, blood pressure problems, obesity, and possibly colon cancer.

16

Legume Futures Report 5.3:
Outlook for knowledge and technology for legume-supported cropping systems
www.legumehub.eu
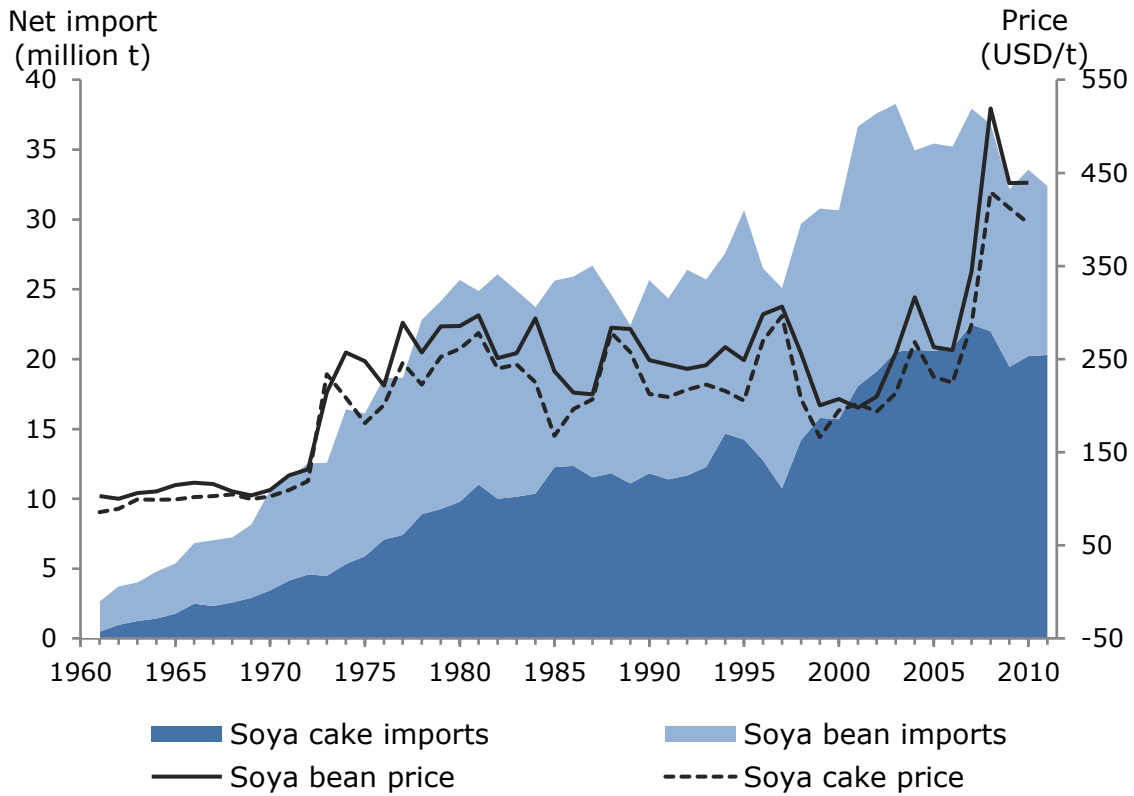
Figure 6. Changes in soya feed imports and import prices (1961 – 2011). Source: Calculations based on data from 1961-2010 - FAOstat (2013), 2011 - EUROSTAT (2013).

Legume Futures Report 5.3:
Outlook for knowledge and technology for legume-supported cropping systems
www.legumehub.eu
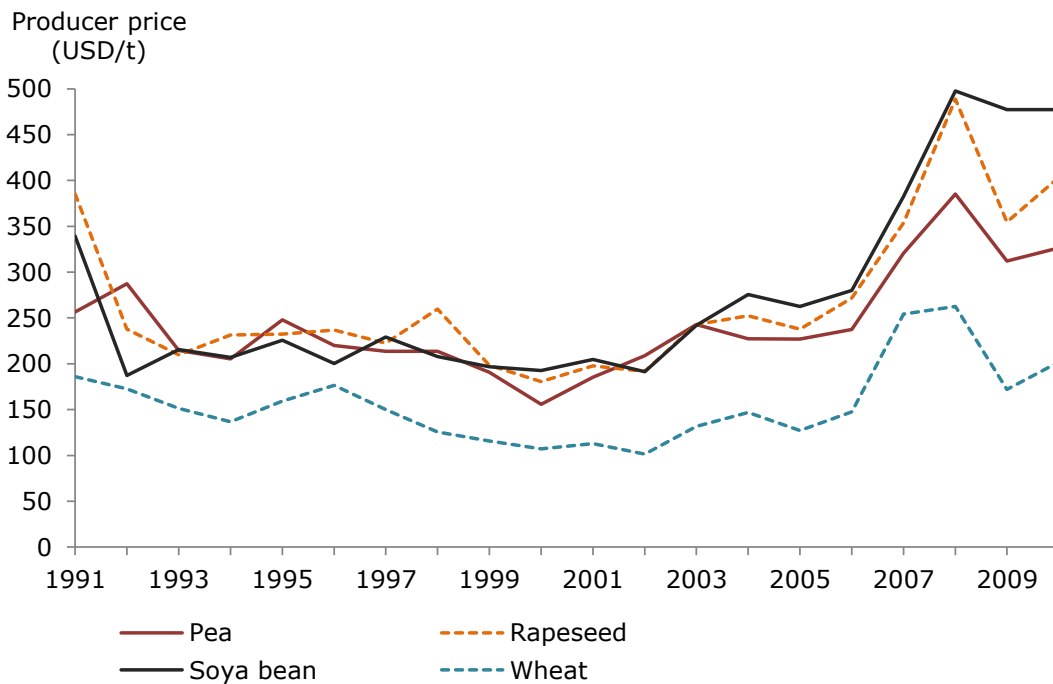
Figure 7. Changes in producer prices for main protein crops, rapeseed and wheat in major producer countries of the EU (1990-2010). Source: Calculations based on data from FAOSTAT (2013). Prices are averages for major EU producer countries.

Cropping system diversity
Diversity is a distinguishing feature of European land us and cropping. If we compare the cropping of grain legumes (excluding soya) in the EU and countries with a significant commercial grain legume sector, we can see that Europe is characterised by a diversity of species used (Fig. 9). This combined with the small proportion of land under legume cropping in Europe leads to fragmentation in markets for technology, especially breeding.

18

Legume Futures Report 5.3:
Outlook for knowledge and technology for legume-supported cropping systems
www.legumehub.eu
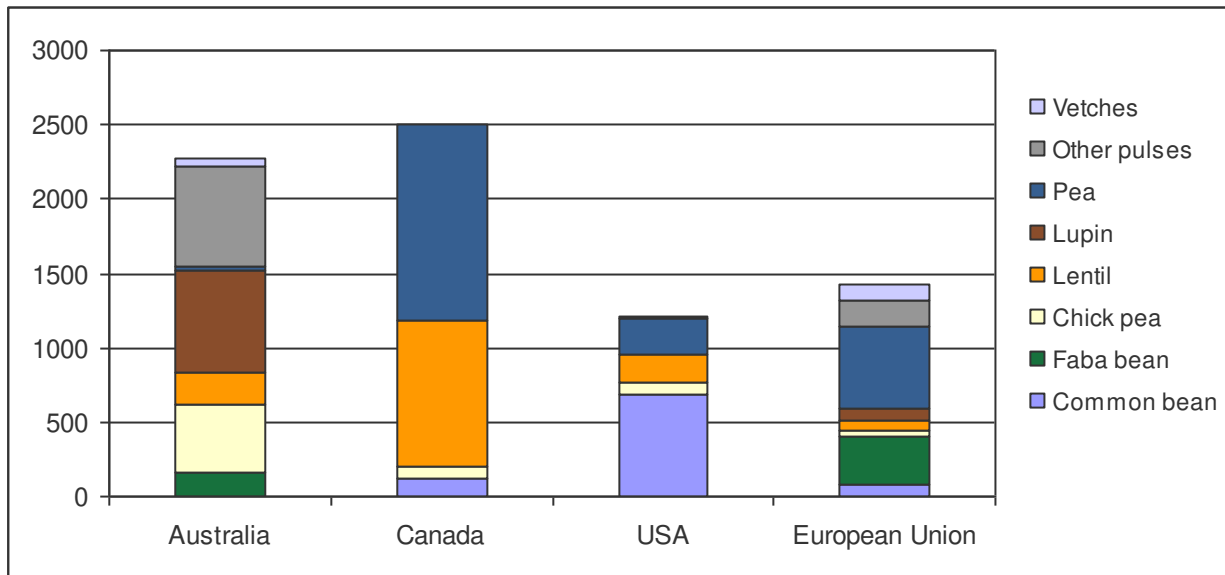
Figure 8. Areas (thousand hectares) of grain legume species grown in Australia, Canada, USA and the European Union. The figure excludes soy which dominates grain legume production in USA and Canada.

Implications for research and innovation

Increasing crop output – the foundation of sustained growth in legume cropping
The economic realities set out above highlight a need for research to increase and stabilise legume crop yields compared with other crops. The current large price difference between soya and cereals (particularly GM free soy) is unlikely to be sustained even if the demand and price for the protein component remain high. Therefore, the core technical challenge for grain legumes is increasing the yield and yield stability of these crops compared with the dominant cropping options, typically cereals or oilseed rape. This provides a foundation for the sustained allocation of more land to grain legumes in particular.

Capturing on-farm economic benefits
As we see above, the legume crop provides indirect non-monitory benefits to the cropping system, estimated to be equivalent to 150 Euros/ha in a German cropping system. [16] These stem from resource protection, linked in particular to biological nitrogen fixation, and reduced disease risks. The effects of resource conservation on farm profitability is difficult for farmers to factor into their cropping decisions. Therefore, the second major challenge

---

[16] Schätzl, R. and Halama, M. (2013). Micro-economics of soya production. Second International Danube Soya Congress. 25-26 November 2013. http://www.donausoja.org/tag-1-forum-i

Legume Futures Report 5.3:
Outlook for knowledge and technology for legume-supported cropping systems
www.legumehub.eu

for technical development is the development of cropping systems that optimise and fully capture these benefits.

Enhancing and exploiting non-provisioning eco-system services
The development of legume cropping over the last 50 years has been linked to public-policy measures, particularly those developed and implemented under the CAP. Environmental measures such as those under the Nitrates Directive also play an indirect role in some situations. The public debate that led to the current reform of the CAP highlighted the potential of legume-supported cropping systems within a 'public money for public goods' framework.

Many on the non-provisioning eco-system services provided by legumes arise from the contribution these crops make to diversity in cropping. Diversity in agro-ecosystems, landscapes and in the range of crops grown is a distinguishing feature of European agriculture. This diversity provides challenges and opportunities in developing cropping systems.

20

Legume Futures Report 5.3:
Outlook for knowledge and technology for legume-supported cropping systems
www.legumehub.eu

CROPPING OPTIONS

This chapter provides an outline of the various legume cropping options available to European farmers. It draws on the material provided by Legume Futures partners and project associates who have contributed to the Legume Futures Book.

There are four broad categories of legume-based cropping:

1. grain legumes (or pulses) such as pea, faba bean and soy;
2. forage legumes such as clover and alfalfa (alfalfa);
3. mixtures of legumes with cereals and catch crops; and
4. legumes harvested green as vegetables (e.g. vining peas and broad beans).

The fourth category (vegetable legumes) comprises, where commercial, specialised crops usually grown on contract for processors. These are specialised crops accounting for small crop areas not considered further here.

Grain legumes

Grain legumes are grown for their seed, harvested when fully mature and when the seed is dry, usually using a combine harvester. They therefore fit well into cropping systems with cereals requiring the same machinery and crop handling facilities. Seven species, or groups of related species, are grown commercially in Europe. These are (in order of area grown):

Pea
Faba bean
Soya
Common bean
Lupins
Lentil
Chickpea

21

Legume Futures Report 5.3:
Outlook for knowledge and technology for legume-supported cropping systems
www.legumehub.eu

Area (million ha)
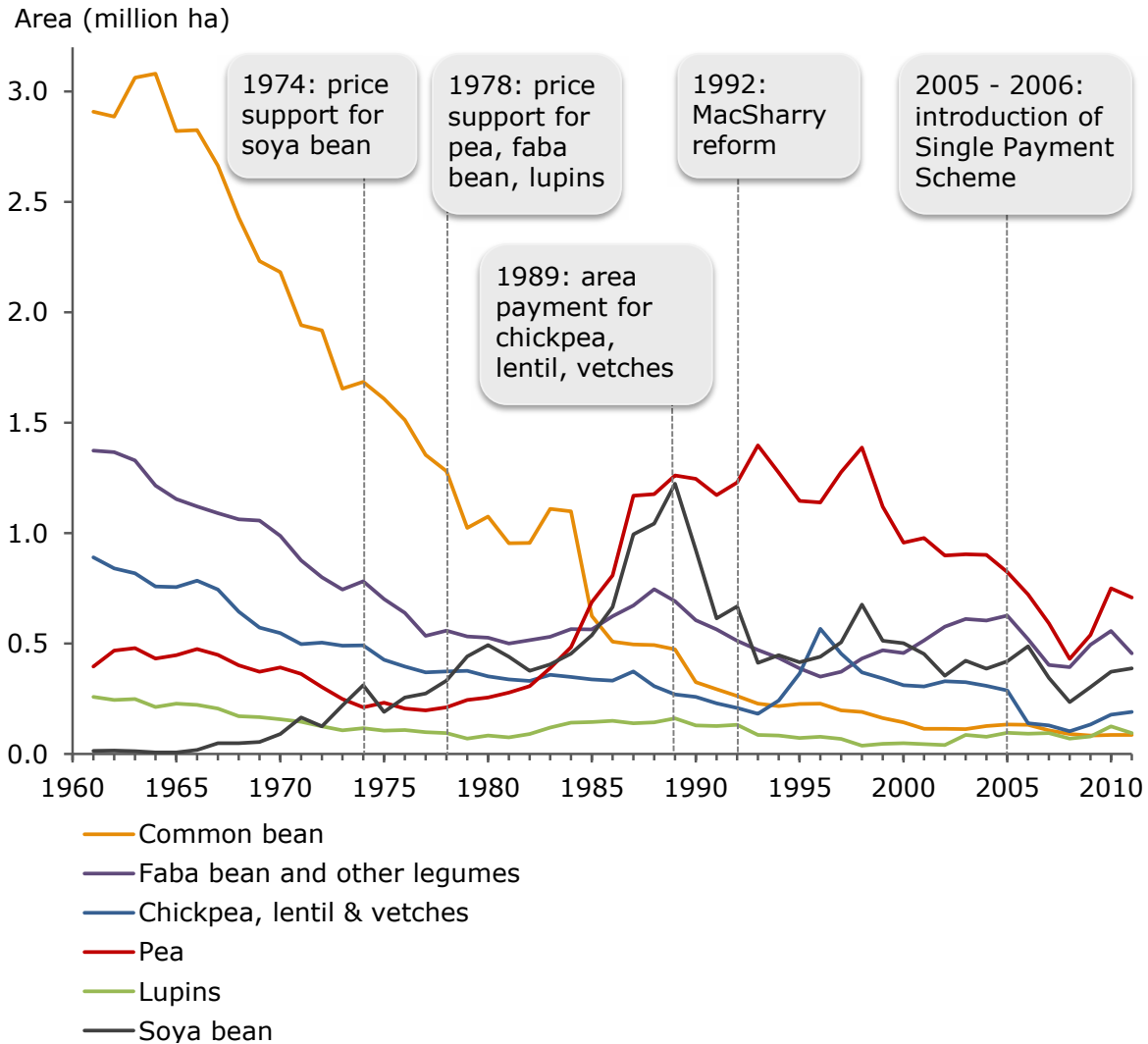
Figure 9. Production areas of different protein crops in the EU-27 in relation to policy events[17] (1961-2011). Data source: FAOSTAT (2013)

In 1961, nearly 6 M ha were cropped to various species of grain legumes in the EU 27 (Fig. 10). More than half of these crops were for direct human consumption and common bean was widely cultivated. Pea and soya bean (the majority being used as animal feed) became the most widely grown protein crops following the introduction of policy support for protein feed crops in the 1970s.

Pea production peaked between 1987 and 1999 (peak area almost 1.4 M ha, peak yields above 4 t/ha in 1990). Since then and particularly associated with the 2003 reforms, the area under pea has continued to decline in all member states except Spain (ca. 700,000 ha in the EU in 2011). Similarly, soya production surpassed 1 M ha in 1988, but after 1989

---

[17] EU-wide aggregated data may mask regional effects of policies. For a regional breakdown of policy effects refer to Chapter 3.1.

22

Legume Futures Report 5.3:
Outlook for knowledge and technology for legume-supported cropping systems
www.legumehub.eu

it declined again and has fluctuated around 400 000 ha since. In Romania the land area of soya bean declined by 75% between 2006 and 2008 (FAOSTAT 2013) due to the decision to stop production of GM soya.[18] Lupin production has fluctuated over time and has now stabilised at a low level (around 100 000 ha in 2011). The small area of all grain legumes in 2008 is partly explained by low yields in 2007. Production of protein crops within organic production systems is currently important: 40% of lupin and faba bean and 20% of pea production areas are certified organic (EUROSTAT 2013).

Pea, faba bean, chickpea and lupin are the four key cool-temperate grain legume species that are widely adapted throughout Europe. With the decline in area grown, Investment in their improvement (esp. breeding) has also declined in Europe. This situation contrasts with that in Australia and Canada, where grain legume areas increased more than 20-fold between 1970 and 2000 in response to demand for alternative crops in rotations, national feed requirements, and international food trade opportunities, leading to investment in crop breeding for stress resistance, yield and quality.

At present, pea is the most widely grown grain legume in Europe, but compared to the other grain legumes it suffers from poor standing ability and low competitive ability against weeds, relatively low protein content (~24%), and on many soils, low productivity. Faba bean and narrow-leafed lupin possess better root systems than pea and are capable of fixing large amount of N. The narrow-leafed or white lupin generally performs better in terms of protein yield on light, sandy and often acid soils. Faba bean performs better on heavy clay soils.

In relation to grain quality, lupin and faba bean trypsin inhibitors are less effective than those of soybean. Breeding has successfully addressed other quality factors, namely alkaloid content in narrow-leafed lupin and vicine-convicine content in faba bean. As a result, faba bean and lupins are potentially important sources of plant protein for alternative food and feed and can be used for producing snacks and drinks. Faba bean and lupin are also highly suitable for planning sustainable crop rotations in northern Europe. The risk of pea root rot (*Aphanomyces euteiches*) infection in these areas means that peas should not recur more often than once every six to eight years in the cropping sequence. It is therefore of great interest to combine cereals with other legumes which are not attacked by this pathogen and can therefore be more appropriate break crops.

---

[18] Dinu, T., Alecu, I.N., Stoian, E. (2010). Assessing the economic impact and the traceability costs in the case of banning the cultivation of GM soybean in Romania. In: Draghici, M., Berca, M. (Eds.). Prospects of Agriculture and Rural Areas Development in the context of Global Climate Change. Management, Marketing, Accounting, Financial Analysis, Finance. 10th International Symposium, 20-21 May 2010. Bucharest, Romania: RAWEX COMS Publishing House, DO-MINOR Publishing House, (Scientific Papers Management Economic Engineering in Agriculture and Rural Development 10(2):62–67)

23

Legume Futures Report 5.3:
Outlook for knowledge and technology for legume-supported cropping systems
www.legumehub.eu

Further improvements in grain yields, yield stability, protein content, amino acid composition, host plant resistance, stress response, and other agronomic and biochemical traits will improve the economic competitiveness of grain legumes. At high latitudes, the combination of long days and short growing season is challenging for production of existing cultivars, some of which are sensitive to low temperature during early spring, so their production is uncertain. At lower latitudes, in the Mediterranean climate, climate change is expected to make growing conditions even more difficult, with incidences of both drought and waterlogging becoming more severe. These challenges may be met through an integrated breeding programme, using the latest developments in phenotyping and genotyping, and benefitting from the potential to translate results from the more extensively analysed species, including chickpea and pea, to the other key species.

Pea

Field pea (*Pisum sativum* L.), which is also known as common pea, dry pea, green pea (green-seeded cultivars), yellow pea (yellow-seeded cultivars) and garden pea is a cool season legume, suited to temperate climates. It is the most widely grown grain legume in the EU more than half a million hectare. France and Spain account for nearly two-thirds of the area, but pea is grown also in all countries, albeit in very small quantities in countries such as Ireland and Finland.

Dry pea seeds are rich in energy (30–50% starch), which together with their protein content makes them suitable for pig and poultry nutrition. On a global scale, pea is a relatively minor crop with total production ranking about fifth among grain legumes and about 40th for arable crops as a whole. In southern Europe, pea is a common choice of grain legumes for cool season cultivation for both for animal feeding and human consumption. Pea cropping is particularly diverse in the Mediterranean region with production for human and animal production.

In recent decades, France has dominated European pea production and accounted more than half of the total European grain pea area during the late 1980s and early 1990s. Average yields were high at about 5 t/ha compared to 7 t/ha for wheat. This high performance could not be sustained due to increased incidence of root diseases.

In terms of area, the principal market for grain pea is animal feeding. A good overview of the role of grain pea in feeding is provided by INRA and CIRAD in Feedipedia. The Grain Legumes Integrated Project (GLIP) final report also provides insights. It should not be overlooked that pea is a starch rich crop with about 60% of the dry matter as starch. Pea is well suited to feeding of a wide range of livestock, including fish. It is comparable to soy in terms of the lysine content of the protein, but lower in some other essential amino acids.

Legume Futures Report 5.3:
Outlook for knowledge and technology for legume-supported cropping systems
www.legumehub.eu

Optimising the use of pea in animal feed is not straightforward. The starch is digested slowly and this has advantages for ruminants. However, the protein is more rumen degradable than other sources. Feed treatment such as grinding and heating can have marked effects and these treatments are animal-species specific, and may vary too due to the type of pea being processed. Pea is palatable for many types of livestock is suitable for fish feeding offering some advantages over soy.

Faba bean

Faba bean (*Vicia faba L*) Faba bean was domesticated in the Middle East. It is still a staple in the diets of many societies in the Middle East, Central and East Asia and North Africa. Over the past few years, the majority of faba beans produced for food worldwide have been exported to these areas. Total demand from these markets is estimated at about 100,000 t. China is the largest producer (60%) together with North African countries and Australia.

As a grain legume, it remains a preferred food in West Asia, North Africa and China, while it is more widely popular as a green vegetable and in many countries is grown as feed. Its large chromosomes are easily stained, so it became a standard material in cytology. In spite of its use in many countries, the global faba bean area decreased from 5 M ha in 1965 to 2.7 M ha in 2011 (FAOSTAT). Despite this decline, strong collaborative research and breeding programs during the last 40 years have made considerable progress in the reduction of anti-nutritional factors, improvement in biotic and abiotic stress resistance, and altered growth habit. Faba bean, among legumes, is a particularly important candidate to provide nitrogen input into temperate agricultural systems, due to its high productivity of dry matter. Genetic variation in biological nitrogen fixation has been found in existing breeding lines, providing an excellent resource for plant breeders.[19] Faba bean has a mixed breeding system, with partial cross-pollination in amounts determined by cultivar, environment and availability of suitable bees[20], whereas pea, chickpea, lentil and common bean are all inbreeding species.

Faba bean has some distinct agronomic advantages over pea due to its root characteristics in particular. It is well adapted to heavy-textured soils and is not susceptible to the root diseases that affect pea. It also has a higher protein content. Like pea, it has a wide geographic range and can be grown as a cool season crop in the Mediterranean as well as a main season crop in the north.

---

[19] Rispail N, Kaló P, Kiss GB, Ellis THN, Gallardo K, Thompson RD, Prats E, Larraizar E, Ladrera R, Gonzales EM, Arrese-Igor C, Ferguson BJ, Gresshoff PM, Rubiales D (2010) Model legumes contribute to faba bean breeding. Field Crops Res 115:253–269

[20] Stoddard FL, Bond DA (1987) The pollination requirements of the faba bean (*Vicia faba* L.). Bee World 68:144-152

25

Legume Futures Report 5.3:
Outlook for knowledge and technology for legume-supported cropping systems
www.legumehub.eu

Soya

Soya (*Glycine max L.)* is the bench-mark grain legume crop with a combination of high yield potential, high protein content combined with an advantageous amino acid profile. The methionine content is higher than other grain legumes and cereals. This is combined with about 21% oil in the dry matter. Soya is officially classified as an oil crop even through it is a legume grown primarily or protein. It is by far the world's largest grain legume crop with an area that exceeds all other pulse crops together. Compared with the traditional European pulses, soya has the advantage of a huge background in breeding technology.

Soya is widely considered as not well adapted to European conditions. This is a misunderstanding. It is a warm season crop, but yields well in many parts of Europe. There is considerable genetic variation with respect to day length responses with the result that early maturing varieties for high latitudes are available.

Due to the high oil content and the need for roasting, soya is not as well adapted to farm feeding as peas or faba beans. However, there is a market premium for GM-free soya and this, combined with premia for locally sourced foods, offers new opportunities such as those explored by Donau Soya.[21]

Common bean

The common bean (*Phaseolus vulgaris L.*) is very widely grown world- wide (53 million ha) but the area in the EU is small (84,000 ha). It was grown on three million ha in the 1960s in the EU 27. Most of the remaining production now is in eastern Europe. It is also grown as green beans for freezing and in gardens (known as 'French beans'). The species is highly variable and delivers a wide range of bean types for human consumption, including the haricot bean which is familiar to consumers as 'baked beans'. The various types of beans are an integral part of traditional cuisine in many countries.

Yields in Europe are lower than major grain legumes and the beans are not used for animal feed.

Lupin

Three species of lupin are relevant to agricultural production: narrow-leafed (*Lupinus angustifolius* L.), white (*L. albus* L.) and yellow (*L. luteus* L.). Lupins all originate from the Mediterranean basin. Owing to their high alkaloid content, lupin seeds had to be washed in running water for up to 2 days before consumption until low-alkaloid germplasm was developed in the 20th century. The domestication of these still half-wild crops was driven particularly in Western Australia from the 1950s. In some circumstances, white lupin may experience up to 10% outcrossing, but narrow-leafed and yellow lupins are strongly self-pollinating.

---

[21] http://www.donausoja.org/donau-soja

26

Legume Futures Report 5.3:
Outlook for knowledge and technology for legume-supported cropping systems
www.legumehub.eu

The white lupin is characterised by a high protein content (38-42%) and the species is potentially the highest protein yielding pulse crop where grown on suitable sites. The oil content is also high enough to justify extraction yielding a valuable co-product. Autumn sowing is a possibility and this provides opportunities for yield increases.

White lupin is well adapted to sandy soils but is intolerant of free lime and of soils with a pH in excess of 7. Inclusion of the meal is restricted to no more than 15% in feed for pigs and 10% for poultry.

In comparison, narrow-leafed lupin (blue) has a lower protein content (33-34%) than white lupin and the yellow lupin is less well adapted to most European situations.

Lentil
The lentil (*Lens culinaris Medik*) is a bushy plant grown for its lens-shaped seeds which are used for human consumption. It is one of the oldest cultivated crops originating from the Middle East. Like the common bean, there are many different types and it is a major component of traditional cuisines world-wide. The seed has a range of health-supporting properties that are particularly advantageous for human consumption.

The lentil area is about 4 million ha world-wide with only about 60,000 ha in Europe. Lentils are grown in France and across the Mediterranean. Lentil is too expensive to be included in animal feeds.

Chickpea
Among the grain legumes, chickpea (*Cicer arietinum L.*) seeds have one of the best nutritional compositions with the most digestible proteins and a high content of soluble fibre. Its seed oil contains however, a high proportion of unsaturated fatty acids (oleic and linoleic acids), which have been linked to heart and circulatory diseases.

Chickpea originates from the region that is now Turkey and Iran. The area in the EU is about 47,000 ha (out of a world total of 12 million ha) with 35,000 in Spain. The yield in Europe and worldwide is about 1 t/ha. It is a cool season legume in the Mediterranean, but tolerates high temperature when mature.

27

Legume Futures Report 5.3:
Outlook for knowledge and technology for legume-supported cropping systems
www.legumehub.eu

Forage legumes

The main forage legumes are white clover, red clover and alfalfa. In addition to alfalfa, there are other minor forage legumes grown with arable cropping systems. The best known of these other forage legumes are sainfoin (*Onobrychis viciifolia*), and serradella (*Ornithopus sativus*).

The area of permanent pasture (for grazing or conservation) has declined since the 1960s but still forms a high proportion of agricultural land and of forage production in several European countries. Grasslands can contain a high proportion of legumes, often around 30%, predominantly white clover, but the contributions of legumes to grassland are not well documented. Forage legumes are used in pasture in many extensive agricultural systems to replace the use of fertiliser nitrogen (e.g. in 15 M ha of Mediterranean grasslands with native legumes.[22] They are also used in some medium intensity systems to reduce the need for fertiliser nitrogen (e.g., organic grasslands covering 6.2% of permanent pastures in the EU[23], EUROSTAT 2013). The use of fertiliser reduces clover content of mixtures below 50%[24] and the combination of high fertiliser use and stocking rates practically eliminates the legume component (clover) and its impact.[25]

The use of legumes in pasture for ruminants presents special challenges and opportunities. Despite the low overall response of grass-clover pasture to synthetic nitrogen application, the use of high applications of synthetic fertiliser in pastures that contain or could contain clover is common, reducing the role of clover in ruminant production and the nitrogen nutrition of the whole system. In addition to nitrogen fixation and drought resistance, clover and other forage legumes offer opportunities to improve forage quality and end-product quality.

Although forage legumes may be grown in pure stands, they are more generally grown in mixtures with grasses, other legumes and forbs. Pure stands were very important in the past. In France, for example, 17% of arable land was cropped with pure forage legumes in

---

[22] Ledda, L., Porqueddu, C., Roggero, P.P. (2000). Role of forage legumes and constraints for forage legume seed production in Mediterranean Europe. In: Sulas, L. (Ed.). Legumes for Mediterranean forage crops, pastures and alternative uses. Cahiers Options Méditerranéennes; no. 45. Zaragoza: CIHEAM, pp. 453–460

[23] More than 20% in Czech Republic, Greece, Austria, and Sweden, and more than 10% in Denmark, Estonia, and Slovakia (data not available for Germany, Ireland, Finland, Portugal)

[24] Carlsson, G., Huss-Danell, K. (2003). Nitrogen fixation in perennial forage legumes in the field. Plant and Soil 253:353–372

[25] O'Mara, F. (2008). Country pasture/forage resource profile for Ireland. Rome, FAO, AGPC. http://www.fao.org/ag/AGP/AGPC/doc/Counprof/PDF%20files/Ireland.pdf (2013-02-26)

Legume Futures Report 5.3:
Outlook for knowledge and technology for legume-supported cropping systems
www.legumehub.eu

1960[26] (Fig. 15). Since then, forage legumes in the EU have been increasingly replaced by N-fertilised pure grass and silage maize.

Areas of pure forage legumes declined by more than 80% in France (1960-2000)[27], by 26-69% in Belgium (depending on the crop, 1990-2000)[28], and by 40% in the EU-12 (1980-2001.[29] The current forage legume area in the EU is not well documented in EUROSTAT and different sources provide widely different estimates[30]. Of the documented pure forage legume area, 34% is dedicated to dehydrated fodder production, mainly the production of irrigated alfalfa in Mediterranean countries (LMC International 2009). In intensive systems, fertilised grass and maize forage are more economic than forage legumes.[31] [32]

---

[26] Cavaillès, E. (2009). La relance des légumineuses dans le cadre d'un plan protéine: quels bénéfices environnementaux? Études et documents No. 15, Décembre 2009, Commissariat général au développement durable, France. http://www.developpement-durable.gouv.fr/IMG/pdf/E_D15.pdf (2013-02-26)

[27] Cavaillès, E. (2009). La relance des légumineuses dans le cadre d'un plan protéine: quels bénéfices environnementaux? Études et documents No. 15, Décembre 2009, Commissariat général au développement durable, France. http://www.developpement-durable.gouv.fr/IMG/pdf/E_D15.pdf (2013-02-26)

[28] Peeters, A. (2010). Country pasture/forage resource profile for Belgium. Rome, FAO, AGPC. http://www.fao.org/ag/AGP/AGPC/doc/Counprof/PDF%20files/Belgium.pdf (2013-02-26)

[29] Rochon, J.J., Doyle, C.J., Greef, J.M., Hopkins, A., Molle, G., Sitzia, M., Scholefield, D., Smith, C.J. (2004). Grazing legumes in Europe: a review of their status, management, benefits, research needs and future Prospects. Review article. Grass and Forage Science 59(3):197–214

[30] According to EUROSTAT (2013), forage legumes were grown on 2.12 M ha in 2010 (Fig. 5), whereas Rochon et al. (2004) cited 6 M ha in 2000, and Yuegao and Cash (2009) estimated that alfalfa alone covered 7.12 M ha in the EU. National statistics of Belgium, Germany and Spain match the figures given by EUROSTAT (2013), while those of Luxembourg and Latvia state much higher areas under forage legumes (BMELV 2012b for Germany, INE Spain, DGSEI Belgium, SER Luxembourg, Statistics Latvia)

[31] Peyraud, J.L., Le Gall, A., Lüscher, A. (2009). Potential food production from forage legume-based-systems in Europe: an overview. Irish Journal of Agricultural and Food Research 48:115–135

[32] Knox, O.G.G., Leake, A.R., Walker, R.L., Edwards, A.C., Watson, C.A. (2011). Revisiting the multiple benefits of historical crop rotations within contemporary UK agricultural systems. Journal of Sustainable Agriculture 35:163–179

29

Legume Futures Report 5.3:
Outlook for knowledge and technology for legume-supported cropping systems
www.legumehub.eu
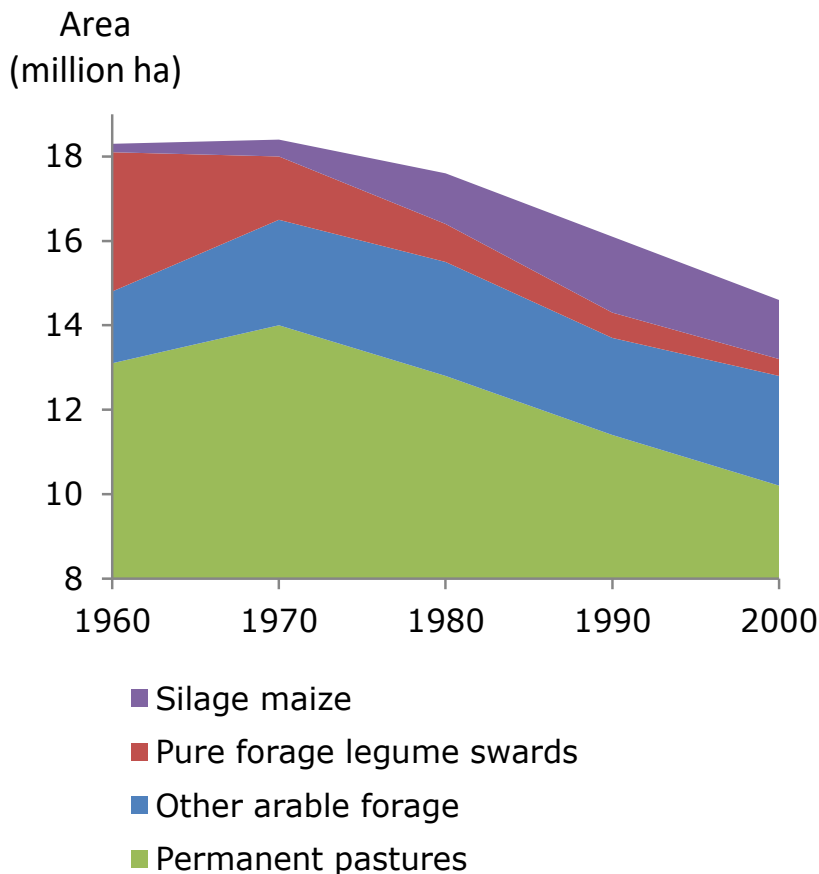
Area
(million ha)

Figure 11.   Forage production area in France (1960-2000). Source: Cavaillès (2009)

Nevertheless, the area under pure stands of legumes underestimates their importance, as they play an important and increasing role in mixed pastures. These figures are hidden in agricultural statistics as they are categorised within other groups. Grass-legume mixtures remained stable in area between 1980 and 2001 in the EU-12.[33] They made up 21% of arable forage areas in Belgium in 2000 (more than 11 times the area of pure legumes) and 35-40% in France in 2006.[34] [35]

There are two belts where forage legumes represent a high proportion of arable land, one from Bavaria through Austria, Slovakia and Hungary to Northern Romania, and the other in south-eastern France, Corsica and Sardinia.

---

[33] Rochon, J.J., Doyle, C.J., Greef, J.M., Hopkins, A., Molle, G., Sitzia, M., Scholefield, D., Smith, C.J. (2004). Grazing legumes in Europe: a review of their status, management, benefits, research needs and future Prospects. Review article. Grass and Forage Science 59(3):197–214

[34] Cavaillès, E. (2009). La relance des légumineuses dans le cadre d'un plan protéine: quels bénéfices environnementaux? Études et documents No. 15, Décembre 2009, Commissariat général au développement durable, France. http://www.developpement-durable.gouv.fr/IMG/pdf/E_D15.pdf (2013-02-26)

[35] Peeters, A. (2010). Country pasture/forage resource profile for Belgium. Rome, FAO, AGPC. http://www.fao.org/ag/AGP/AGPC/doc/Counprof/PDF%20files/Belgium.pdf (2013-02-26)

Legume Futures Report 5.3:
Outlook for knowledge and technology for legume-supported cropping systems
www.legumehub.eu

Reasons for the decline in forage legume production

As for grain legumes, forage legumes have declined as the use of nitrogen fertiliser and soya meal increased. These factors favoured fertilised forage crops (pure grasses, silage maize) and ruminant diets based on maize and grasses supplemented by soya. Forage legumes have never specifically benefitted from any specific EU-wide aid. Only the production of dehydrated fodder was subsidised. The inclusion of forage maize into area aid payments under the past CAP further increased the competition between forage crops.

These challenges come on top of agronomic drawbacks. Clover often presents problems of lack of persistence and annually variable production[36][37][38], although agronomic techniques have been developed for maintaining the clover content.[39] Red clover leys generally last 2-3 years, whereas white clover can last 15 or more. Excessive clover intake in grazed swards can lead to bloat, the production of foam in the rumen, and this can be managed with appropriate mixtures of forage species.[40] Grass-legume mixtures provide significant agronomic benefits in terms of yield, agronomic quality, low input costs, and feed quality as compared to pure grass and silage maize, but have the disadvantage of slow growth in spring.[41]

---

[36] O'Mara, F. (2008). Country pasture/forage resource profile for Ireland. Rome, FAO, AGPC. http://www.fao.org/ag/AGP/AGPC/doc/Counprof/PDF%20files/Ireland.pdf (2013-02-26)

[37] Cavaillès, E. (2009). La relance des légumineuses dans le cadre d'un plan protéine: quels bénéfices environnementaux? Études et documents No. 15, Décembre 2009, Commissariat général au développement durable, France. http://www.developpement-durable.gouv.fr/IMG/pdf/E_D15.pdf (2013-02-26)

[38] Peeters, A. (2010). Country pasture/forage resource profile for Belgium. Rome, FAO, AGPC. http://www.fao.org/ag/AGP/AGPC/doc/Counprof/PDF%20files/Belgium.pdf (2013-02-26)

[39] Humphreys, J., O'Connell, K., Casey, I.A. (2008). Nitrogen flows and balances in four grassland based systems of dairy production on a clay-loam soil in a moist maritime climate. Grass and Forage Science 63:467–480

[40] Peeters, A. (2010). Country pasture/forage resource profile for Belgium. Rome, FAO, AGPC. http://www.fao.org/ag/AGP/AGPC/doc/Counprof/PDF%20files/Belgium.pdf (2013-02-26)

[41] Peyraud, J.L., Le Gall, A., Lüscher, A. (2009). Potential food production from forage legume-based-systems in Europe: an overview. Irish Journal of Agricultural and Food Research 48:115–135

Legume Futures Report 5.3:
Outlook for knowledge and technology for legume-supported cropping systems
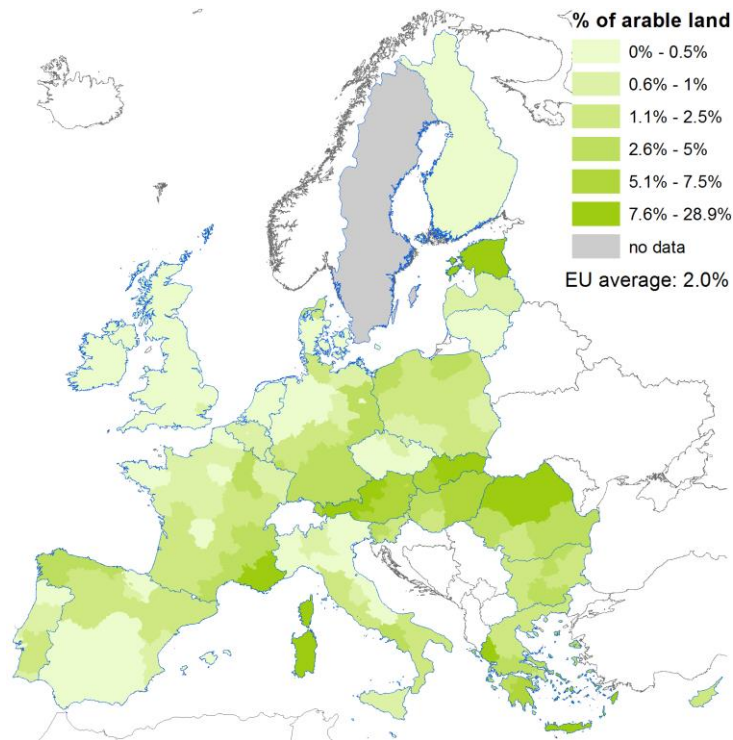www.legumehub.eu

Figure 12. Proportion of EU-27 arable land used for pure stands of forage legume crops in 2010 (%)

Source: Calculations based on data from: EUROSTAT (2013)

Drivers for a revival in forage legume production

Agricultural policies in the milk sector (limitations set by milk quotas, reduction in support prices in the 1980s) reduced the need for high productivity per unit area, and the Nitrate Directive limited stocking rates. These factors supported more extensive pasture management based on legumes rather than highly fertilised grasses.[42]

Positive economic effects of including forage legumes into pastures and leys have been found due to increased fertiliser prices, and their high value as animal feed. In addition, there are niches for forage legume production in the dehydrated fodder sector, organic agriculture and several traditional farming systems.

Dehydrated fodder production, including non-legumes as well as legumes, represents a niche.[43] A subsidy was paid in the past to dehydration plants and later partly included in the single payment scheme for producers[44] (33 €/t for each party, phased out 2012).[45]

---

[42] Rochon, J.J., Doyle, C.J., Greef, J.M., Hopkins, A., Molle, G., Sitzia, M., Scholefield, D., Smith, C.J. (2004). Grazing legumes in Europe: a review of their status, management, benefits, research needs and future Prospects. Review article. Grass and Forage Science 59(3):197–214

[43] Marrugat, F.O. (2001). The evolution of fodder dehydration in Spain: future prospects. In: Delgado, I., Lloveras, J. (Eds.). Quality in alfalfa and medics for animal production. Options Méditerranéennes. Série A: Séminaires Méditerranéens. Zaragoza: CIHEAM:13–18

[44] Based on a maximum guaranteed quantity of almost 5 M t for the EU-27

Legume Futures Report 5.3:
Outlook for knowledge and technology for legume-supported cropping systems
www.legumehub.eu

The EU produces around 4 M t of dehydrated fodder each year, and it is one of the largest hay exporters worldwide (LMC International 2009). Dehydrated fodder production is an especially important agricultural sector in southern European countries[46] and 92% of the Spanish dehydrated forage production area is occupied by alfalfa, mostly grown under intensive irrigation. The EU contributes 25% of the world's alfalfa production area, of which 1.3 M ha are in Italy, while Romania, France, Bulgaria, Spain and Hungary are other major producers. [47]

Traditional systems using forage legumes

Forage legumes are an important source of protein for livestock feed, so play a key role in integrating livestock and crop production, increasing the recycling of nutrients on farms and thereby reducing nutrient losses.[48] Traditional ley/arable rotations in cool temperate agriculture typically include 3–6 years of grass/clover leys to supply N fertility and livestock feed, and rotate them with other crops. [49] Within such systems, the length and management of the ley component has a critical effect on both the environmental impact and production. A well-managed ley can reduce N leaching losses and GHG emissions[50][51] and longer duration leys lead to better weed control in the following crop.[52] This type of rotation is still prevalent in organic farming, extensive production systems and regions where mixed farming is traditional. Mixed farming has a number of possible environmental advantages over specialised arable farming, including lower energy use for transport of home-produced feed and replacement of fertiliser by the effective use of manures.

[45] Guerrero, M. (2010). Spain's dehydrated fodder sector. Global agricultural Information Network, USDA foreign agricultural service. GAIN Report Number: SP1002

[46] The largest producers are France, Spain and Italy. The guaranteed national quantities have been repeatedly exceeded by Spain, Italy, Greece and the Czech Republic, demonstrating a high interest in this sector (PROLEA 2011)
http://gain.fas.usda.gov/Recent%20GAIN%20Publications/SPAIN%E2%80%99S%20DEHYDRATED%20FODDER%20SECTOR_Madrid_Spain_2-18-2010.pdf (2013-02-26)

[47] Yuegao, H., Cash, D. (2009). Chapter 1. Global Status and Development Trends of Alfalfa. In: Cash, D. (Ed.): Alfalfa Management Guide for Ningxia. Developing modern and sustainable alfalfa production systems in the Ningxia Hui Autonomous Region. Beijing, People's Republic of China: FAO, p. 1–14.
http://www.fao.org/ag/AGP/AGPC/doc/ningxia_guide/chapter1.pdf (2013-02-26)

[48] Granstedt, A. (2000). Increasing the efficiency of plant nutrient recycling within the agricultural system as a way of reducing the load to the environment - experience from Sweden and Finland. Agriculture, Ecosystems and Environment 80:169–185

[49] Tivy, J. (1990). Agricultural Ecology. Harlow: Longman Scientific and Technical, UK

[50] Ball, B.C., Watson, C.A., Crichton, I. (2007). Nitrous oxide emissions, cereal growth, N recovery and soil nitrogen status after ploughing organically managed grass/clover swards. Soil Use Manage 23:145–155

[51] Watson, C.A., Younie, D., Armstrong, G. (1999). Designing crop rotations for organic farming: Importance of the ley-arable balance. In: Olesen, J.E., Eltun, R., Gooding, M.J., Jensen, E.S., Kopke, U. (Eds.). Designing and Testing Crop Rotations for Organic Farming. DARCOF Report No 1, pp. 91–98

[52] Watson, C.A., Younie, D., Armstrong, G. (1999). Designing crop rotations for organic farming: Importance of the ley-arable balance. In: Olesen, J.E., Eltun, R., Gooding, M.J., Jensen, E.S., Kopke, U. (Eds.). Designing and Testing Crop Rotations for Organic Farming. DARCOF Report No 1, pp. 91–98

33

Legume Futures Report 5.3:
Outlook for knowledge and technology for legume-supported cropping systems
www.legumehub.eu

Legumes play a role in agroforestry, such as Spanish silvopastoral systems. These farming systems combine grazing areas with forestry (predominantly oak trees), and cover about 4 M ha. Intensive and continuous livestock grazing[53] creates and maintains a high representation of several legume species such as subterranean clover (*T. subterraneum*), and there are many self-sown legumes (e.g., 29 species in the Madrid region.[54] Forage legumes are often used in silvoarable systems where trees such as olive or carob are combined with mixed ley-arable rotations.[55]

Environmental and resource impacts
The environmental impacts of grain legumes on the farm scale (discussed in Section 2.1) apply to forage legumes. However, forage legume production systems differ greatly from those of grain legumes, so they provide additional and increased environmental benefits, which are described below.

Soil biodiversity improves under legume-supported grasslands, with increases in populations of earthworms[56] and of collembola, soil insects important in plant residue decomposition.[57]

The effect of soil carbon sequestration is more clearly shown for forage legumes than for grain legumes, primarily because forages are in the ground 365 days per year, often for more than one year, and tend to have a high root biomass. Similarly, rotations that include forage legumes can improve soil organic matter levels compared with non-legume monocultures. 35 years of an alfalfa/maize rotation provided about 20 t/ha more soil carbon than continuous maize.[58] Mixtures of grasses and legumes have been shown to sequester more carbon than the corresponding monocultures.[59]

---

[53] Olea, L., San Miguel-Ayanz, A. (2006). The Spanish dehesa. A traditional Mediterranean silvopastoral system linking production and nature conservation. Grassland Science in Europe 11:3–13

[54] González Bernáldez, F. (1991). Ecological consequences of the abandonment of traditional land use systems in central Spain. In: Baudry, J., Bunce R.G.H. (Eds.). Land abandonment and its role in conservation. Options Méditerranéennes: Série A. Séminaires Méditerranéens, no. 15. Zaragoza: CIHEAM, pp. 23–29

[55] Eichhorn, M.P., Paris, P., Herzog, F., Incoll, L.D., Liagre, F., Mantzanas, K., Mayus, M., Moreno, G., Papanastasis, V. P., Pilbeam, D.J., Pisanelli, A., Dupraz, C. (2006). Silvoarable Systems in Europe – Past, Present and Future Prospects. Agroforestry Systems 67:29–50

[56] Eisenhauer, N., Milcu, A., Sabais, A.C.W., Bessler, H., Weigelt, A., Engels, C., Scheu, S. (2009). Plant community impacts on the structure of earthworm communities depend on season and change with time. Soil Biology and Biochemistry 41:2430–2443

[57] Sabais, A.C.W., Scheu, S., Eisenhauer, N. (2011). Plant species richness drives the density and diversity of Collembola in temperate grassland. Acta Oecologica 37:195–202

[58] Gregorich, E.G., Drury, C. F., Baldock, J.A. (2001). Changes in soil carbon under long-term maize in monoculture and legume-based rotation. Canadian Journal of Soil Science 81(1): 1-31

[59] Fornara, D.A., Tilman, D. (2008). Plant functional composition influences rates of soil carbon and nitrogen accumulation. Journal of Ecology 96:314-322

Legume Futures Report 5.3:
Outlook for knowledge and technology for legume-supported cropping systems
www.legumehub.eu

Forage legumes take a larger proportion of their N from BNF than grain legumes[60], and fix more N in total due to their high biomass production and longer growth period. Average annual BNF for clover-grass mixtures (>60% clover) and pure stands of red clover in Germany were 221 and 306 kg N/ha, respectively.[61] In pure stands, forage legumes fix most nitrogen per hectare and derive a similar proportion of N in their shoot biomass from BNF as grain legumes (ca. 70%).[62] In mixtures, total N fixation per hectare is somewhat lower but N efficiency is increased (80-95% of the N in shoot biomass is derived from BNF.

Perennial legume-grass mixtures lead to much lower N leaching compared to annual crops and pure grass systems[63], because the grass component of the mixture takes up reactive nitrogen as soon as it is released, and there is low input of fertiliser or manure nitrogen. However, N losses may occur in ley/arable rotations after the ley is ploughed, and these can be avoided when the forage crop is allowed to grow through the fallow season as a cover crop.[64]

Conclusions

Forage legumes provide an important complement to protein crops when the aim is to reduce reliance on imported vegetable protein and synthetic fertilisers. Their production has declined in the last decades but is currently becoming more profitable as a consequence of increased fertiliser prices and limitations on stocking rates under the Nitrates Directive. Forages fit readily into mixed farming systems with ruminants either on the same farm or nearby, but long-distance transport of either silage or hay is seldom economically viable.

Some environmental benefits, such as soil carbon storage and biodiversity effects, are clearer for forage legumes than for grain legumes. Legume-grass mixtures are particularly beneficial in terms of biodiversity, carbon storage, and resource impacts. The resource impacts are related to BNF, eliminating the need for N fertilisation of the forage and

---

[60] Carlsson, G., Huss-Danell, K. (2003). Nitrogen fixation in perennial forage legumes in the field. Plant and Soil 253:353–372

[61] KTBL [Kuratorium für Technik und Bauwesen in der Landwirtschaft] (2009). Faustzahlen für die Landwirtschaft. 14. Auflage. Darmstadt: KTBL

[62] Stein-Bachinger, K., Bachinger, J., Schmitt, L. (Eds.) (2004). Nährstoffmanagement im Ökologischen Landbau - Ein Handbuch für Beratung und Praxis mit Anwendungs-CD. KTBL-Schrift 423. Darmstadt: KTBL.

[63] Crews, T.E., Peoples, M.B. (2004). Legume versus fertilizer sources of nitrogen: ecological tradeoffs and human needs. Agriculture, Ecosystems and Environment 102:279–297

[64] Crews, T.E., Peoples, M.B. (2004). Legume versus fertilizer sources of nitrogen: ecological tradeoffs and human needs. Agriculture, Ecosystems and Environment 102:279–297

Legume Futures Report 5.3:
Outlook for knowledge and technology for legume-supported cropping systems
www.legumehub.eu

reducing the need for fertilisation of the following crop. From an environmental perspective, it is unfortunate that forage legumes have never been considered in the CAP beyond some regional agri-environment schemes, but the CAP reform provides a opportunity to integrate measures relevant to forage legumes into measures used for protein crops.

36

Legume Futures Report 5.3:
Outlook for knowledge and technology for legume-supported cropping systems
www.legumehub.eu

OUTLOOK FOR INVESTMENT IN RESEARCH AND DEVELOPMENT

Chapter 1 here and associated reports (particularly the Agronomic Case Studies, Legume Futures Report 1.2) show that the current low contribution of legumes to European agriculture is due to a number of inter-connected factors. These vary between forage and grain legume crops. They also vary from region to region.

Economic competitiveness
A major underlying factor is the competition from carbohyrate-rich or oil crops for scarce agricultural resources (especially land). In almost all production regions studied in Legume Futures, the yield of grain legumes has increased slower han the yield of the dominant cereal species. In addition, linked to lucrative markets for vegetable oils, oilseeds (oilseed rape and sunflower) have become the dominant non-cereal crops in many areas.

Diversity.
The diversity of species and cropping systems that using legumes involves is a distinguishing feature, particularly in Europe. Fig. 10 shows that in contrast to major legume-growing regions of the world, Europe is characterised by diversity in cropping options. This reduces the incentive to invest in the improvement of any single option, reinforcing market failure in relation to investment in plant breeding in particular.

Under-appreciated farm-level benefits
Our interaction with local farming stakeholders has consistently shown that the economic benefits for the whole farming system are under-estimated in crop planning. The applies to the long-term benefits for the management of diseaes, pests and weeds, the reduction in crops in follow-on crops, and the increased yield potential of those crops.

Capturing public benefits
The DAFA Expert Forum[65] emphasised the need for the valuation of ecosystem services to support farm business decision-making, including for the economic assessment of public benefits.

---

[65] DAFA (2012). Science, economy and society – making ecosystem services from legumes competitive. A research strategy of the German Agricultural Research Alliance (DAFA). Wissenschaft, Wirtschaft, Gesellschaft – Ökosystemleistungen von Leguminosen wettbewerbsfähig machen. Forschungsstrategie der Deutsche Agrarforschungsallianz (DAFA) c/o Thünen-Institut Bundesallee 50 38116 Braunschweig www.dafa.de

37

Legume Futures Report 5.3:
Outlook for knowledge and technology for legume-supported cropping systems
www.legumehub.eu

The challenge of combining these effects is presented in Fig. 13.
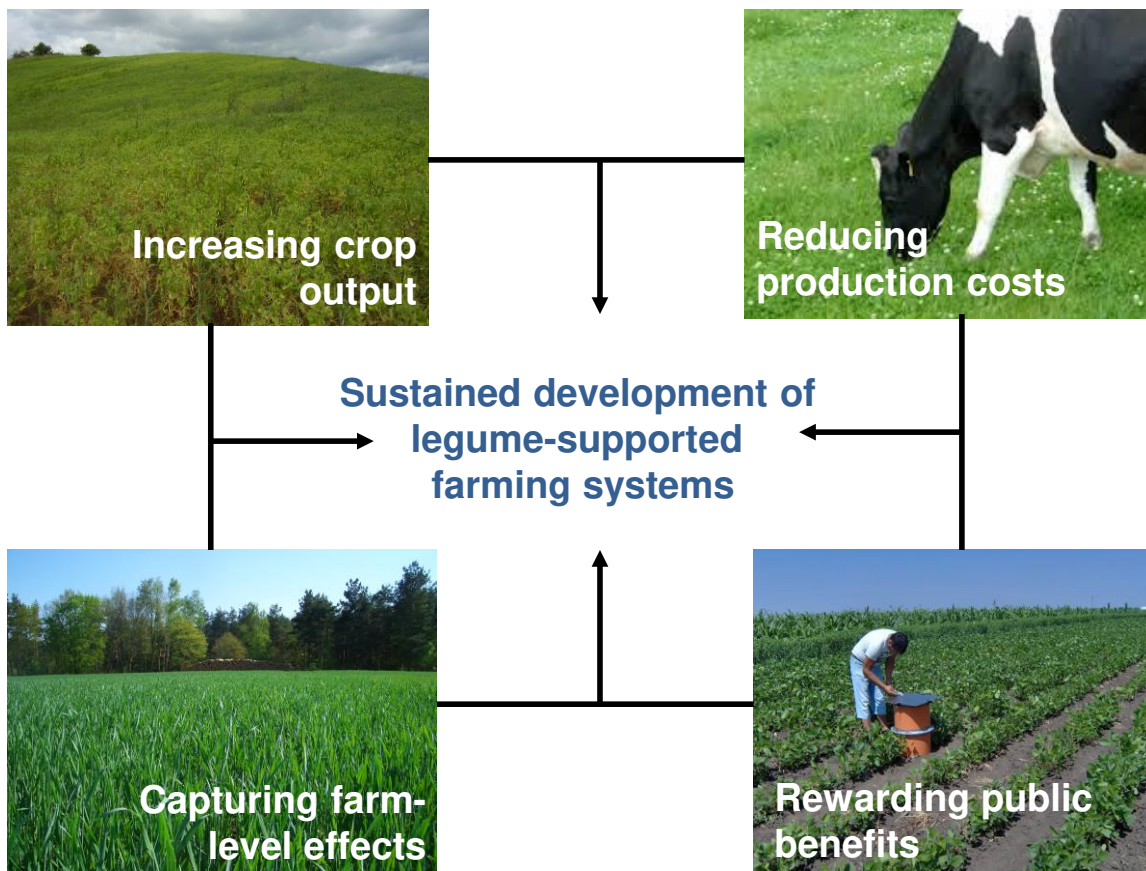
Figure 13.   Interactions between four key framework conditions for sustaining the development of legume-supported cropping systems.

Increasing crop output

There are two basic approaches to increasing crop output: better cultivars and better crop management

Delivering better cultivars: research for breeding
Crop breeding is a key technology for the sustained development of crops. The growth in the yield of Europe's major crops since 1960 is in large part due to plant breeding progress and the interaction between better cultivars and management techniques. This is particularly marked in cereals.

Legume breeding in Europe is currently conducted by a small number of organizations with relatively few personnel and restricted budgets. Apart from the low level of commercial activity, investment in research supporting crop breeding in general is

38

Legume Futures Report 5.3:
Outlook for knowledge and technology for legume-supported cropping systems
www.legumehub.eu

subject to market failure[66], and this applies at least as much to legumes as other species. We have identified 12 apparently active grain legume breeding companies in the EU27. Seven of these work on pea, 9 on faba bean, 3 on narrow-leafed lupin, 2 each on yellow and white lupin, and only 1 on chickpea. There are also a small number of forage breeding programmes, some such as the white clover programme in Ireland in the public sector.

This estimate of breeding activity may omit small companies and those that temporarily do not have a current cultivar, and may include others that have stopped breeding but still have cultivars for sale. However, the overall picture is clear – the legume breeding sector is fragmented and based on small enterprises. In some companies, the grain legume effort may be as little as half of a person's time. This contrasts with the multi-person teams that drive the large grain-legume programmes in Canada and Australia. Public-sector involvement and multi-national coordination, provided in this project, are required to get European legume breeding around this resource bottleneck.

A strategic modern approach to breeding combines a search for genetic variation with its confirmation using phenotyping and the identification of its genetic basis with precision genomic techniques. A set of key objectives for genetic improvement is required and here the development of ideotype concepts helps. Among the abiotic stresses, drought (generally transient drought) is the top priority. For adaptation, early maturity is important at high latitudes. Winter-hardiness opens up opportunities for step-changes in yield analogous to the step-change that the development of winter cereals brought to cropping in many parts of Europe. For quality, low vicine-convicine for faba bean, low trypsin inhibitor for feed pea, maintaining low alkaloid and high oil content for lupins are targets. Root traits are underexplored in most agricultural crops, even though rooting depth and architecture are vitally important for uptake of nutrients and water, and critical for drought avoidance. Precision phenotyping is anticipated to provide greater resolution of the components of competitiveness, such as ground cover and rate of establishment, which will become examples of new targets for direct selection.

Newly identified germplasm with newly important attributes generally needs to be crossed with otherwise well adapted or high-yielding material. Selection for many traits is considered most effective in late generations such as F_6 or beyond, when the plants are 97% homozygous, but this represents a delay of six growing seasons, so accelerated breeding is used. Doubled haploid (DH) technologies, whereby homozygosity is established in a single step, replacing 6 years of inbreeding with one year of labour, are

---

[66] Moran D, Barnes A, McVittie A (2007) The rationale for Defra investment in R&D underpinning the genetic improvement of crops and animals. Defra report for project IF0101. SAC Commercial Ltd, Scotland, United Kingdom
http://randd.defra.gov.uk/Default.aspx?Menu=Menu&Module=More&Location=None&Completed=0&ProjectID=14403

Legume Futures Report 5.3:
Outlook for knowledge and technology for legume-supported cropping systems
www.legumehub.eu

routine in many cereal and oilseed breeding programmes, and need to be developed in grain legumes.

Unlike the case in some other major crop groups, DHs are not routinely used in breeding grain legumes. Significant progress in DH, particularly through androgenesis (anther and microspore culture), requires an intensive research effort.[67] The first difficulty is altering the developmental pathway of the pollen grain toward a proembryo, the second is maintaining the tissue cultures, and the third is regenerating plants from the embryoids. The small anther size and the low number of microspores per anther in grain legumes are among the additional obstacles, while *in vitro* manipulation of morphogenesis, rooting and the genotype-specific nature of the *in vitro* response are other challenges. In the last decade, there have been advances in developing DH protocols in pea[68], chickpea[69] and narrow-leafed, white and yellow lupins[70 71] Response frequencies remain very low in all species, and in chickpea the 4-way combination of cold shock, centrifugation, electroporation and osmotic shock was required for reasonable numbers of embryos to be obtained (Grewal et al. 2009). Maintenance of any faba bean tissue in culture is difficult, sometimes attributed to the tannins but may be associated with other secondary compounds such as vicine, convicine and their aglycones, which are powerful oxidants. Plant regeneration has yet to be achieved from anther-derived callus in lupins.[72]

Applying genomic tools in breeding legumes
The use of genomic tools to improve the efficiency of breeding programmes by developing markers as selection aids (i.e., marker-assisted selection or MAS) offers the prospect of accelerating the release of cultivars better adapted to production conditions. During the last decade, significant progress has been made in developing genomic resources in model species (*Medicago truncatula* or barrel medic and *Lotus japonicus*), major legumes (soybean and common bean, peanut, and pea), and a number of so-called orphan crops (chickpea, cowpea and pigeonpea).[73] As a result, reference genome sequences are now

[67] Croser JS, Lulsdorf MM, Davies PA, Clarke HJ, Bayliss KL, Mallikarjuna N, Siddique KHM (2006) Toward doubled haploid production in the Fabaceae: progress, constraints, and opportunities. Critical Rev Plant Sci 25:139–157

[68] Ochatt S, Pech C, Grewal R, Conreux C, Lulsdorf M, Jacas L (2009) Abiotic stress enhances androgenesis from isolated microspores of some legume species (Fabaceae). J Plant Physiol 166:1314–1328

[69] Grewal RK, Luisdorf M, Croser J, Ochatt S, Vandenberg A, Warkentin TD (2009) Doubled-haploid production in chickpea (*Cicer arietinum* L.): role of stress treatments. Plant Cell Rep 28:1289–1299

[70] Bayliss KL, Wroth JM, Cowling WA (2004) Pro-embryos of *Lupinus* spp. produced from isolated microspore culture. Aust J Agric Res 55: 589–593

[71] Skrzypek E, Czyczyło-Mysza I, Marcińska I, Wędzony M (2008) Prospects of androgenetic induction in *Lupinus* spp. Plant Cell Tiss Organ Cult 94:131–137

[72] Lulsdorf MM, Croser JS, Ochatt S (2011) Androgenesis and doubled-haploid production in food legumes. Chapter 11 in: Pratap A, Kumar J (eds) Biology and Breeding of Food Legumes, CAB International, Wallingford, UK

[73] Varshney RK, Thundi M, May GD, Jackson SA (2010) *Legume genomics and breeding.* Plant Breeding Rev 33:257-304

Legume Futures Report 5.3:
Outlook for knowledge and technology for legume-supported cropping systems
www.legumehub.eu

available for barrel medic, *Lotus*, soybean, chickpea and pigeonpea. In contrast, there is a lack of comparable genomic data and resources ready to be used in breeding for the main traits affecting yield of the cool-season grain legumes.

Research is required to progress from basic mapping of quantitative trait loci (QTL) to fine mapping or gene identification, thus allowing development of markers for MAS in breeding linked to genes underlying agronomic traits. Chickpea could especially benefit from the recently obtained whole genome sequence[74], allowing wide genome comparative mapping studies with less-studied legume crops such as faba bean and lupins. Additional tools such as the faba bean [75] http://www.viciatoolbox.org/) and chickpea (University of Saskatchewan, Canada) single nucleotide polymorphism (SNP) platforms, the *M. truncatula* genome information (http://www.plantgdb.org/MtGDB/) together with comparative genomics will further identify microsyntenic regions among *crops* and legume model species and unravel candidate genes for the traits explored.

Genetic resources and germplasm exploitation

Natural agro-biodiversity stored in germplasm banks or genebanks can be used to enhance the diversity of crops. These collections are considered the best source for pre-breeding programmes, because they store a wide diversity of genotypes and safeguard them over time. Around 7.4 million accessions are conserved ex-situ globally in genebanks, of which 15% are food legumes.[76] There are 229,944 soybean accessions and 14 % are kept in the Institute of Crop Germplasm Resources, Chinese Academy of Agricultural Sciences (ICGR-CAAS). Searching for specific and often rare traits is like searching for the proverbial needle in a haystack, and phenotyping or evaluating a large number of accessions can be extremely costly. Table 1 shows the collections of germplasm accessions of some of the legume species that are important in Europe.

Table 1. Collections of germplasm accessions of some legume species essential for Europe. Collections are listed by institutes in downward order of the collection size. The percentage of accessions is the percentage of the total of the genus (except for faba bean which is remote from the rest of its genus).

Species	Genus	Total	Rank		
			1	**2**	**3**
Grain					
Soybean	*Glycine*	229,944	ICGR-CAAS (14 %)	SOY (9 %)	RDAGB-GRD (8

---

[74] Varshney RK et al. (2013) Draft genome sequence of *kabuli* chickpea (*Cicer arietinum*): genetic structure and breeding constraints for crop improvement. Nature Biotech 31:240-246

[75] Cottage, A., Gostkiewicz, K., Thomas, J. E., Borrows, R., Torres, A.-M. and O'Sullivan, D. M. (2012) Heterozygosity and diversity analysis using mapped single nucelotide polymorphisms in a faba bean inbreeding programme. Molecular Breeding 30:1799-1809

[76] FAO (2010) The second report on the state of the world's plant genetic resources for food and agriculture. Rome, Italy, 398 p

41

Legume Futures Report 5.3:
Outlook for knowledge and technology for legume-supported cropping systems
www.legumehub.eu

					%)
Chickpea	*Cicer*	98,313	ICRISAT (20 %)	NBPGR (15 %)	ICARDA (13 %)
Pea	*Pisum*	94,001	ATFCC (8 %)	VIR (7 %)	ICARDA (7 %)
Lentil	*Lens*	58,405	ICARDA (19 %)	NBPGR (17 %)	ATFCC (9 %)
Faba bean	*Vicia*	43,695	ICARDA (21 %)	ICGR-CAAS (10 %)	ATFCC (6 %)
Lupins	*Lupinus*	38,050	WADA (10 %)	IPK (6 %)	VIR (6 %)
Grass pea	*Lathyrus*	26,066	LEM/IBEAS (14 %)	ICARDA (12 %)	NBPGR (11 %)
Forage					
Medics	*Medicago*	91,922	AMGRC (30 %)	UzRICBSP (11 %)	ICARDA (10 %)
Clovers	*Trifolium*	74,158	WADA (15 %)	AGRESEARCH (9 %)	ICARDA (6 %)
Vetches	*Vicia*	38,460	ICARDA (16 %)	VIR (15 %)	IPK (8 %)

Source (FAO 2010)

ICGR-CAAS Institute of Crop Germplasm Resources, Chinese Academy of Agricultural Sciences (China)
SOY Soybean Germplasm Collection, United States Department of Agriculture, Agricultural Research Services (USA)
RDAGB-GRD Genetic Resources Division, National Institute of Agricultural Biotechnology, Rural Development Administration (Republic of Korea)
ICRISAT International Crops Research Institute for the Semi-Arid Tropics (India)
NBPGR National Bureau of Plant Genetic Resources (India)
ICARDA International Centre for Agricultural Research in the Dry Areas (Syria)
ATFCC Australian Temperate Field Crops Collection (Australia)
VIR N.I. Vavilov All-Russian Scientific Research Institute of Plant Industry (Russia)
WADA Western Australian Department of Agriculture (Australia)
IPK Genebank, Leibniz Institute of Plant Genetics and Crop Plant Research (Germany)
LEM/IBEAS IBEAS, Laboratoire d'Ecologie Moléculaire, Université de Pau (France)
AMGRC Australian Medicago Genetic Resource Centre, South Australian Research and Development Institute (Australia)
UzRICBSP Uzbek Research Institute of Cotton Breeding and Seed Production (Uzbekistan)
AGRESEARCH Margot Forde Forage Germplasm Centre, Agriculture Research Institute Ltd (New Zealand)

Complementing these basic collections, core collections are used to manage a relatively small number of accessions (200 to 2,000) that represent most of the genetic variation in the species and that can be screened to get a measure of the diversity for a given trait. There are several examples of methodologies to develop core collections[77], which tend towards limiting the size of the core collection to around 10% of the original collection size. In addition, there are alternative types of collections, or subsets of collections, designed to enhance the efficiency of capturing diversity or addressing utilisation in legumes, including the mini core subsets in chickpea[78] and composite collections in lentil.[79] [80] Core

---

[77] Hodgkin T, Brown ADH, van Hintum Th JL, Morales EAV (1995) Core collections of plant genetic resources, John Wiley & Sons, Chichester UK, 265 p
[78] Upadhyaya HD, Ortiz R (2001) A mini core subset for capturing diversity and promoting utilization of chickpea genetic resources. Theor Appl Genet 102:1292–1298
[79] Furman BJ (2006) Methodology to establish a composite collection: case study in lentil. Plant Genet Resour 4:2–12
[80] Bacchi M, Leone M, Mercati F, Preiti G, Sunseri F, Monti M (2010) Agronomic evaluation and genetic characterization of different accessions in lentil (*Lens culinaris* Medik.). Italian J Agron 4:303–314

Legume Futures Report 5.3:
Outlook for knowledge and technology for legume-supported cropping systems
www.legumehub.eu

collections of common bean from southern Europe have been evaluated in Spain[81] [82] and Italy[83] [84] and one has been constructed for white lupin[85]

The Focused Identification of Germplasm Strategy (FIGS) is a novel approach to germplasm selection that allows the whole germplasm collection to be searched for potential outliers. FIGS has the potential to identify greater extremes and more unusual genotypes than those in a core collection. The core collection approach asks "what is the range of variation" in the species whereas the FIGS approach asks "where can we find the most extreme expression of this trait". FIGS uses available environmental information associated with the collection sites of accessions to identify sets of accessions that are either most likely or least likely to express the trait of interest. In a test case, eco-geographic data from the collection sites of 402 faba bean accessions (201 from wet and 201 from dry region of the world) was correlated with morpho-physiological and phenological traits related to drought adaptation using machine-learning algorithms.[86] FIGS has been used to identify novel sources of drought resistance such as root characteristics and early flowering in faba bean. This strategy clearly has the potential to identify putative parent lines carrying useful alleles for important traits and will be applied more widely.

Inducing genetic variation
Genetic diversity is a prerequisite for the success of a legume breeding programme, and new diversity needs to be continuously included into breeding material. In commercial breeding, reliance on advanced populations and local elite stocks may erode diversity, with a long-term reduction in the efficiency of the breeding effort. This is a problem in small breeding programmes, where limited resources and time may not allow the introduction of novel diversity.

Where adequate genetic variation in a trait is not found in available germplasm, chemical- or radiation-induced mutagenesis has been applied in several crops, accelerating the natural process of random mutation by several orders of magnitude. The radiation-

---

[81] Rodiño AP, Santalla M, De Ron AM, Singh SP (2003) A core collection of common bean from the Iberian peninsula. Euphytica 131:165–175

[82] Rivera A, Fenero D, Almirall A, Ferreira JJ, Simó J, Plans M, Romero del Castillo R, Casañas F (2013). Variability in sensory attributes in common bean (*Phaseolus vulgaris* L.): a first survey in the Iberian secondary diversity center. Genet Resour Crop Evol 60:1885-1898

[83] Angioi SA, Rau D, Rodriguez M, Logozzo G, Desiderio F, Papa R, Attene, G (2009) Nuclear and chloroplast microsatellite diversity in *Phaseolus vulgaris* L. from Sardinia (Italy). Mol Breed 23:413–429

[84] Mercati F, Leone M, Lupini A, Sorgonà A, Bacchi M, Abenavoli, MR, Sunseri F (2013) Genetic diversity and population structure of a common bean (*Phaseolus vulgaris* L.) collection from Calabria (Italy). Genet Resource Crop Evol 60:839–852

[85] Annicchiarico P, Harzic N, Huyghe C, Carroni AM. 2011. Ecological classification of white lupin landrace genetic resources. Euphytica 180:17-25

[86] Khazaei H, Street K, Bari A, Mackay M, Stoddard FL (2013a) The FIGS (Focused Identification of Germplasm Strategy) approach identifies traits related to drought adaptation in *Vicia faba* genetic resources. PLoS ONE doi:10.1371/journal.pone.0063107

Legume Futures Report 5.3:
Outlook for knowledge and technology for legume-supported cropping systems
www.legumehub.eu

induced terminal-inflorescence mutation in faba bean[87] is used in Spanish broad bean cultivars to enhance uniformity of harvest.[88] The corresponding natural trait in lupins, reduced branching, has been used in narrow-leafed lupin cultivars Sonet (Polish) and Haags Blaue (German) and the white lupin cultivar Deter 1 (Russian). Extremely early onset of flowering ('neoteny') has been identified in faba bean[89], and while it leads to the setting of pods that are too close to the ground to be harvested, it shows the possibility of making substantial progress towards earlier flowering. Ion beams have been tested as a mutagen for faba bean at the University of Helsinki.

Diversity is also generated by genetic recombination through crosses between lines that are from different geographical origins and genetically distant. Although cultivar pedigrees often show more than two parents, genetic populations have generally been built on bi-parental crosses that allow precise detection of the effects of pairs of alleles and localisation of genes on chromosome arms. "Multiparent advanced generation inter-cross" (MAGIC) populations have become viable [90] since the necessary high-throughput genotyping systems are available to extract genetic data from the complex background. In this way, 4 or more alleles of each gene can be assessed and novel intergenic interactions detected, which is of advantage when analyzing and manipulating multigenic traits such as yield. The provision of multiple opportunities for recombination disrupts linkage disequilibrium and enhances the opportunity for detecting fine effects.[91] Development of such populations takes 2-3 generations of crossing followed by 6 or more generations of inbreeding and the ideal population size for is around 1000 lines[92], thus it is not surprising that there are as yet no publications on MAGIC populations of legumes.

---

[87] Sjodin J (1971) Induced morphological variation in *Vicia faba* L. Hereditas 67:155–180

[88] Avila CM, Atienza SG, Moreno MT, Torres AM (2007) Development of a new diagnostic marker for growth habit selection in faba bean (*Vicia faba* L.) breeding. Theor Appl Genet 115:1075–1082

[89] Chapman GP (1981) Determinate growth in *Vicia faba*: an opportunity for accelerated genetic turnover. Vicia faba: physiology and breeding. In: Proc Seminar in the EEC Programme of Coordination of Research on the Improvement of the Production of Plant Proteins. Wageningen Univ, Netherlands, pp 236–243

[90] Kover PX, Valdar W, Trakalo J, Scarcelli N, Ehrenreich IM, Purugganan MD, Durrant C, Mott R (2009) A multiparent advanced generation inter-cross to fine-map quantitative traits in *Arabidopsis thaliana*. PLoS Genetics 5: e1000551

[91] Huang BE, George AW, Forrest KL, Kilian A, Hayden MJ, Morrell MK, Cavanagh CR (2012) A multiparent advanced generation inter-cross for genetic analysis in wheat. Plant Biotech J 10:826–839

[92] Rakshit S, Rakshit A, Patil JV (2012) Multiparent intercross populations in analysis of quantitative traits. J Genet 91:111-117

44

Legume Futures Report 5.3:
Outlook for knowledge and technology for legume-supported cropping systems
www.legumehub.eu

'Omics' - based breeding tools

Genomic research is generating new tools and knowledge that increase the efficiency and precision of crop genetic improvement [93]. One important contribution is genetic fingerprinting to assess the level of genetic diversity, avoid overlapping within germplasm and maximize diversity. Biotechnology also provides tools to assist the conventional plant breeding. Genomic selection in backcrossing allows recovery of the adapted background much more quickly than is otherwise possible, while retaining the desired allele of the targeted gene. Genome sequencing projects also contribute to our understanding of legume genetic systems of biological importance, especially with respect to legume-specific phenomena, and will continue augmenting the availability of DNA markers that can be further used in high-throughput genotyping to facilitate genomics-assisted breeding of grain legumes.[94] [95]

Next-generation sequencing (NGS) offers a means for large-scale development of DNA markers for use in linkage mapping, association genetics and alien introgression using marker-aided backcrossing. NGS offers opportunities to efficiently turn semi-domesticated legumes into fully domesticated crops. For example, the application of NGS allowed rapid marker development for host plant resistance to anthracnose in narrow-leafed lupin.[96] In the project LEGRESIST (http://www.genxpro.info/science_and_technologies/Legresist/), transcriptomic analysis using SuperSAGE combined with 454 sequencing allowed analysis of the interacting transcriptomes of faba bean[97], chickpea, lentil and *Lathyrus* with their corresponding *Ascochyta* pathogens and provided a set of cDNA libraries from different crops. The combined approach allows targeting of mRNAs encoding regulatory components in different species and will provide new insights and markers for further use in legume breeding.

Model plants facilitate the study of complex biological processes. In the case of legumes, the complete genomes of *Medicago truncatula, Lotus japonicus* and soya bean provide key information about development, responses to biotic and abiotic stresses and evolutionary biology. A goal of legume genomics is to transfer knowledge between model and crop legumes, and although the work is challenging, comparative genomics has

[93] Pérez de la Vega M, Torres A-M, Cubero JI, Kole C (2011) Genetics, genomics and breeding of cool season grain legumes. CRC Press, Enfield, MA, USA
[94] Varshney RK, Close TJ, Singh NK, Hoisington DA, Cook DR (2009a) Orphan legume crops enter the genomics era! Curr Op Plant Biol 12:1–9
[95] Varshney RK, Thundi M, May GD, Jackson SA (2010) *Legume genomics and breeding.* Plant Breeding Rev 33:257-304
[96] Yang H, Tao Y, Zheng Z, Li C, Sweetingham MW, Howieson JG (2012) Application of next-generation sequencing for rapid marker development in molecular plant breeding: a case study on anthracnose disease resistance in *Lupinus angustifolius* L. BMC Genomics 13:318
[97] Madrid E, Palomino C, Jüngling R, Frank A, Horres R, Rotter B, Winter P, Kahl G, Torres AM (2013) DeepSuperSage analysis of the *Vicia faba* transcriptome in response to *Ascochyta fabae* infection. Phytopathologia Mediterranea 52: 166

45

Legume Futures Report 5.3:
Outlook for knowledge and technology for legume-supported cropping systems
www.legumehub.eu

shown that information from model species can be translated to closely related crops. The availability of expressed sequence tags (ESTs) from model or closely related species constitutes a novel source of markers physically associated with coding regions that are extensively exploited for gene discovery and translational genomics among crops. Numerous genetic maps of the most relevant European legume crops have been constructed, using RIL populations (Recombinant Inbred Lines, usually F6 or later progeny of a cross). These maps have been joined to create consensus maps in pea, chickpea and faba bean, thus increasing marker density. Relatively neglected crops such as faba bean or lupins that do not have any extensive marker repertoire now have achieved notable advances thanks to the synteny with related species. As a result, the availability of DNA markers is no longer a bottleneck, but there is still a need to construct dense genetic maps facilitating QTL fine mapping and gene discovery. Subsequently, development of transferable and cost effective markers targeting agronomic traits of interest in different legume crops will be ready to be used in more efficient breeding programmes.

Pea was Mendel's model species for elucidating the laws of inheritance and became the pioneering species in genetic research. The advent of new generation easy-to-use PCR markers facilitated a significant increase of linkage mapping capacity in pea. After the first, anonymous genetic maps using RAPD and/or AFLP, highly polymorphic microsatellite or simple sequence repeat (SSR) were developed and applied in different mapping projects. Today's advances in pea genomics are used to solve genetics and breeding questions in other grain legumes with less research investment. Several EU initiatives, in particular the *Grain Legumes Integrated Project (GLIP),* provided new tools for the development of genomic analysis in pea and related species, including a high-throughput method of characterisation using microarrays, a set of ESTs to provide candidates for gene identification and comparative mapping, a pea bacterial artificial chromosome (BAC) library to explore microsynteny between species, and a TILLING platform to develop a high-throughput forward and reverse genetics tool. As a result, a reference pea map including SSR markers was constructed allowing the exchange of information between different population.[98] Likewise, the number of ESTs and EST-SSRs has increased, and several pea functional maps have been developed using a range of methods to reveal size or single nucleotide polymorphism (SNP) in the mapped genes. Disease resistance genes reported in pea include *er1*, *er2, Er3* and *Fwf.*[99] Additional genes controlling seed

---

[98] Loridon K, McPhee K, Morin J, Dubreuil P, Pilet-Nayel ML, Aubert G, Rameau C, Baranger A, Coyne C, Lejeune-Hènaut I, Burstin J (2005) Microsatellite marker polymorphism and mapping in pea (*Pisum sativum* L.). Theor Appl Genet 111:1022–1031

[99] Rubiales D, Ambrose MJ, Domoney C, Burstin J (2011). Pea. In: Pérez de la Vega M, Torres AM, Cubero JI, Kole C (eds) Genetics, genomics and breeding in crop plants: cool season food legumes. Science Pubs Inc, New Hampshire, Jersey, Plymouth, pp 1–49

46

Legume Futures Report 5.3:
Outlook for knowledge and technology for legume-supported cropping systems
www.legumehub.eu

composition such as *Tri* [100], or flowering time and plant architecture[101] [102], have also been identified and mapped.

QTL mapping has been also performed in pea for a wide range of agronomic traits. Thus, Pilet-Nayel et al.[103] [104] reported 3 QTLs (*Aph1*, *Aph2*, and *Aph3*) underlying *Aphanomyces* resistance that were consistently identified in a pea population. Ascochyta blight resistance QTLs have also been mapped in six pea populations, both in field and growth chamber experiments and several common QTLs have been reported.[105] [106] [107] Further relevant QTLs underlying broomrape or *Fusarium* root rot resistance, frost tolerance, seed yield, protein content, and other phenological and physiological traits have been reported as well. In all these studies, the need to establish a set of common easy-to-use markers was stressed, to allow comparing QTL results from different studies and to identify consistent QTL regions, a challenge that may be extended to all the relevant legume crops.

Translational genomics is also assisting in the identification of candidate genes or the saturation of zones of interest in pea. Thus, candidate genes responsible for two floral loci in pea were identified using genomic information from *L. japonicus*[108] and the flowering locus GIGAS was identified using a candidate gene approach with *M. truncatula*. Major genes controlling the pea-*Rhizobium* symbiosis were identified as well in orthologous

[100] Page D, Aubert G, Duc G, Welham T, Domoney C (2002) Combinatorial variation in coding and promoter sequences of genes at the *Tri* locus in *Pisum sativum* accounts for variation in trypsin inhibitor activity in seeds. Mol Genet Genom 267:359–69

[101] Rameau C, Dénoue D, Fraval F, Haurogné K, Josserand J, Laucou V, Batge S, Murfet IC (1998) Genetic mapping in pea. 2. Identification of RAPD and SCAR markers linked to genes affecting plant architecture. Theor Appl Genet 97:916–928

[102] Von Stackelberg M, Lindemann S, Menke M, Riesslemann S, Jacobsen HJ (2003) Identification of AFLP and STS markers closely linked to *def* locus in pea. Theor Appl Genet 106:1293–1299

[103] Pilet-Nayel ML, Muehlbauer FJ, McGee RJ, Kraft JM, Baranger A, Coyne CJ (2002) Quantitative trait loci for partial resistance to Aphanomyces root rot in pea. Theor Appl Genet 106:28–39

[104] Pilet-Nayel ML, Muehlbauer FJ, McGee RJ, Kraft JM, Baranger A, Coyne CJ (2005) Consistent QTL in pea for partial resistance to *Aphanomyces euteiches* isolates from United States and France. Phytopathology 95:1287–1293

[105] Timmerman-Vaughan GM, Frew TJ, Russell AC, Khan T, Butler R, Gilpin M, Murray S, Falloon K (2002) QTL mapping of partial resistance to field epidemics of *Ascochyta* blight of peas. Crop Sci 42:2100–2111

[106] Timmerman-Vaughan GM, Frew TJ, Butler R, Murray S, Gilpin M, Falloon K, Johnston P, Lakeman MB, Russell A, Khan T (2004) Validation of quantitative trait loci for *Ascochyta* blight resistance in pea (*Pisum sativum* L.), using populations from two crosses. Theor Appl Genet 109:1620–1631

[107] Prioul S, Frankewitz A, Deniot G, Morin G, Baranger A (2004) Mapping of quantitative trait loci for partial resistance to *Mycosphaerella pinodes* in pea (*Pisum sativum* L.), at the seedling and adult plant stages. Theor Appl Genet 108:1322–1334

[108] Wang Z, Luo Y, Li X, Wang L, Xu S, Yang J, Weng L, Sato S, Tabata S, Ambrose M, et al. (2008) Genetic control of floral zygomorphy in pea (*Pisum sativum* L.) Proc Natl Acad Sci USA 105:10414–10419

genes of *M. truncatula* and *L. japonicus.*[109] [110] Finally, *det* and *lf* were identified[111] as homologs of the TFL1 family controlling flowering time in several plant species. Different transcriptome analyses were performed using a pea 6k oligo-array (Ps6kOLI1) developed especially from seed EST libraries[112], and the transcriptomic variation elicited by biotic stresses was also analysed using microarrays. [113] Several examples of the use of proteomics for the development of root, leaf and seed reference maps under different stresses have been reported.[114] [115] [116]

Among the cool season food legumes, the faba bean has one of the largest genomes (13 Gbp), arranged in six remarkably large chromosomes. While this biological feature has made this species an excellent tool for cytogenetic studies, it has complicated the development of saturated genetic linkage maps and the identification of important genes. In the last two decades, however, significant efforts have been made to enrich genetic and genomic resources in this crop. As a result, many markers and maps have now been developed, which can be used to investigate faba bean genetics and for comparative genomic studies.

Molecular markers have been sought for both simple and complex traits.[117] In the case of major genes, the bulked segregant analysis (BSA) method has been exploited for the identification of markers that are tightly linked to the genes underlying seed quality parameters such as the absence of tannins (controlled by *zt-1* and *zt-2,* two independent

[109] Levy J, Bres C, Geurts R, Chalhoub B, Kulikova O, Duc G, Journet EP, Ané JM, Lauber E, Bisseling T, et al. (2004) A putative Ca^{2+} and Calmodulin-dependent protein kinase required for bacterial and fungal symbioses. Science 303:1361–1364

[110] Krusell L, Madsen LH, Sato S, Aubert G, Genua A, Szczyglowski K, Duc G, Kaneko T, Tabata S, de Bruijn F et al. (2002) Shoot control of root development and nodulation is mediated by a receptor-like kinase. Nature 420:422–426

[111] Foucher F, Morin J, Courtiade J, Cadioux S, Ellis N, Banfield MJ, Rameau C (2003) Determinate and late flowering are two terminal flower1/centroradialis homologs that control two distinct phases of flowering initiation and development in pea. Plant Cell 15:2742–2754

[112] Weigelt K, Kuster H, Radchuk R, Muller M, Weichert H, Fait A, Fernie AR, Saalbach, I, Weber H (2008) Increasing amino acid supply in pea embryos reveals specific interactions of N and C metabolism, and highlights the importance of mitochondrial metabolism. Plant J 55:909–926

[113] Fondevilla S, Küster H, Krajinski F, Cubero JI, Rubiales D (2011) Identification of genes differentially expressed in a resistant reaction to *Mycosphaerella pinodes* in pea using microarray technology. BMC Genomics 12:28

[114] Dumont E, Fontaine V, Vuylsteker C, Sellier S, Bodèle S, Voedts N, Devaux R, Frise M, Avia K, Hilbert JL, Bahrman N, Hanocq E, Lejeune-Henaut I, Delbreil B (2009) Association of sugar content QTL and PQL with physiological traits relevant to frost damage resistance in pea under field and controlled conditions. Theor Appl Genet 118:1561–1571

[115] Bourgeois M, Jacquin F, Savois V, Sommerer N, Labas V, Henry C, Burstin J (2009) Dissecting the proteome of pea mature seeds reveals the phenotypic plasticity of seed protein composition. Proteomics 9:254–271

[116] Castillejo MA, Curto M, Fondevilla S, Rubiales D, Jorrin, JV (2010) Two-dimensional electrophoresis based proteomic analysis of the pea (*Pisum sativum*) in response to *Mycosphaerella pinodes*. J Agric Food Chem 58:12822–12832

[117] Torres AM, Avila CM, Gutierrez N, Palomino C, Moreno MT, Cubero JI (2010) Marker-assisted selection in faba bean (*Vicia faba* L.). Field Crops Res 115:243-252

Legume Futures Report 5.3:
Outlook for knowledge and technology for legume-supported cropping systems
www.legumehub.eu

but complementary genes) and of vicine-convicine[118], or tagging the gene controlling the hypersensitive resistance to rust.[119] The performance of these markers is not completely satisfactory because of their genetic distance from the trait and their lack of conservation in all genetic backgrounds. In contrast to BSA, the use of the candidate-gene approach allows the development of diagnostic or perfect markers that are completely linked to the selected trait. This approach is only possible when the target gene is well characterized in the species or in related species carrying orthologous genes. This strategy has been also used to develop molecular markers linked to the determinate growth habit in faba bean.[120]

Some complex traits in faba bean, such as yield and resistance to parasitic plants or pathogenic fungi has been mapped. Two of the major constraints, namely ascochyta blight and crenate broomrape, have been the subject of particularly intensive QTL studies on F_2 and RIL populations. QTLs accounting for significant proportions of these resistances have been identified, mapped and validated in multi-environment trials [121] [122] [123] together with QTLs for flowering and yield-related traits.[124] Some progress has also been made in identifying QTLs for frost tolerance, chocolate-spot resistance and rust resistance[125] and, more recently, drought resistance.[126] Saturation of the genomic regions associated with target regions and QTL validation in multiple environments and genetic backgrounds are prerequisites to uncover reliable marker-trait associations.

Genomic and transcriptomic approaches have now opened new opportunities for fine mapping or uncovering of candidate genes in the crop. Thus, considering the strong

---

[118] Gutierrez N, Avila CM, Duc G, Marget P, Suso MJ, Moreno MT, Torres AM (2006) CAPs markers to assist selection for low vicine and convicine content in faba bean (*Vicia faba* L.). Theor Appl Genet 114:59–66

[119] Avila CM, Sillero JC, Rubiales D, Moreno MT, Torres AM (2003) Identification of RAPD markers linked to *Uvf-1* gene conferring hypersensitive resistance against rust (*Uromyces viciae-fabae*) in *Vicia faba* L. Theor Appl Genet 107:353–358

[120] Avila CM, Sillero JC, Rubiales D, Moreno MT, Torres AM (2003) Identification of RAPD markers linked to *Uvf-1* gene conferring hypersensitive resistance against rust (*Uromyces viciae-fabae*) in *Vicia faba* L. Theor Appl Genet 107:353–358

[121] Roman B, Satovic Z, Avila CM, Rubiales D, Moreno MT, Torres AM (2003) Locating genes associated with *Ascochyta fabae* resistance in *Vicia faba* L. Aust J Agric Res 54:85–90

[122] Avila CM, Satovic Z, Sillero JC, Rubiales D, Moreno MT, Torres AM (2004) Isolate and organ-specific QTLs for ascochyta blight resistance in faba bean. Theor Appl Genet 108:1071–1078

[123] Díaz-Ruiz R, Satovic Z, Avila CM, Alfaro CM, Gutierrez MV, Torres AM, Román B (2009) Confirmation of QTLs controlling Ascochyta fabae resistance in different generations of faba bean (*Vicia faba* L.) Crop Pasture Sci 60:353–361

[124] Cruz-Izquierdo S, Avila CM, Satovic Z, Palomino C, Gutierrez N, Ellwood SR, Phan HTT, Cubero JI, Torres AM (2012) Comparative genomics to bridge *Vicia faba* with model and closely-related legume species: stability of QTLs for flowering and yield-related traits. Theor Appl Genet 125:1767–1782

[125] Torres AM, Avila CM, Stoddard FL and Cubero JI (2012) Faba bean. In: Pérez de la Vega M, Torres AM, Cubero JI, Kole C (ed) Genetics, genomics and breeding in crop plants: cool season food legumes. Science Pubs Inc, New Hampshire, Jersey, Plymouth, pp 50–97

[126] Khazaei H, O'Sullivan DM, Sillanpää MJ & Stoddard FL (submitted) Using Medicago truncatula-derived SNPs and synteny to identify QTLs and candidate genes for morpho-physiological traits related to drought adaptation in faba bean (Vicia faba L.)

synteny among *M. truncatula* and closely related species, a set of ESTs from *Medicago*, pea, lupin, lentil and soya bean has been recently included in the faba bean maps (Cruz-Izquierdo et al. 2012). These new markers provide anchor points for genome comparison, marker development and saturation of target genomic regions. Moreover, advances in NGS combined with techniques for the quantification of gene expression (such as SuperSAGE), facilitate genome-wide transcriptome studies and target gene identification in organisms such as faba bean from which massive nucleotide sequence information is not yet available. As a result, possible regulators revealed by SuperSAGE analysis and associated with the ascochyta-faba bean and ascochyta-lentil interactions are being genotyped in the faba bean maps[127] in order to identify potential targets for molecular breeding for Ascochyta resistance. Existing information on faba bean is combined with the *Medicago* and chickpea whole genome sequences [128] in genome-wide comparative mapping studies in order to identify orthologous genes and further develop efficient markers for MAS.[129] *M. truncatula* sequence data have been used by an international consortium to develop 750 SNPs in faba bean, and this panel has been used to identify candidate genes associated with drought tolerance.[130]

Chickpea is the second most important cultivated cool-season grain legume after pea, especially in arid and semi-arid regions of the world, and it is almost entirely a food crop. The species is divided into *desi* and *kabuli* types on the basis of seed shape and colour. Both forms also differ on a series of agronomic traits with the *kabuli* types being more resistant to cold and ascochyta blight, whereas heat and drought tolerance, resistance to fusarium wilt and early flowering are more prevalent in *desi* types.[131] Increasing and stabilizing seed yield together with resistance to ascochyta blight and fusarium are nowadays the major aims in chickpea breeding.

As in other legume crops, efforts to develop genetic maps and to identify markers close to relevant genes or QTLs started in the 1990s, and recent achievements have provided the necessary framework to achieve chickpea maps useful for breeding purposes.[132] Genetic maps developed in F_2 populations using isozymes were followed by DNA markers (RFLP

---

[127] Madrid E, Palomino C, Jüngling R, Frank A, Horres R, Rotter B, Winter P, Kahl G, Torres AM (2013) DeepSuperSage analysis of the *Vicia faba* transcriptome in response to *Ascochyta fabae* infection. Phytopathologia Mediterranea 52: 166

[128] Varshney RK et al. (2013) Draft genome sequence of kabuli chickpea (*Cicer arietinum*): genetic structure and breeding constraints for crop improvement. Nature Biotech 31:240-246

[129] Cottage A, Gostkiewicz K, Thomas JE, Borrows R, Torres AM, and O'Sullivan DM (2012) Heterozygosity and diversity analysis using mapped SNPs in a faba bean inbreeding programme. Mol Breed 30:1799–1809

[130] Khazaei H, O'Sullivan DM, Sillanpää MJ & Stoddard FL (submitted) Using Medicago truncatula-derived SNPs and synteny to identify QTLs and candidate genes for morpho-physiological traits related to drought adaptation in faba bean (Vicia faba L.).

[131] Singh KB (1987) Chickpea breeding. In: MC Saxena, KB Singh (eds) The Chickpea. CABI Publ, Wallingford, UK, pp 127–162

[132] Rubio J, Gil J, Cobos MJ and Millán T (2012) In: Pérez de la Vega M, Torres AM, Cubero JI, Kole C (ed) Genetics, genomics and breeding in crop plants: cool season food legumes. Science Pubs Inc, New Hampshire, Jersey, Plymouth, pp 205–236

Legume Futures Report 5.3:
Outlook for knowledge and technology for legume-supported cropping systems
www.legumehub.eu

RAPDs, ISSRs, DAF and SCARs) required for mapping expansion and detection of genes or QTLs of interest. Chickpea genetic maps made a great step forward with the incorporation of sequence tagged microsatellite sites/simple sequence repeat-(STMS/SSR)[133] [134] that provided the framework for the identification of loci conferring resistance to fusarium wilt.[135] New STMS markers were later obtained and mapped in advance populations (RILs and NILs), thus increasing the possibilities of fine mapping and saturation of specific genomic regions. Many of those maps identified areas controlling the major chickpea diseases, ascochyta blight, fusarium wilt and rust as well as some quality components and agronomic traits.[136] Thousands of ESTs derived from expression studies related to biotic or abiotic stresses have also been obtained and could be used to expand and saturate former genetic maps.[137] [138] STMS/SSR and EST-based markers have allowed the comparison of maps developed in different populations, the unification of linkage-group nomenclature and the establishment of reference maps providing anchor points for genome comparison with model and related species. [139] [140] [141] Several bacterial artificial chromosome (BAC) libraries could facilitate future map-based gene/QTL cloning, genome sequencing and physical map construction. Large-scale transcriptome data together with genomic markers based on SNPs now enables the development of highly saturated second-generation genetic maps. This information, together with physical mapping obtained using the ~738 Mb sequence of the *kabuli* chickpea (cultivar CDC

[133] Huettel B, Winter P, Weising K, Choumane W, Weigand F, Kahl G (1999) Sequence-tagged microsatellite-site markers for chickpea (*Cicer arietinum* L.). Genome 42:210–217

[134] Winter P, Pfaff T, Udupa SM, Hüttel B, Sharma PC, Sahim S, Arreguin-Espinoza R, Weigand F, Muehlbauer FJ, Kahl G (1999) Characterization and mapping of sequence-tagged microsatellite sites in the chickpea (*Cicer arietinum* L.) genome. Mol Gen Genet 262:90–101

[135] Winter P, Benko-Iseppon AM, Hüttel B, Ratnaparkhe M, Tullu A, Sonnante G, Pfaff T, Tekeoglu M, Santra D, Sant VJ, Rajesh PN, Kahl G, Muehlbauer FJ (2000) A linkage map of the chickpea (*Cicer arietinum* L.) genome based on recombinant inbred lines from a *C. arietinum* x *C. reticulatum* cross: localization of resistance gene for fusarium wilt races 4 and 5. Theor Appl Genet 101:1155–1163

[136] Rubio J, Gil J, Cobos MJ and Millán T (2012) In: Pérez de la Vega M, Torres AM, Cubero JI, Kole C (ed) Genetics, genomics and breeding in crop plants: cool season food legumes. Science Pubs Inc, New Hampshire, Jersey, Plymouth, pp 205–236

[137] Mantri NL, Ford R, Coram TE, Pang ECK (2007) Transcriptional profiling of chickpea genes differentially regulated in response to high-salinity, cold and drought. BMC Genomics 8:303–317

[138] Molina C, Rotter B, Horres R, Udupa SM, Besser B, Bellarmino L, Baum M, Matsumura H, Terauchi R, Kahl G, Winter P (2008) SuperSAGE: the drought stress-responsive transcriptome of chickpea roots. BMC Genomics 9:553–581

[139] Winter P, Pfaff T, Udupa SM, Hüttel B, Sharma PC, Sahim S, Arreguin-Espinoza R, Weigand F, Muehlbauer FJ, Kahl G (1999) Characterization and mapping of sequence-tagged microsatellite sites in the chickpea (*Cicer arietinum* L.) genome. Mol Gen Genet 262:90–101

[140] Millán T, Clarke HJ, Siddique KHM, Buhariwalla HK, Gaur PM, Kumar J, Gil J, Kahl G, Winter P (2006) Chickpea molecular breeding: New tools and concepts. Euphytica 147:81–103

[141] Nayak SN, Zhu H, Varghese N, Datta S, Choi HK, Horres R, Jüngling R, Singh J, Kishor PBK, Sivaramakrishnan S, Hoisington DA, Kahl G, Winter P, Cook DR, Varshney RK (2010) Integration of novel SSR and gene-based SNP marker loci in the chickpea genetic map and establishment of new anchor points with *Medicago truncatula* genome. Theor Appl Genet 120:1415–1441

51

Legume Futures Report 5.3:
Outlook for knowledge and technology for legume-supported cropping systems
www.legumehub.eu

Frontier)[142], will provide a powerful tool to develop new molecular markers for future MAS in this crops.

The genus *Lupinus* is evolutionarily remote from the other genera of cool-season grain legumes. Several molecular markers have been developed for *lupin* species, including RFLPs, AFLPs, intron targeted amplified polymorphic sequences (ITAPs), gene-based sequence tagged site (STS) markers, microsatellite-anchored fragment length polymorphism (MFLP) markers and EST-SSRs. Those markers have been used to build genetic linkage maps in both white and *narrow-leafed lupins.* The first comprehensive linkage maps in narrow-leafed lupin[143] [144] were based on a population differing for key domestication traits, allowing identification of several QTLs and the maps have been merged. Two linkage maps have been developed as well for *L. albus* (white lupin) in Australia[145] and the UK[146], reporting genes/QTLs for anthracnose resistance, flowering time, seed alkaloid content, and stem height. Maps for other lupin species have not yet been reported. A draft assembly of the narrow-leafed lupin genome, estimated at 960 Mbp, has been obtained .[147]

Synteny analysis of *L. angustifolius* and *L. albus* with *M. truncatula*[148] [149], revealed more frequent rearrangements and breakages of synteny between the lupin species compared to that seen between the galegoid and phaseolid clades.[150] Two BAC libraries of *L.*

---

[142] Varshney RK et al. (2013) Draft genome sequence of kabuli chickpea (*Cicer arietinum*): genetic structure and breeding constraints for crop improvement. Nature Biotech 31:240-246
Von Stackelberg M, Lindemann S, Menke M, Riesslemann S, Jacobsen HJ (2003) Identification of AFLP and STS markers closely linked to *def* locus in pea. Theor Appl Genet 106:1293–1299
[143] Boersma JG, Pallotta M, Li CD, Buirchell BJ, Sivasithamparam K, Yang H (2005) Construction of a genetic linkage map using MFLP and identification of molecular markers linked to domestication genes in narrow-leafed lupin (Lupinus angustifolius L.). Cell Mol Biol Lett 10:331–344
[144] Nelson MN, Moolhuijzen PM, Boersma JG, Chudy M, Lesniewska K, Bellgard M, Oliver RP, S ´ wie̦cicki W, Wolko B, Cowling WA, Ellwood SR (2010) Aligning a new reference genetic map of Lupinus angustifolius with the genome sequence of the model legume, *Lotus japonicus*. DNA Res 17:73–83
[145] Phan HTT, Ellwood SR, Adhikari K, Nelson MN, Oliver RP (2007) The first genetic and comparative map of white lupin (*Lupinus albus* L.): identification of QTLs for anthracnose resistance and flowering time and a locus for alkaloid content. DNA Res 14:59–70
[146] Croxford, A. E., Rogers, T., Caligari, P. D. S. and Wilkinson, M. J. (2008), High-resolution melt analysis to identify and map sequence-tagged site anchor points onto linkage maps: a white lupin (*Lupinus albus*) map as an exemplar. New Phytologist, 180: 594–607
[147] Yang H, Tao Y, Zheng Z, et al. (2013). Draft genome sequence, and a sequence-defined genetic linkage map of the legume crop species *Lupinus angustifolius* L. PloS One 8: e64799
[148] Nelson MN, Moolhuijzen PM, Boersma JG, Chudy M, Lesniewska K, Bellgard M, Oliver RP, S ´ wie̦cicki W, Wolko B, Cowling WA, Ellwood SR (2010) Aligning a new reference genetic map of Lupinus angustifolius with the genome sequence of the model legume, *Lotus japonicus*. DNA Res 17:73–83
[149] Phan HTT, Ellwood SR, Adhikari K, Nelson MN, Oliver RP (2007) The first genetic and comparative map of white lupin (*Lupinus albus* L.): identification of QTLs for anthracnose resistance and flowering time and a locus for alkaloid content. DNA Res 14:59–70
[150] Choi HK, Kim D, Uhm T, Limpens E, Lim H, Mun JH, Kalo P, Penmetsa RV, Seres A, Kulikova O, Roe BA, Bisseling T, Kiss GB, Cook DR (2004b) A sequence-based genetic map of *Medicago truncatula* and comparison of marker colinearity with M. sativa. Genetics 166:1463–1502

52

Legume Futures Report 5.3:
Outlook for knowledge and technology for legume-supported cropping systems
www.legumehub.eu

angustifolius, from cv. Sonet[151] and cv. Tanjil[152] were developed with the aim of facilitating physical genome mapping, positional gene cloning and sequencing in this genus. Several lupin cDNA libraries have also been developed [153] [154] [155] as useful tools for identifying and sequencing new genes and characterize their expression in different plant organs under influence of biotic and abiotic stresses. NGS genomic resources are also available in the genus and the yellow lupin (*L. luteus*) has benefited from transcriptomics research for the recent construction of EST libraries and the development of EST-SSR markers.[156] These genomic tools will continue to produce raw materials for gene discovery, identification of polymorphisms for DNA marker development, anchoring sequences for genome comparisons, and putative gene candidate identification.

[151] Kasprzak A, Safar J, Janda J, Dolezel J, Wolko B, Naganowska B (2006) The bacterial artificial chromosome (BAC) library of the narrow-leafed lupin (*Lupinus angustifolius* L.). Cell Mol Biol Lett 11:396–407

[152] Foley R, Gao L, Lichtenzveig J, Smith E, Shi B, Atkins C, Rosen B, Carrasquilla-Garcia N, Farmer A, Penmetsa V, Cook D, Singh K (2008) How can the genomic revolution help improve lupins. In: Palta JA, Berger JD (eds) Proceedings of the 12th international lupin conference, 14–18 Sept, Fremantle, Western Australia, pp 231–235

[153] Regalado AP, Pinheiro C, Vidal S, Chaves I, Ricardo CP, Rodrigues-Pousada C (2000) The Lupinus albus class-III chitinase gene, IF3, is constitively expression in vegetative organs and developing seeds. Planta 210:543–550

[154] Nuc P, Nuc K, Szweykowska-Kulinska Z, Pawełkiewicz J (1997) Nucleotide sequence of nuclear tRNAGly genes and tRNA^{Gly} pseudogenes from yellow lupine (*Lupinus luteus*): expression of the tRNA^{Gly} genes in vitro and in vivo. Acta Biochim Pol 44:259–274

[155] Tian L, Peel G, Lei Z, Aziz N, Dai X, He J, Watson B, Zhao P, Sumner L, Dixon R (2009) Transcript and proteomic analysis of developing white lupin (*Lupinus albus* L.) roots. BMC Plant Biol 9:1 doi:10.1186/1471-2229-9-1

[156] Parra-González LB, Straub SCK, Doyle JJ, Mora Ortega PE, Salvo Garrido HE, Maureira Butler IJ (2010) Development of microsatellite markers in *Lupinus luteus* (fabaceae) and cross-species amplification in other lupine species. Am J Bot 97: e72–e74

53

Legume Futures Report 5.3:
Outlook for knowledge and technology for legume-supported cropping systems
www.legumehub.eu

Table 2. Examples of recently generated genomic resources in grain legumes. (SSR simple sequence repeat**.** EST: expressed sequence tags. SNP: single nucleotide polymorphisms. AFLP: amplified fragment length polymorphism.)

Species	Genomic resource	Reference
Faba bean	EST-SSR	**Kaur et al. 2012**
	SNP genotyping platform (KASPar)	Cottage et al. 2012
	EST-derived markers	Ellwood et al. 2008; Cruz-Izquierdo et al. 2012
Narrow-leafed lupin	Bacterial artificial chromosome (BAC) library and BAC-end sequencing	Gao et al. 2011
Yellow lupin	Microsatellites	Parra-González et al. 2010
	EST-SSR	Parra-González et al. 2012
White lupin	AFLPs	Phan et al. 2007
Pea	EST-SSR	Gong et al. 2010; De Caire et al. 2012; Mishra et al. 2012
Chickpea	SNP	Hiremath et al. 2012
	Transcript map using genic molecular markers	Gujaria et al. 2011
	Genome sequence	Varshney et al. 2013

Improved crop management to increase output

Optimising legume-supported cropping systems needs both new knowledge and innovative technology that will deliver 'know how' for enhancing legume cropping at a local level across Europe. Grain legume-supported cropping systems will capitalise on the advances in plant breeding and will expand if the industry uses the grain as ingredient or innovative foods in human diets or in animal feed. To complement improvements in breeding, an interdisciplinary research approach is required to assess the potential of grain legumes in EU agro-ecosystems and to define their best way for cropping them across its diverse farming systems and growing environments. Genetic and agronomic improvements need to proceed hand-in-hand as new genotypes often require changed agronomy in order to optimize productivity[157] including quality aspects for both human and livestock consumption.

Legumes are grown in crop rotation, which means that research needs to consider the effect on other crops in crop sequences and the interaction of sequences with management (e.g. tillage, fertilisation). *In silico* research and biophysical modelling will allow definition of which grain legume crops and rotation options should be chosen for

---

[157] Siddique KHM, Johansen C, Turner NC, Jeuffroy M-H, Hashem A, Sakar D, Gan Y, Alghamdi SS (2012) Innovations in agronomy for food legumes. A review. Agron Sustain Dev 32:45–64

Legume Futures Report 5.3:
Outlook for knowledge and technology for legume-supported cropping systems
www.legumehub.eu

further field-testing across the various EU agro-ecosystems. In developing cropping systems with grain legumes, there are questions to address about the production of the grain legumes themselves. Improving yield stability in grain legumes is widely accepted as a challenge for both breeding and agronomy.[158] [159] For the grain legumes themselves, issues include the ability to compete against weeds, lodging and nutrition. Kiær et al.[160] show the potential of mixtures of cereal cultivars to confer yield stability benefits over single cultivars, and although mixtures have not been widely explored in grain legumes, the same benefits could occur and be useful in situations such as feed production. Weed competition has a strong relationship with loss of grain legume yields.[161] Most grain legumes establish quite slowly and can struggle to compete against weeds. Manipulating plant density, undersowing and intercropping are all options. Legumes and non-legumes grown together in intercrops to combine the ability of the legume to fix nitrogen with the yield characteristics of the non-legume. The interactions between the species grown together may be positive or negative in terms of overall grain yield by influencing factors such as lodging. The interactions caused by interspecific competition need to be taken into account before recommending any intercropping with grain legumes. Intercropping research has been neglected in temperate agro-ecosystems due to its complexity and lesser relevance in cropping systems that rely on agrochemicals.

Reducing production costs

Legumes are generally low-input crops. This is due largely to biological nitrogen fixation. However, there are other aspects of crop production that generate significant costs, and these may increase as the range of pesticides available is constrained by policy on crop protection products.

Nitrogen fertilisation

The first approach to maintaining or reducing costs is the optimisation of biological nitrogen fixation (BNF). Where indigenous rhizobia are inadequate in number or of the wrong species, inoculants boost BNF, improving the grain yield and quality. Even where the same inoculant species infects several hosts, there are differences between bacterial accessions, so the isolate of *Rhizobium leguminosarum* used on pea differs from that used

---

[158] Sass O (2009) Market situation and breeding input in faba beans and field peas in the EU. J Cultiv Plants 61:306–308

[159] Flores F, Nadal S, Solis I, Winkler J, Sass O, Stoddard FL, Link W, Raffiot B, Muel F, Rubiales D (2012) Faba bean adaptation to autumn sowing under European climates. Agron Sust Dev 32, 727-734

[160] Kiær LP, Skovgaard IM, Østergård H (2012) Effects of inter-varietal diversity, biotic stresses and environmental productivity on grain yield of spring barley variety mixtures. Euphytica 185:123–138

[161] Corre-Hellou G, Crozat Y (2005) N_2 fixation and N supply in organic pea (*Pisum sativum* L.) cropping systems as affected by weeds and pea weevil (*Sitona lineatus* L.) Eur J Agron 22:449–458

on faba bean. There are several methods of inoculating legumes, and inoculants often require special care to maintain their viability.

Furthermore, rhizobial inoculants and grain legumes must match (i.e. symbiosis) to realize the BNF benefits. Where legumes respond, inoculation with rhizobia results in stimulation of photosynthesis, and improves the photosynthetic nutrient use efficiency and harvest index, at least in soybean and faba bean.[162] Other non-rhizobial bacteria such as plant growth promoting bacteria can also improve nodulation and grain yield of the legumes upon co-inoculation with crop-specific rhizobia.[163]

Inoculation does not always generate a positive response. When the population of indigenous root-nodule bacteria for the given crop is high, introduced inoculant bacteria are often outcompeted by indigenous rhizobia.[164] Soil pH correlates with survival of the indigenous population of *R. leguminosarum*[165], thereby giving a farmer a simple tool to assess the need for inoculation with this symbiont.

Legume host determines nodule morphology and structure while bacterial symbionts control the BNF effectiveness, which vary greatly in genotypic and phenotypic characters. Genomic research has provided a better understanding of the rhizobium–legume interaction.[166] Genomics can help to define and demonstrate what rhizobial genes are involved in symbiotic events. Biological research on BNF will provide insights into gene expression and function involved in these rhizobia–legume interactions.

Lupin rhizobia have not been systematically screened for properties valuable in inoculant preparations and therefore deserve attention. Lupins are nodulated by rhizobia belonging to the genera, *Bradyrhizobium*, *Mesorhizobium*, *Microvirga*, *Ochrobactrum*, *Phyllobacterium*, and *Rhizobium* - all placed in the alpha branch of proteobacteria. The genus *Bradyrhizobium* is a dominant lineage among lupin rhizobia and it appears that strains belonging to this genus tend to form more effective symbiosis than other lupin rhizobia. Collection of strains from gene centres and appropriate genetic and phenotypic

---

[162] Kaschuk G, Kuyper TW, Leffelaar PA, Hugria M, Giller KE (2009) Are the rates of photosynthesis stimulated by the carbon sink strength of rhizobial and arbuscular mycorrhizal symbioses? Soil Biol Biochem 41:1233–1244

[163] Tariq M, Hameed S, Yasmeen T, Ali A (2012) Non-rhizobial bacteria for improved nodulation and grain yield of mung bean [*Vigna radiata* (L.) Wilczek]. Afr J Biotech 11:15012–15019.

[164] Thies JE, Singleton PW, Bohlool BB (1991) Influence of the size of indigenous rhizobial populations on establishment and symbiotic performance of introduced rhizobia on field-grown legumes. Appl Environ Microbiol 57:19–28

[165] Leinonen P (1996) The effects of soil properties on indigenous *Rhizobium*-population nodulating peas. Sci Legumes 3:227–232

[166] Musarrat J, Zaidi A, Khan MS (2010) Recent advances in rhizobium–legume interactions: a proteomic approach. In Khan MS et al. (eds), Microbes for legume improvement. Springer-Verlag, Vienna, Austria. DOI 10.1007/978-3-211-99753-6_4, # 2010

Legume Futures Report 5.3:
Outlook for knowledge and technology for legume-supported cropping systems
www.legumehub.eu

characterization followed by symbiotic screening in appropriate conditions (cold, acidic) should yield a collection of strains useful to boost lupin BNF in Europe. Lupin inoculation today, if practiced at all in Europe, employs rhizobial strains selected from a narrow genetic resource base. Strain selection does not so far consider climatic and soil conditions in the north. Strain effectiveness and plant-rhizobium compatibility has relied solely on cross-inoculation testing of plant-bacterial accessions providing no understanding of underlying genetic determinants responsible for high-yielding symbioses. Research could address this by providing inoculant manufacturers with superior strains regarding environmental adaptation and effective BNF. These strains will be utilised for the production of pre-inoculated seed, not yet widely available for grain legumes. This advancement will benefit the farmers utilizing BNF by reducing their workload during sowing, and thus lead to an increase of the cultivation of inoculated grain legumes in Europe.

Crop protection

Protecting crops against weeds, diseases and pests is generally outside the scope of Legume Futures although all partners are accutely aware of the role crop protection plays. Failing crop protection was a major factor in the collapse of pea yields in France and in the constraints on pea production there. Crop protection has not featured strongly in the forward-looking processes that members of the consortium have been involved in.

Plant breeding, the scope for which is fully described above, is the primary tool in protecting crops, particularly against diseases. Breeding can also contribute to the control of pests and weeds. Beyond these, developing control practices at farm level has a strong regional and local dimension. It is also a target for applied research conducted by the crop protection industry.

Capturing farm-level effects

There is a worldwide trend to simpler and more intensive cropping systems. To progress more sustainable crop development, farmers and policy-makers need well-founded evidence that crop rotations with grain legumes genuinely reduce costs and minimize risks associated with input dependency. Achieving this requires integrated management practices supported by appropriate tools. Grain legumes have the potential to work as effective break crops in cereal-based rotations, although there are clear questions about the selection and agronomy of following crops to optimize the break-crop effect. Management tools, including fact sheets and budgeting tools, will help to demonstrate how legume crops can provide economic and ecological advantages at the cropping system level. It is now possible to deliver cropping know-how via 'user friendly' on-line farm management tools including fact sheets and budgeting tools. The search/information tree will ease the access to information regarding different farm types, agro-environmental

57

Legume Futures Report 5.3:
Outlook for knowledge and technology for legume-supported cropping systems
www.legumehub.eu

zones, cropping systems (rotation, use of cover crop, tillage, crop protection, fertilisation), crops, cultivars, intercropping and varietal associations.

Fernandez and Trolinger[167] emphasise the growing importance and suitability of web-based decision support systems for farm management. However, uptake of decision support systems technology in the agriculture sector has been limited. Options to increase uptake, include 'participatory approaches, involving the user early in the development process and considering the decision-making styles and social context of potential users'.

To provide farmers with knowledge and management tools to reinforce grain legume cropping in a regionally appropriate way, different information channels need to be addressed (including online tools and printed fact sheets). Kutter et al.[168] found significant differences across European countries in the use of the Internet as an information source for precision farming. Farm management tools are successfully used or under development in several ongoing EU and national projects:

BERAS Implementation (EU project): user friendly software tools for nutrient management and crop rotation design in organic farming; URL: www.beras.eu

SOLID (EU project): decision support system to optimize the management of on-farm feed resources and feed supply systems within organic and conventional low input dairy systems; URL: www.solidairy.eu

INKA BB (National project, Germany): on-line decision support system for selecting the appropriate tillage system; URL: www.klima-bob.de/

OSCAR (EU project): Cover Crop and Living Mulch toolbox providing an on-line and one-stop access point for information on Cover Crop and Living Mulch based cropping systems; URL: http://web3.wzw.tum.de/oscar/

---

[167] Fernandez CJ, Trolinger TN (2007) Development of a web-based decision support system for crop managers: structural considerations and implementation case. Agron J. 99:730–737
[168] Kutter T, Tiemann S, Siebert R, Fountas S (2011) The role of communication and co-operation in the adoption of precision farming. Precision Agric 12:2–17

Legume Futures Report 5.3:
Outlook for knowledge and technology for legume-supported cropping systems
www.legumehub.eu

Rewarding public benefits

Grain legumes in crop rotations provide interesting options for reducing environmental impacts of agriculture, particularly when considering both depleted fossil energy resources and climate change. The existing evidence for this was examined by Legume Futures partners for the European Parliament.[169] Bringing grain legumes into the intensive EU cereal-based farming systems will reduce energy use in cropping systems, greenhouse gas emissions, ozone formation and acidification as well as eco- and human- toxicity. There is, however, a need to ensure that any less desirable effects of introducing grain legumes, such as leaching, are understood and minimised.[170] However, the challenges faced in increasing the production of grain legumes in EU agricultural systems are associated with a lack of means to fully assess and demonstrate the full range of effects on public goods. Cropping system modelling can be used to assess and predict the main agronomic and economic effects at cropping system level of current and novel grain legumes including the ecological side effects (reduction of N-fertiliser use, soil fertility, pre-crop effects, break crop effects on weeds, diseases, and N_2O-emissions). The model ROTOR for example[171] which Legume Futures partners developed in earlier research could be used to assess impacts of legumes on the cropping system scale, extend the coverage of results and fill information gaps. ROTOR has been modified and calibrated for conventional cropping systems in a number of geographic regions in Europe, and is described as a viable method for multi-criteria assessments.[172] Linear cropping system models such as NDICEA [173] can generate data for the fact sheets and tools.

Research policy for improving the performance of cropping systems

The exercises in identifying research priorities that Legume Futures partners have contributed to have all identified the need for long term investment in coherent research targets. This is a general challenge in managing public investment in agricultural research, as exemplified by an evaluation of the German organic farming research programme[174]

---

[169] Bues, A., Kuhlmann, T., Lindstrom, K., Murphy-Bokern, D., Preissel, S., Reckling, M., Stoddard, F.L., Topp, K., Watson, C. and Zander, P. (2013) The environmental role of protein crops in the new common agricultural policy. The European Parliament (http://www.europarl.europa.eu/delegations/en/studiesdownload.html?languageDocument=EN&file=93370

[170] Jensen ES, Peoples MB, Hauggaard-Nielsen H (2010) Faba bean in cropping systems. Field Crops Res 115:203–216

[171] Bachinger J, Zander P (2007) ROTOR, a tool for generating and evaluating crop rotations for organic farming systems. Eur J Agron 26:130–143

[172] Carof M, Colomb B, Aveline A (2013) A guide for choosing the most appropriate method for multi-criteria assessment of agricultural systems according to decision-makers' expectations. Agric Syst 115:51–62

[173] van der Burgt GJHM, Oomen GJM Habets ASJ, Rossing WAH (2006) The NDICEA model, a tool to improve nitrogen use efficiency in cropping systems. Nutr Cycling Agroecosyst 74:275–294

[174] Ekert, S; Döring, T., Häring, A.M.; Lampkin, N., Murphy-Bokern, D., Otto, K., Padel, S. and Vieweger, A. (2012). Evaluation of the German Federal Research Programme on Organic Agriculture. BLE (http://orgprints.org/22369/)

Legume Futures Report 5.3:
Outlook for knowledge and technology for legume-supported cropping systems
www.legumehub.eu

and by assessment of EU Framework research.[175] The DAFA Expert Forum[176] concluded that the generation of knowledge through long-term research combined with a suitable policy framework provides the foundation of a successful strategy for increasing the use of legumes. For achieving this objective, it is important to identify specific and coherent research questions and to address these in well-designed research projects.   The research funding and in particular the research programming framework are important so that research projects complement each other and together focus effectively on strategic goals.

The record of EU research and of research funded at national levels shows that a considerable investment has been made in research aimed at improving legume cropping. These research projects have been funded in a range of context and a significant proportion is linked to organic farming research programmes. However, the recent assessments mentioned above indicate that the impact of previous research has been compromised by short-term projects and a lack of a strategic approach. The research community needs to identify coherent and strategically relevant research questions that will drive research that effectively supports the technical and policy change required. This must be supported by a willingness to make long-term investments. This is true for research related to crop sequences and the need to understand the long-term implications of the introduction of legumes into farming systems.

An EU-sponsored crop research priority setting exercise (EUROCROP) [177] completed about five years ago emphasised the importance of identifying coherent science facing research targets that cut across the wide range of public and private objectives that should drive that research. That work showed that some areas of research core to agricultural science remain relevant across a wide range of policy scenarios and over time. This points to the need to translate present and future policy and market conditions into coherent research programmes. This involves a degree of 'intelligent decoupling' of policy (public or commercial) and research objectives which, although challenging work, has the merit of focusing investment on targets that serve a wide range of potential futures and users.

This is especially true of research that uses novel plant genetic resources to support plant breeding.   Similarly, sustainable farming systems can be developed only if legume-

[175] Murphy-Bokern, D., Gherghinescu, O., Kraigher, H., Lazzeri, P., Peeters, A., Schmid, O., Scudamore, J., Toepfer, S., Westergaard, J. (2011). Impacts of EU Framework Programmes (2000-2010) and prospects for research and innovation in agriculture, animal health and welfare, and forestry. Unpublished report to the European Commission. Summary presentation available at www.murphy-bokern.com

[176] DAFA (2012).   Science, economy and society – making ecosystem services from legumes competitive. A research strategy of the German Agricultural Research Alliance (DAFA). Wissenschaft, Wirtschaft, Gesellschaft – Ökosystemleistungen von Leguminosen wettbewerbsfähig machen. Forschungsstrategie der Deutsche Agrarforschungsallianz (DAFA) c/o Thünen-Institut Bundesallee 50 38116 Braunschweig www.dafa.de

[177] Agricultural Research for Improving Arable Crop Competitiveness(EUROCROP)

60

Legume Futures Report 5.3:
Outlook for knowledge and technology for legume-supported cropping systems
www.legumehub.eu

supported cultivation systems are the subject of long-term field experiments. To support the necessary programming, the identification of coherent research questions is a research activity in itself.

In the past, large multi-disciplinary projects have been used to address challenges set out above. This was particularly the case in FP6 which embraced the 'fork-to-farm' adage to guide research strategies. Large project that addressed multiple questions along the supply chain were also used, for example GLIP in the grain legumes area. It may seem plausible that the way to increase the relevance of research to supply chain challenges is to structure research projects in line with those supply chains. However, there is always the risk that the resourcing of core challenges is compromised by attention to marginal questions. Where it is useful in relation to the research questions, multi-disciplinary research is appropriate. Systems- and interdisciplinary-thinking are essential if farming systems which effectively utilise the agronomic, environmental and economic potential of legume crops are to be realised. However, much of what passes as interdisciplinary research is in fact a loose and temporary alliance between separate disciplines – there is a lot of multi-disciplinary activity, but relatively little interdisciplinary thinking.