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The Legumes Expert Forum

Science, economy and society – making ecosystem services from legumes competitive

A research strategy of the German Agricultural Research Alliance

Imprint

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The Legumes Expert Forum

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Content

Preamble

This research strategy is the result of intensive discussions between experts from the research, farming and food communities. These discussions were initiated in January 2011 with the establishment of the Legumes Expert Forum by the German Agricultural Research Alliance (DAFA). The purpose of the Forum is to examine and report on the research required to support the use of legumes in Germany. A steering group led more than 40 discussions with experts and organised a conference in June 2011 which was attended by more than 100 scientists, representatives from farming, agri-business, policy, civil society and research funders. The conference led to the formation of a planning group which drove the development of the strategy forward. As the responsible ministry, the Federal Ministry of Food, Agriculture and Consumer Protection (BMELV) was kept informed of the strategy process and results as it progressed.

Reflecting the scientific character of this process, this research strategy is presented in the form of a comprehensive and scientific document. Details of the potential of legumes in relation to acknowledged socio-economic challenges, the state of research on legumes, and the research needs arising from these are presented in the relevant chapters.

A wide range of research questions emerged from the expert discussions. Based on these, the strategy sets out a research framework and makes proposals at the programme level. It addresses research policy directly and sets out research priorities. The presentation of the research priorities in Chapter 4 is structured scientifically and their order should not be seen as a ranking of their importance. The research needs identified are not proposals for specific projects. The development of research at the level of individual projects is a matter for the research funders, researchers and their cooperating partners.

Because of the breadth of participation in discussions, this strategy is independent from the interests of specific research funders or specific political, commercial and societal viewpoints. The document should not be regarded as a complete account of all research questions relevant to the development of legume crops. It is particularly relevant to guiding policy in the development of a wider strategy for supporting protein crop production. The DAFA research strategy recommendations can be regarded as a contribution to the formation of wider support measures relevant to the development of legume-supported cropping systems and a contribution to the development of a policy for a sustained research effort aimed at enabling the realisation of the potential of legumes.

Summary

An increase in the production of legumes species (e.g. beans, peas and clover) on farms in Germany and in many European regions in the next decades would provide far-reaching benefits. Why?

Today's agriculture is expected to produce more than just food. Farmers must deliver a range of environmental services, high-quality affordable food, feed, and raw materials for energy production and other non-food applications. Production must conserve non-renewable resources, protect water bodies from depletion and pollution, minimise greenhouse gas and other emissions, and protect and enhance farmland biodiversity. There is also an increasing societal awareness of the broad and intrinsic benefits of more diverse rotations and cropping sequences. The production of legumes in Europe helps to meet these demands. These protein-rich crops that improve soil fertility and enhance agricultural biodiversity can make an essential contribution to the sustainable development of the farming and food sectors.

What needs to be done? The DAFA (German Agricultural Research Alliance) has developed this research strategy 'Science, economy and society – making ecosystem services from legumes competitive' to provide a foundation for planning public investment in research. It is the result of intensive discussions between farmers, advisors, processors, trade representatives, policy-makers and organisations responsible for publicly funded research. It has become clear during the development of this strategy that legume production and use is an opportunity for the whole farming and food sector. Representatives of organic and conventional farming worked together on the strategy from the beginning.

The strategy identifies two fundamental needs:

- A coherent research effort is required. Continuation of a fragmented approach that provides a large number of individual research findings will not lead to effective practical solutions.

- Agricultural policy (e.g. support from the "greening" of the CAP) alone will not deliver a long-term breakthrough. Progress in plant breeding and production and new approaches to the processing and use of legumes on farms are needed to make legume crops competitive.

Research programmes need to address coherent research questions aimed at increasing the competitiveness of legume production. Six strategic science and technology outcomes are of specific relevance.

Strategic science and technology outcomes

- **Increased investment in pre-breeding and breeding**
- **Exploitation of production potential**
- **Valuation of ecosystem services to support farm business decision-making**
- **Exploitation of regional opportunities to develop supply chains**
- **Removal of barriers to the use of legumes in livestock feeds**
- **Implementation of dietary concepts to exploit the potential health benefits**

Coming from this background, the DAFA recommends that the development of research investment should emphasise programmes that coherently support research in six areas:

Research areas

1. Sustainable healthy diets
with emphasis on:

- nutritional and physiological effects of foods containing legume products;
- quality and attractiveness of legume-containing foods.

2. Sustainable protein sources for animal feeds
with emphasis on:

- valuation of feed ingredients;
- processing technologies to optimise value;
- additional value chains.

3. Non-food uses
with emphasis on:

- optimising the use of land;
- identifying potential raw material uses.

4. Crop productivity
with emphasis on:

- improving the genetic potential for yield and quality;
- improving crop production.

5. Resource protection
with emphasis on:

- soil and water;
- biodiversity in agricultural landscapes;
- climate change adaptation and mitigation.

6. Socio-economic research
with emphasis on:

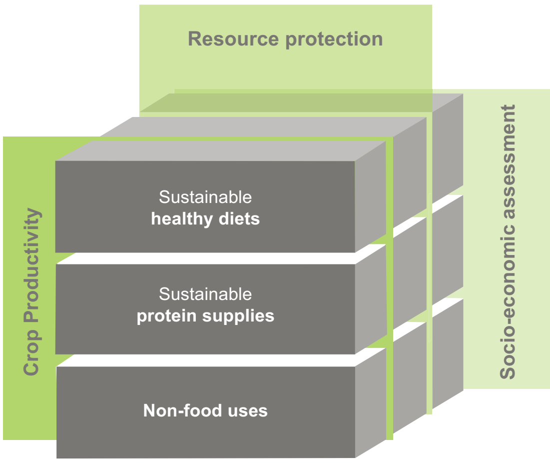
- farming system cost-benefit assessments;
- economic assessments of public benefits;
- market development.

These research areas are important not only because of their individual impacts. They are also important because of the synergy between them. Research areas 1 to 3 align with the supply chains that deliver the benefits of legumes. Research areas 4 to 6 strategically underpin these being relevant to all uses of legumes. Combining these by integrated programming is proposed as a key to success.

This concept is illustrated by the DAFA Legume Research Matrix. It shows how the research areas are inter-linked and mutually supportive. The matrix illustrates a concept that should be a guiding principle in developing this research and for implementing funding schemes and the design of individual projects.

Delivering real solutions and impact will depend on (i) research funding concepts designed to meet the needs of the legume research challenge and (ii) research frameworks that effectively address complex research questions.

Figure 1: Legume Research Matrix



The DAFA recommends that organisations involved in developing research programmes

1. support long-term research on legumes to enable, for example, research supporting pre-breeding and the development of production systems;

2. enable the formation of consortia to conduct trans-disciplinary research;

3. support integrative research to address supply chain questions and needs;

4. stimulate regional crop centres that provide reference systems, pilot testing and demonstration;

5. stimulate exploitation of research results by systematically engaging organisations involved in education, training and the provision of advice; and

6. promote the production and utilization of legumes via **agricultural policies**.

Why is research to support legume production needed?

The legume crop area in Germany dropped from 1.4 million to 0.4 million ha between 1949 and 1991. The area has remained stable at this low level since 1991. Why has this happened? A major reason is the availability of relatively cheap imported soy meal combined with the increased production of forage maize and cereals displacing home-grown legumes. Under current market conditions, the displacement of legumes grown on Europe's farms is understandable. Low production has a knock-on effect on commercial breeders who have abandoned many of their efforts to improve legumes. This has led to a cycle of decline.

Farm-level economic performance is the driving force behind these changes. The sum of commercial decisions made at the farm level does not always lead to an optimal allocation of resources from a wider societal viewpoint. The ecosystem benefits of legumes are tightly linked to the location of production and so are forfeited where imported legumes displace local production. This is the situation today; most of the legumes we use are imported from South America. In addition to forfeiting the ecosystem benefits of their production in Europe, it would be unacceptable in the longer term to ignore the potential of legumes in healthy diets and not to explore the innovation potential of non-food uses. The system or market failure giving rise to this situation provides the rationale for the DAFA as an association of German agricultural and food scientists to focus on legumes.

The scope and depth of the DAFA research strategy demands a wide-ranging and systematic approach to research planning. The DAFA's position is shared by a large number of German actors in academia, business, government and non-governmental organizations. This shared stance is also evident across groups focused on specific projects and themes as well as organisations operating predominantly at the strategic level. All these actors share the goal of strengthening the sustainable development of the wider bio-based economy.

The DAFA 'legumes' strategy serves a central goal: the expansion in the production of legumes in Germany and Europe. Only through this expansion can these crops play a role in farming that reflects their benefits for our society.

Grain peas *(Pisum sativum)*

Mixed cropping of winter peas and rye.

1 Introduction

Legume crops protect and enhance public goods. However, the area of legumes grown in Germany has stagnated over the last 20 years and has been about 400,000 ha over the last 10 years. Parallel to this, the number of breeding programmes has declined to about one per crop species or has ceased completely for some species. The result is that our cropping systems are not delivering the benefits to society that legumes can offer. To realise these public benefits, public support for a significant increase in the cultivation and use of legumes in Germany is justified. To achieve this, investment in research and development that considers scientific, economic and wider societal interests is required.

Society rightly expects agricultural and food research to deliver insights and solutions relevant to global food security, scarcity of fossil resources, loss of biodiversity, climate change and the development of rural areas. These challenges cannot be met with simple approaches. Increasingly, integrated and holistic strategies are required that acknowledge the complexity of these themes and address the needs of the various groups involved.

In this context, the use and optimisation of **ecosystem services** that are delivered by legume crops is of strategic importance. Ecosystem services encompass all the utility provided to mankind by ecosystems. This includes the sustainable production of food, the economic benefits of food and raw materials produced, and the environmental, climate and resource protection enabled by ecosystems.[1]

The range of ecosystem services delivered by legume crops are set out in the following chapters. Of particular economic and agro-ecological relevance are, for example, the support of healthy sustainable diets and climate protection. The substitution of soy imports is often the focus of current public debate, but the benefits of legume production in Germany extend beyond this.

Collaboration on the ground – a field meeting between breeders, agricultural researchers, farmers, representative bodies and policy makers.

Considering the multiple benefits offered by legumes in the sustainable development of our agriculture and food sectors, integrated research and policy measures are required that engage the various research disciplines and interest groups from science, business, policy, farming and wider society. To pursue the benefits consistently, focused research must be conducted across the full range of ecosystem services delivered. The wider impact potential of such research can only be realised if the cultivation of legumes in Germany is expanded and sustained.

[1] Cf. Millennium Ecosystem Assessment, 2005: Ecosystems and Human Well-Being: Synthesis. Island Press, Washington, D.C., pp. 1-137
Additionally cf.: Burkhard, B., Groot, R. de, Costanza, R., Seppelt, R., Jörgensen, S.E. & Potschin, M., 2012: Solutions for sustaining natural capital and ecosystem services. Ecological Indicators, 21, 1-6, doi:10.1016/j.ecolind.2012.03.008
UK National Ecosystem Assessment, 2012: Ecosystem Services, http://uknea.unep-wcmc.org/EcosystemAssessment Concepts/EcosystemServices/tabid/103/Default.aspx (Date: 11.04.2012)

2 Ecosystem services: societal goals and the potential of legumes

The cultivation of legumes delivers a wide range of ecosystem services that are demanded by society. These contribute to protecting the environment and natural resources, deliver valuable raw materials for food, feed and other supply chains, and support healthy and sustainable diets.

The German government recognises that global food security, climate change and environmental protection, and a higher independence from fossil resources are all themes directly relevant to the development of agriculture.[2] It follows that for the development of sustainable solutions, the whole system from farm production to the point of consumption needs to be considered.[3]

Because of the increasing burdens on the environment, constraints on agricultural land and depletion of high quality phosphorus fertilisers, increasing the productivity of cropping systems while minimising the use of pesticides and fertilisers are central challenges. This needs to be achieved while reducing greenhouse gas emissions and contamination of water resources.[4]

In 2011, the German Federal Ministry for Agriculture, Food and Consumer Protection (BMELV) initiated a public debate about the role and future of the farming and food sectors in Germany. The result of this debate was incorporated into the Charter for Agriculture and Consumers. The Charter process showed how important broad acceptance and consensus in society is to advancing the sustainable development of agriculture and food. A wide range of public goods from agricultural resources and activities are increasingly expected. These include global food security with access to safe food, protection of the environment and natural resources, rural development, and high process standards in production.[5]

Discussing protein crops and the BMELV protein crop strategy under the frame of the Charter process in June 2012.

The current reliance on a few crop species is a cause of problems in crop production and increases the vulnerability of German agriculture. If we are to protect agri-biodiversity and soils, we need to grow a wider range of crops in more diverse rotations and cropping sequences.[6] The current neglect of legumes has negative implications for the sustainable production of crops and the development of new value chains.

[2] BMELV, 2011: Moderne Landwirtschaft – nachhaltig und verbraucherorientiert, www.bmelv.de/SharedDocs/Standardartikel/Ministerium/Leitung/Namensbeitraege/Aigner-ModerneLandwirtschaft.html

[3] BMELV, 2008: Nachhaltigkeit konkret.

[4] Nationaler Aktionsplan zur nachhaltigen Anwendung von Pflanzenschutzmitteln (NAP) lt. Beschluss der Agrarministerkonferenz vom 11. April 2008

[5] de Haen H, Reisch L, 2011: Charta für Landwirtschaft und Verbraucher. Ergebnisse des Dialogs mit gesellschaftlichen Gruppen: Handlungsfelder und Empfehlungen. Göttingen, Kopenhagen, September 2011

[6] BMELV, 2008: Bericht des BMELV für einen aktiven Klimaschutz der Agrar-, Forst- und Ernährungswirtschaft und zur Anpassung der Agrar- und Forstwirtschaft an den Klimawandel

Our consumption patterns, our food culture and how we value food products have changed radically in recent decades. There is increasing emphasis on the enjoyment of food and on healthy eating. These trends have resulted in the growth of parts of the food industry and offer further potential for the introduction of innovative products.[7] A transition to healthier eating is a high priority for public policy. The increased demand for foods that are produced under high production standards, support healthier eating, and provide enhanced eating experiences presents a long-term challenge for the agricultural and food sector. In addition to providing high-quality protein and fibre, legumes deliver biologically active compounds that play a role in functional foods.

The public debate about the sustainable development of agriculture and food has resulted in an increased scrutiny of the quality of processes used in producing food.[8] Consumers increasingly express preferences in relation to how food is produced.[9] There is increasing demand for regional foods and foods that are produced at high standards in terms of environmental protection and animal welfare. There is increased interest in traceability and in using plant-based raw materials. Consumers increasingly demand food that is authentic to particular cultural traditions and that contributes to diversity in cuisine.[10]

Defining legumes

The legume family (Fabaceae or Leguminosae) is one of the largest plant families. Worldwide it comprises almost 20,000 cultivated and wild species. This includes annual, biennial and perennial plants, including woody species such as trees and lianas. Most legumes host rhizobium bacteria that fix nitrogen in nodules on their roots. Through this biological nitrogen fixation, most legume crops are independent from soil nitrogen supplies and play a major role in maintaining soil fertility. This unique agricultural characteristic combined with the high protein content of the seeds means that legumes are used in all agricultural systems, from the tropics to high latitudes.[11]

In German agriculture, the important legumes include the annual pulse crops such as peas, field beans (Faba), and lupines as well as various perennial forage species such as clover and alfalfa (lucerne). These crops are grown particularly for animal feed and forage, or to build soil fertility via green manuring and to protect soils from erosion. For direct human consumption, lentils and soy, peas, green beans, and faba beans are important. All these are annual plants.

[7] BMBF, 2010: Studie zum Innovationssektor „Lebensmittel und Ernährung“. Freising, Berlin, 2010
[8] BMELV, 2008: Fn. 6, S. 19
[9] Internet resources supporting the charter for agriculture and consumers; http://www.bmelv.de/DE/Ministerium/Charta-Diskussion/Prozess/Prozess_node.html
[10] BMELV, 2011: Workshopbericht zur Charta für Landwirtschaft und Verbraucher – Thema Lebensmittel. Vierter Workshop zur Charta für Landwirtschaft und Verbraucher, Berlin, 7. Juni 2011
[11] Werner & Newton, 2005: Nitrogen fixation in agriculture, forestry, ecology, and the environment

The fixation of nitrogen in nodules on the roots of legumes plays a central role in ecosystem service provision. Up until the development of the Haber-Bosch process used to synthesise nitrogen fertiliser, agricultural production was almost totally dependent on legume-based nitrogen fixation. Organic farming systems remain largely dependent on legumes for the supply of reactive nitrogen. In addition, some species such as lupine and alfalfa can mobilise other soil-based nutrients through their deep and extensive root systems.

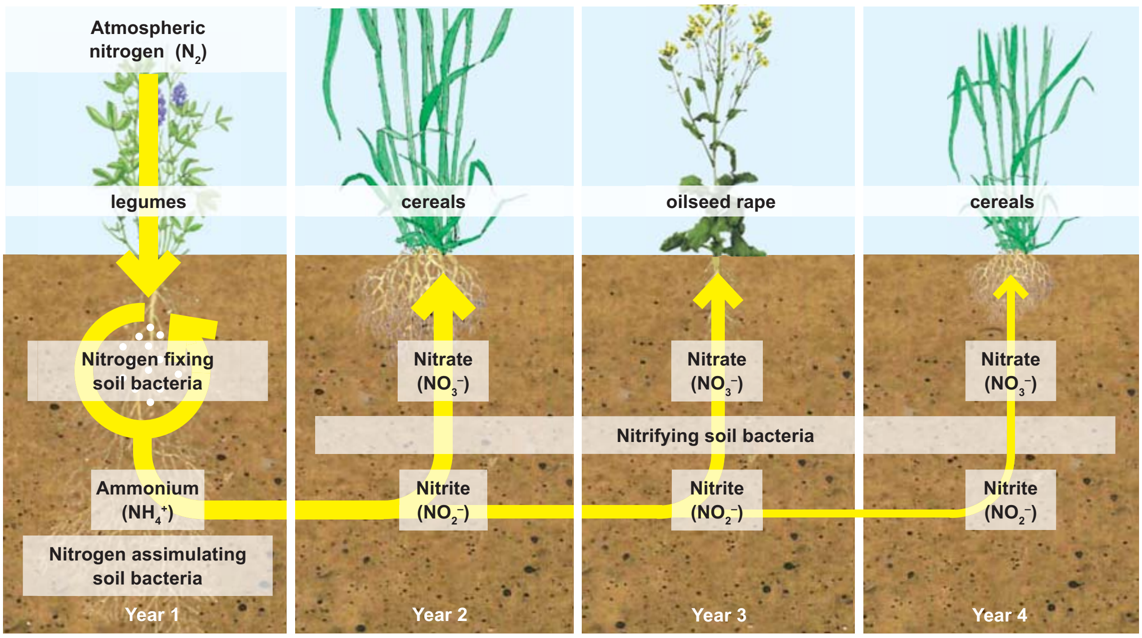
The ecosystem services provided by legumes

A wide range of important ecosystem services are provided by legumes:

- Protection of soil, water and fossil resources.
- Crop rotation benefits.
- Enhanced farmland biodiversity.
- Adaptation to climate change.
- Reduced greenhouse gas emissions.
- Healthy and sustainable foods.
- A wide range of valuable raw materials

Some of these ecosystem services do not depend on the legumes being produced in Germany. This applies for example to benefits arising from the use of legumes in healthy diets. Other ecosystem services are delivered where the legume crops are grown, which currently is mostly outside Germany. This applies in particular to benefits for soils, succeeding crops, and biodiversity.

Figure 2: Role of legumes in the cropping system nitrogen supply



Schematic representation of nitrogen fixation in the combinable cropping part of the rotation without organic or mineral N fertilisation or nitrogen from the soil organic matter pool.

Ecosystemservices of legumes at detail:

Cropping sequence or rotational benefits

Biological nitrogen fixation in the root nodules provides the legume plant with the nitrogen it needs. Residues of legumes crops make this nitrogen available to subsequent crops and, via the organic matter in the crop residues, improve soil fertility generally. Other crops grown after legumes benefit from the well-known rotation or cropping sequence effect. Through this crop sequence effect, legumes play a key role in developing and maintaining soil fertility in some farming systems. As much as 500 kg N/ha/year can be fixed. In France, where legumes are more widely grown than in Germany, it is estimated that nitrogen fixation in legumes could replace about 215,600 t fertiliser nitrogen with an estimated value of about 100 million Euro per year if the area of legumes increased to 7% of the cropped area.[12]

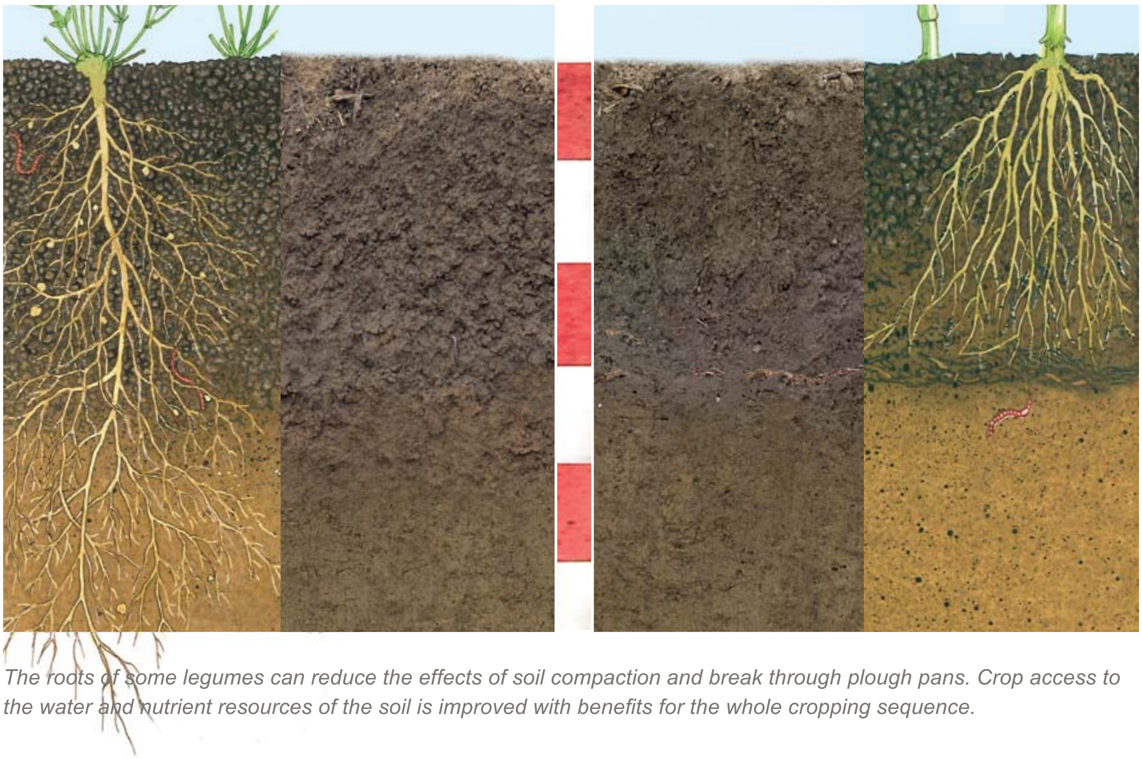
Soil fertility

Many legume species (e.g. alfalfa, red clover, sainfoin, lupine, field beans) are deep-rooted and reduce soil compaction. The perennial forage species in particular have positive effects on the humus balance of the soil. In addition, lupine and some other legumes have special advantages when cropped on light soils.[13] The fine root systems, for example those of the vetches, play a special role in improving the water-holding capacity of soils. In addition to

[12] Cavaillès E, 2009: La relance des légumineuses dans le cadre d'un plan protéine: quels bénéfices environnementaux? Etudes & Document n°15, CGDD, MEEDDM (42 p.), www.developpement-durable.gouv.fr

[13] Deutsche Landwirtschaftsgesellschaft, 1895: Zwischenfruchtanbau auf leichtem Boden, Heft 7., 4. Auflage 1927
Sprengel, C., 1838: Die Lehre von den Urbarmachungen und Grundverbesserungen, Baumgartner Verlag, Leipzig

Figure 3: Tapping soil resources using deep rooted legumes



The roots of some legumes can reduce the effects of soil compaction and break through plough pans. Crop access to the water and nutrient resources of the soil is improved with benefits for the whole cropping sequence.

the direct effect of these roots systems on soil structure, legume crops promote earthworm activity due to the larger crop residue, the shading of soils and the reduced disturbance in the case of perennial crops. In cropping systems using red clover and alfalfa, the earthworm deposits combined with the effect of the fine and deep root system lead to an increase and stabilisation of the medium-sized pores, especially in sandy soils. Wind and water erosion is greatly reduced. This erosion benefit can also be gained using catch crops, undersowing or intercropping. In addition to the general soil protection effects, catch cropping offers additional cropping opportunities on light or drought-prone sites.

Nutrient efficiency

The efficiency of the use of mineral nitrogen in the soil is less than 50% in most cropping systems. This is manifest in the chronic surplus of nitrogen in German agriculture that has remained constant at about 100 kg N/ha. The target for 2011, to reduce this to 60 kg N/ha, has not been met.[14] While the use of phosphorus and potassium has been reduced by about 43% in this period, even though crop yields have risen, the use of nitrogen fertiliser has remained remarkably stable, declining by just 2.3% in the same time period.[15] The poor efficiency of nitrogen use has not only economic consequences, but is also the driving force behind emissions of ammonia to air, emissions of nitrous oxide from soil, and nitrate pollution of

[14] Bundesministerium für Ernährung, Landwirtschaft und Verbraucherschutz, 2012: Statistischer Monatsbericht 04/2012, S. 258 f. Verordnung über die Anwendung von Düngemitteln, Bodenhilfsstoffen, Kultursubstraten und Pflanzenhilfsmitteln nach den Grundsätzen der guten fachlichen Praxis beim Düngen (Düngeverordnung - DüV) in der Fasung vom 27.02.2007, § 6, Abs. 2, 1d

[15] Umweltbundesamt, 2011: Nationale Trendtabellen für die deutsche Berichterstattung atmosphärischer Emissionen seit 1990 (Stand: 15. April 2011), www.umweltbundesamt.de/emissionen/publikationen.htm

Using the soil loosening effects of some legume species, the crop carbon gain can be increased and energy use reduced using direct drilling.

ground and surface waters. However, this low nitrogen use efficiency offers opportunities for significant improvements.

The greater use of legumes in cropping systems could make a significant contribution to reducing nitrogen-related problems. The natural and close connection between biological nitrogen fixation and uptake in the root zone (synlocation) and the subsequent slow release of mineral nitrogen from the residues of the legume plants offers opportunities to design cropping systems around a legume component with the aim of increasing nitrogen use efficiency and reducing these environmental problems.[16] The nitrogen fixed by legumes needs to be considered particularly carefully in regions characterised by intensive animal production or the production biogas from crops (e.g. maize) when making nutrient balances and devising cropping strategies. Deep-rooted legumes such as alfalfa or blue lupine access phosphorus and other nutrients and make these available for the whole cropping system.

Carbon balance

Legumes, particularly the perennial forage legumes, leave a large crop residue in the form of stubble and roots. The production of legumes in general results in a positive carbon balance. Crops such as alfalfa can make a very important contribution to the restoration of degraded soils.

Energy balance

Biological nitrogen fixation is an alternative to synthetic nitrogen fixation. Synthetic nitrogen fixation typically uses natural gas as the energy supply. Nitrogen fertiliser manufacture is energy-demanding (approx. 49 MJ Primary Enengy/kg N).[17] Legume-based cropping systems reduce the use of such energy because: (i) the legume crop itself does not require N fertiliser, (ii) the following crops require less N fertiliser and (iii) the energy required for soil cultivation and pesticide manufacture and application is reduced due to the other benefits. A cropping sequence using legumes once every five years was estimated to reduce the primary energy input into crop production by 14% for a German site.[18]

Mitigation of greenhouse gas (GHG) emissions

Due to the reliance on natural gas in particular, the production of synthetic nitrogen fertiliser results in large CO_2 and N_2O emissions. In addition, nitrogen enrichment of soils increases emissions of N_2O.[19] Reducing the use of synthetic fertiliser using legumes provides opportunities to reduce GHG emissions. In addition, the soil loosening effects of legumes can re-

[16] Arlauskiene A. and Maiksteniene S., 2007: Effect of legume catch crops management on the dynamics of soil mineral nitrogen and nitrate leaching. Permanent and temporary grassland: plant, environment and economy. Proceedings of the 14th Symposium of the European Grassland Federation, Ghent, Belgium, 3-5 September 2007, Pages: 331–334

[17] Patyk, A. and Reinhardt, G.A., 1997: Energie- und Stoffstrombilanzen von Düngemitteln, Friedr. Vieweg & Sohn Verlag, Braunschweig/Wiesbaden

[18] Nemecek, T., von Richthofen, J.-S., Dubois, G., Casta, P., Charles, R., Pahl, H., 2008: Environmental impacts of introducing grain legumes into European crop rotations. European Journal of Agronomy 28:380–393.

[19] Kern, J., Hellebrand, H.-J., Scholz, V., Linke, B., 2010: Assessment of nitrogen fertilization for the CO_2 balance during the production of poplar and rye. In: Renewable and Sustainable Energy Reviews, 14, S. 1453–1460

duce N_2O emissions. A holistic assessment of emissions from cropping sequences shows that the use of legumes reduces these emissions because of the direct and indirect effects of biological nitrogen fixation on CO_2 and N_2O emissions.[20] Greater use of legumes in cropping systems is expected to result in a net reduction of GHG emissions from agricultural systems.[21]

Adaptation to climate change

The combination of deep rooting, increased earthworm activity, and the positive carbon balance results in increased water infiltration and water holding capacity which is particularly beneficial where drought periods are interrupted by heavy rainfall. The deep root system reaches soil water resources not accessed by other crop types. These characteristics help cropping systems adapt to the type of climate change expected in Germany.

Agricultural biodiversity

The introduction of legumes into the cropping system increases the taxonomic range of the crops grown. It also extends the crop cover time and has a positive effect on non-crop flora, insects, and mammals. Some of the characteristics of legume species are very rare in agricultural ecosystems. In particular, the crop cover diversity brought by legumes combined with the effects of legume flowering has benefits for in-field biodiversity. For example, grass/clover swards show the highest occurrence of field birds and hares compared to other crop types.[22]

The co-evolution of legumes and the insects that feed on their flowers results in mutual benefits with insect activity enhancing pollination and seed set.

Legume flowers are an excellent source of food for insects.

With their flowering system that has evolved to facilitate insect pollination, legumes offer opportunities for a wide range of nectar feeding insects. Such opportunities are very valuable where these insects have difficulty finding nectar sources in the agro-ecosystem. With the use of legumes in catch crops, nectar sources are provided in late summer and autumn up until the first frost. This is of great significance for endangered pollinator insects.[23] Apart from addressing the problem of the decline of these insects, this ecosystem service has benefits for food chains that rely on pollinator insects. A positive and interesting direct economic effect arises from honey production supported by some annual and woody perennial legumes.

Healthy and sustainable human diets

Research on the health effect of diet is of increasing interest to the food sector.[24] In this context, legumes have the potential to contribute

[20] Nemecek T, et. al., Fn. 18 or cf. v Richthofen, J.S., Pahl, H., Nemecek, T., 2006: Was Körnerleguminosen in Anbausystemen leisten. RAPS 1/2006:35-39, www.proplant.de/data/2006/2006-01_Raps_vonRichthofen_Koernerleguminosen.pdf

[21] Nemecek et. al., 2008, report the legume-supported rotation emitted 11 % less greenhouse gas emissions than the comparison rotation. Cavaillès, E., 2009: Fn.12

[22] Stein-Bachinger, K., Fuchs, S., Gottwald, F., 2010: Naturschutzfachliche Optimierung des ökologischen Landbaus – „Naturschutzhof Brodowin" . Naturschutz und Biologische Vielfalt 90, 409 S, ISBN 978-3-7843-3990-0
Lang, J. & Godt, J., 2009: Profitiert der Feldhase vom ökologischen Landbau? In: Mayer, J.; Alföldi, T.; Leiber, F.; et al. (Hrsg.): Werte - Wege - Wirkungen: Biolandbau im Spannungsfeld zwischen Ernährungssicherung, Markt und Klimawandel. Beiträge zur 10. Wissenschaftstagung Ökologischer Landbau, Zürich 11. – 13. Februar 2009. Band 1: Boden, Pflanzenbau, Agrartechnik, Umwelt- und Naturschutz, Biolandbau international, Wissensmanagement. Verlag Dr. Köster, Berlin, S. 434–437

[23] UNEP, 2011: Global honey bee colony disorders and other threats to insect pollinators. www.unep.org/dewa/Portals/67/pdf/Global_Bee_Colony_Disorder_and_Threats_insect_pollinators.pdf (besucht 12.12.2011)

[24] BMBF, 2012, Fn. 7

Legumes are not just sources of nutrients in the human diet, other components have important health benefits.

Domestic legumes deliver valuable raw materials (here lupine seeds).

to solutions. The provision of proteins is a key consideration in developing diets. Worldwide, legumes such as beans, soy, lentils, chickpeas, peas and groundnuts are the most important sources of plant protein. In addition, some legumes are characterised by proteins with an amino acid profile that complements that of cereals. These are particularly valuable in animal feeding and in human diets that are low in meat and dairy products.

For human nutrition, legumes have a range of health-enhancing characteristics independent from the provision of protein and carbohydrates. Human and animal-based studies in Germany show that the presence of some lupine components in food reduces total and LDL cholesterol in the blood. These also have benefits for the circulatory system generally, the health of the intestine, and lipid metabolism.[25] Studies of a sub-population in China point to an inverse relationship between the intake of unsweetened and un-fried isoflavin-rich soy-based foods and the risk of type 2 diabetes.[26]

Strategies to support healthy and sustainable eating must encourage a significant reduction in the consumption of animal-based protein.[27] Due to their high protein content, healthenhancing fibre components and the effect of secondary plant compounds, legumes can play a key role in such diets.

Valuable raw materials for a wide range of uses

The material harvested from legume crops has high potential as raw material. Besides oil extraction from soybeans, legumes are mostly used for feed purposes. Legumes are used less in human nutrition but these uses offer high value markets to producers. Apart from food and feed uses, there is further potential in non-food uses in both energy and other supply chains.

[25] Sirtori, C.R., Galli, C., Anderson, J.W., Arnoldi, A., 2009: Nutritional and neutraceutical approaches to dyslipidemia and atherosclerosis prevention: Focus on dietary proteins. Atherosclerosis 203:8
Fechner, A., Schweiggert, U., Hasenkopf, K. & Jahreis, G., 2011: Lupine kernel fiber: metabolic effects in human intervention studies and use as a supplement in wheat bread. In: V.R. Preedy, R.R. Watson, V.B. Patel (Eds.) Flour and breads and their fortification in health and disease prevention, pp. 463-473.

[26] Mueller, N.T., Odegaard, A.O., Gross, M.D., Koh, W.-P., Yu, M.C., Yuan, J.-M., Pereira, M.A., 2011: Soy intake and risk of type 2 diabetes in Chinese Singaporeans. European Journal of Nutrition (DOI 10.1007/s00394-011-0290-4)

[27] Woitowitz, A., 2007: Auswirkungen einer Einschränkung des Verzehrs von Lebensmitteln tierischer Herkunft auf ausgewählte Nachhaltigkeitsindikatoren – dargestellt am Beispiel konventioneller und ökologischer Wirtschaftsweise. Dissertation TUM.
Von Koerber, K., Kretschmer, J., 2000: Zukunftsfähige Ernährung – Gesundheits-, Umwelt-, Wirtschafts- und Sozialverträglichkeit im Lebensmittelbereich. Zeitschrift für Ernährungsökologie 1, 39-46.

3 Legume production and research: Status quo

Both the ecosystem services provided by legumes and the knowledge that support their development are for the most part public goods that cannot be optimally provided by markets without public intervention. Many of the ecosystem services have both regional and global impacts. Research is essential to legume crop productivity and competitiveness with other cash crops. However, their production area has declined in recent years with this decline linked to weak processing and other supply chain infrastructure. This raises the question why legumes play such a small role in German agriculture.

Despite the many advantages for society from their production, legumes remain uncompetitive in the context of current agricultural systems.

- The energy used by legumes to reduce atmospheric nitrogen to reactive nitrogen in the root nodules is provided by the plant through photosynthesis. This physiological cost of biological nitrogen fixation and the comparatively modest efforts in plant breeding mean that the grain yield of pulse crops is lower than that of other crops, notably cereals. While producing legumes brings benefits for society linked to the diversity of cropping, this diversity often increases farm management costs linked to the complexity of the cropping system.

- The marginal role of legumes in German agriculture means that private research and development costs, particularly in crop breeding, are high in relation to the market's capacity to generate returns to breeding. Breeding programmes cost approx. 500,000 Euro per year which is a high cost compared to the returns to breeding possible in this small market. In addition, these legumes are inbred self-pollinators. This means that farmers can save seeds from crops for the next year without rewarding the breeder. As a result, breeders investing in research and development cannot exploit the full benefits of their work in the market. The end result is weak market incentives for research and development supporting private breeding and under-investment in relation to the full public and private benefit potential.

Field bean *(Vicia faba)*

- Weaknesses in market signals are also evident in the development and approval of new plant protection products (pesticides) that are used particularly for legumes. The approval process is costly and this impacts particularly the development of products for minor crops such as legumes.

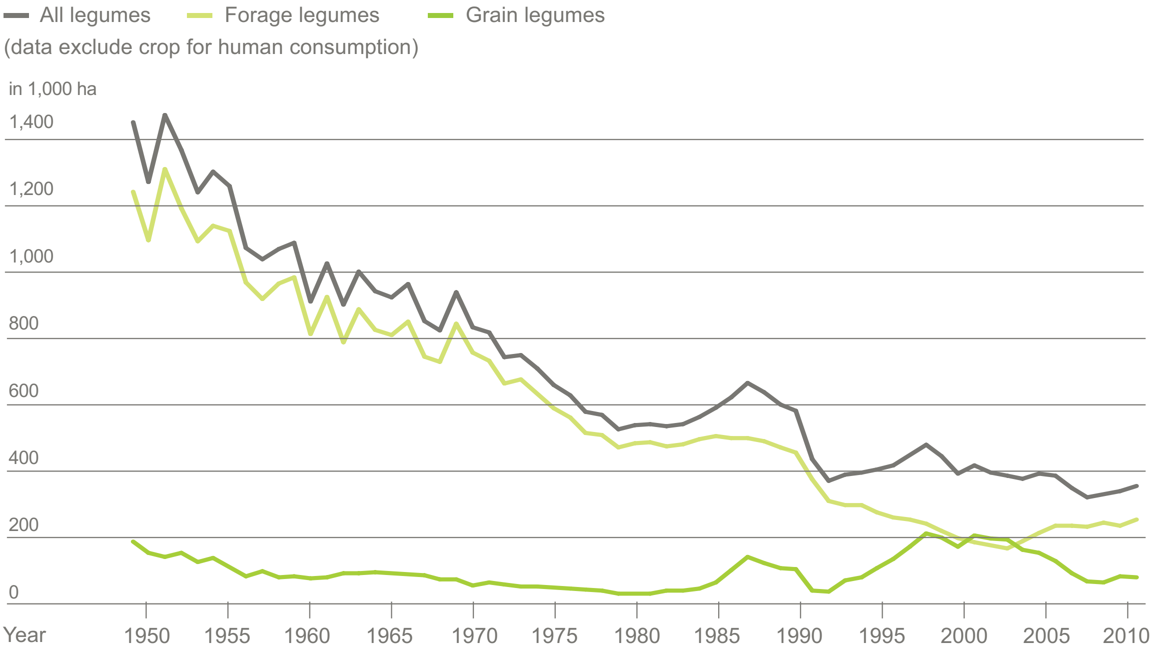
In summary, the development of legume crops is hindered by market failure with the result that the potential benefits of legumes for wider society are not realised. The private costs of development are large in relation to the private benefits with the result that there is under-investment in relation to the full range of public and private benefits achievable. Radical change is required to stop the spiral of decline and to establish a system that rewards mutually supporting public and private benefits. In this, research and development play a very important role in reducing internal costs and in measuring, improving, and realising the external benefits. In addition to supporting conventional technical change, research helps develop mechanisms to internalise external benefits so that the full socio-economic potential of legumes can be better realised.

3.1 Changes in the production area

The yield per hectare of crops have increased significantly in recent years with an annual 2 to 3 % increase in the important field crops.[28] The increase seems to have slowed for some crops recently due to reductions in the use of inputs and increased incidence of extreme weather that lead to strong variation in yields. About half of this growth can be traced to breeding progress and half to improvements in production techniques such as fertilisation, crop protection and engineering advances.

Good markets for food and feed, and in recent years for commodities used in energy markets, have led to a situation where winter wheat,

Figure 4: Changes in the area of legume crops in Germany



Sources: Federal Statistical Office: Lange Reihe der Landwirtschaftsstatistik from 1938 to 1996 for the current Federal area, Fachserie 3 Reihe 3.1.2 (several editions and years) and Genesis-Online Datenbank (Code 41241). Statistisches Jahrbuch der DDR (various annual editions).

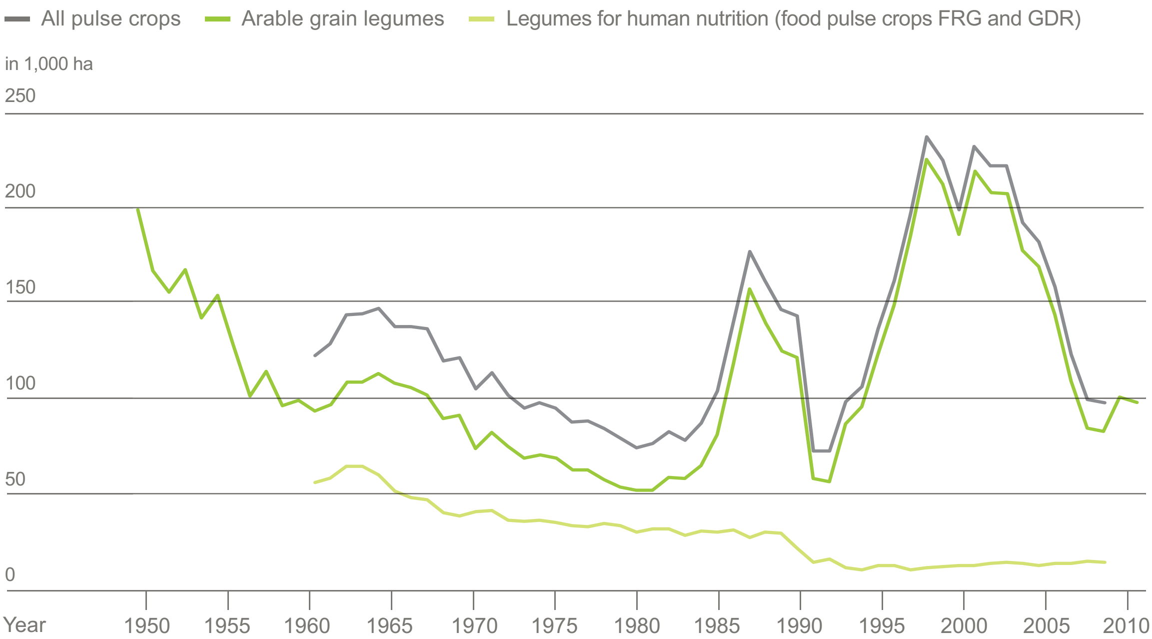
[28] von Witzke, H., Kirschke, D., Lotze-Campen, H., Noleppa, S., 2004: Die gesamtwirtschaftliche Verzinsung der Pflanzenzüchtung in Deutschland – Endbericht. Agripol network for policiy advice, Berlin

maize, winter oilseed rape and winter barley account for 70 % of the cropped area.

The yields of forage and grain legumes have increased, however not at the pace of species that are subject to intensive breeding programmes. Because of the dominance of imported soy in plant protein supplies for livestock feeds, and the conditions set out above, the breeding and further development of home-grown legumes is now confined to a few breeding programmes. The growing of some species for human consumption (e.g. lentils) has been abandoned.

The role of legumes in arable production in Germany is below its potential and production is in long-term decline (Fig. 4). The area grown on arable land has declined from 1.4 million hectares in 1949 to about 0.4 million hectares in 1991. It has remained relatively stable since then. The reduction is largely due to the decline in forage legumes. In 1949, 1.2 million hectares of forage legumes were grown. By 1991, this area had declined to 0.3 million hectares. This decrease was associated with an increase in the area of silage maize. The area of grain legumes declined 50 % up until 1980. Since then, the area of grain legumes has fluctuated greatly (Fig. 5) and amounted to ca 225,000 ha in 1998. The area has declined further and was about 95,000 ha in 2011. This represents just 0.9 % of the arable area. Organic farming accounts for 25 to 30 % of the grain legume area. The area of grain legumes on organically farmed land was about 6 % in Germany in 2010.

Figure 5: Changes in the pulse crop area in Germany



Sources: Federal Statistical Office: Lange Reihe der Landwirtschaftsstatistik from 1938 to 1996 for the current Federal area, Fachserie 3 Reihe 3.1.2 (several editions and years), Genesis-Online Datenbank (Code 41241) and personal communication at 01.09.2011. Statistisches Jahrbuch der DDR (various annual editions).

The area of forage legumes on organic farms is higher at 36 % of the organically farmed area in 2010.[29]

The area of soybeans grown for animal feed in organic farming systems and for human consumption has grown significantly in recent years in Germany in regions with suitable climate, but from a low base. It reached about 5,000 ha in 2011. The production of legumes in Europe is greatly influenced by agricultural policy instruments.[30] The GATT/WTO negotiations after the Second World War allowed duty-free imports of oilseed products, including soy. Against this, EU compensation payments for the production of oil and protein crops were higher that those for cereals through the 1990s (Fig. 6). At the same time, the introduction of GMO soybean cultivars and the expansion of the world soy area were drivers of a considerable increase in the global soy production. This expansion is at least partly responsible for increased land-use change (e.g. deforestation) in production regions of South America.

European-grown grain legumes compete with low-cost soybeans and soybean meal imports from North and South America. The use of soybean meal in Germany rose to about 5 million tonnes in 2007 (Fig. 7). Since 2007, the use of soy meal for animal feed has stabilised at about 4.5 million tonnes and the net import of soybeans and soybean products seems to have stabilised.

Figure 6: Changes in the EU support payments

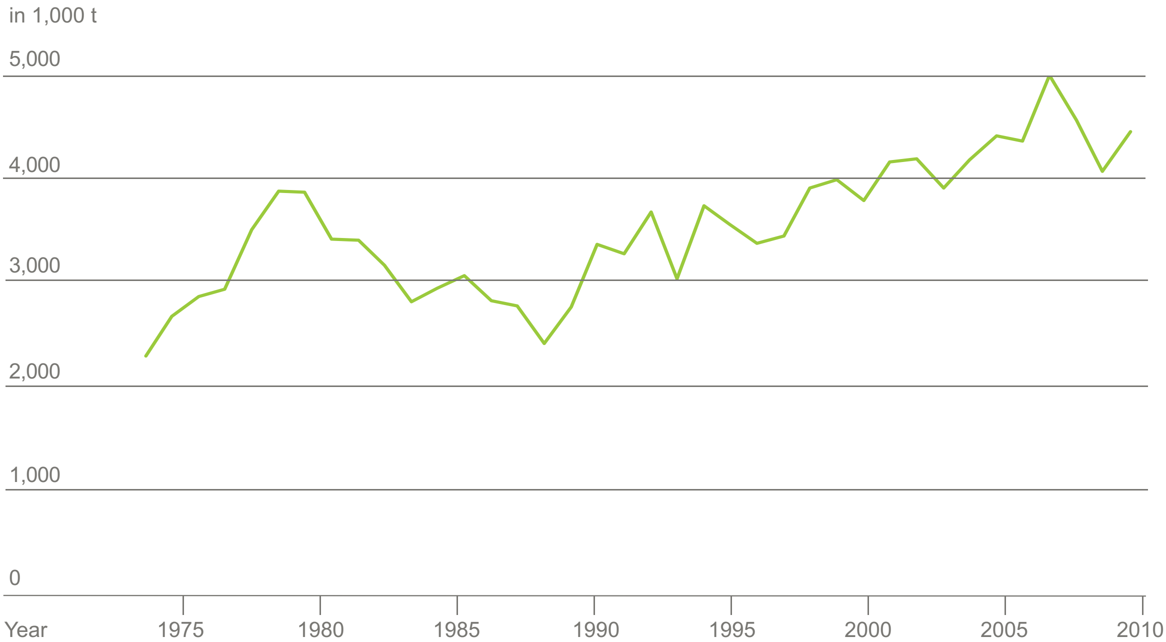
Source: Eurostat, vTI-Marktanalyse, 2011
Note: The compensation for oilseeds applies to grain legumes.

[29] BÖLW, 2012: Zahlen, Daten, Fakten: Die Bio-Branche 2012
[30] Cf. for the politics in the 1990s e.g. AID, ZMP (Hrsg.) 1997: Agrarmarktordnungen in der Europäischen Union und Agrarmärkte in Deutschland, Kap. B, C, F, G,
CAP Monitor 2002: Oilseeds and protein crops, Agra Europe (London) Ltd., 01.11.2002

This change in the use of soy meal over the last 40 years reflects changes in animal production in Germany. Since the early 1970s, the number of pigs has increased by about 40 % and poultry production has grown by 300 %. During the same period, the cattle population has declined by about 5 %. This structural change in the livestock sector increased the demand for protein from pulses.[31]

Under the last CAP reform, agricultural support instruments to promote directly and indirectly the use of legume on up to 10 % of the arable area were available for use in Germany. These measures have been used in only a few Federal States. Meanwhile, a number of measures proposed for reform of the Common Agricultural Policy from 2014 are relevant to the production of legumes. Some sector and NGO groups argue for a requirement to grow legumes and the consideration of legume crops as areas of high ecological value under the 'greening' proposals.

Figure 7: Changes in the use of soy meal in animal feeds in Germany



Source: Eurostat, vTI-Marktanalyse, 2011 and BMELV, 2012 Note: The data for calendar years relate to the financial years. For example, for the calendar year 2005, the data for the financial year 2005/2006 are provided.

[31] ISTA Mielke GmbH, 2011: Oil World Annual 2011, Vol. 1 - up to 2010/11, Global Analysis of all Major Oilseeds, Oils & Oilmeals – Supply, Demand and Price Outlook, Hamburg
UN comtrade 2012: Datenbankabfrage Sojabohnen, SITC / Rev. 2, abgerufen am 16.03.2012, http://comtrade.un.org/db/dqBasicQuery.aspx

3.2 Past and current research

A wide range of research projects on protein crops have been conducted in Germany over the last 25 years. These have delivered a wide range of results on specific and separate research questions and they have contributed to slowing the decline in production. While the decline in production was due mainly to market and policy forces, the research effort was not designed to support crop development. There are several reasons for this. Many of the research projects were individually focused on specific isolated scientific questions and conducted with little reference to the wider economic realities. The normal project and programme timeframe is not long enough to effectively address some long-term research challenges, notably in plant breeding.

Between 1986 and 2012, 136 research projects on protein plants received public funds from the German Federal Ministry of Food, Agriculture and Consumer Protection (BMELV). Of these, 93 addressed crop production questions, 18 addressed animal production issues, and 25 were connected to measures to support the material use of biomass. Over time there was increasing emphasis on collaborative projects that included farm and practice-based partners. These looked at cross-disciplinary research themes, mainly relevant to grain legumes such as beans, peas and lupines.

Funds from other federal sources were used to support a range of projects.[32] Three of these incorporated partners are from the relevant supply chains, “PlantsProFood” (Blue Lupine), “LeguAN” (Field beans, grain peas) and “Extending the production of soy in Germany”. The other projects addressed key questions regarding crop production, crop breeding, and animal nutrition. Two collaborative projects on soil fertility and a project started in 2012 on animal nutrition take multi-disciplinary approaches with a strong focus on practical relevance and knowledge transfer. These and further grant-funded research projects addressing nutritional/physiological issues are time-limited typically running over 2 to 3 years. Economic analysis and the analysis of agricultural policy measures was the subject of only a few projects.

[32] A list from 05/2012 with 27 ongoing and recently completed projects is available at http://www.dafa.de/de/startseite/fachforen/leguminosen.html

***Soybean** (Glycine max)*

***White lupine** (Lupinus albus)*

***Blue lupine** (Lupinus angustifolius)*

***Yellow lupine** (Lupinus luteus)*

Complementing contract research projects, core-funded research is conducted on faba beans, Andean lupines, blue lupines, yellow lupines, white lupines, and soybeans at the Julius Kühn-Institut (the Federal Research Centre for Cultivated Plants). Most of this is focused on plant breeding, with work done also on the development of early maturing soybean crops. Research relevant to the production of legume crops is conducted at the Johann Heinrich von Thünen Institute (The Federal Research Institute for Rural Areas, Forestry and Fisheries). This includes research on grain legumes (peas, faba beans, blue and white lupines) with emphasis on inter-cropping and on assessing the feeding value for organic farming, including the calibration of near-infrared spectrometry (NIRS) for this purpose.

At the Federal State level, the Bavarian action programme for home-grown protein crops and the associated protein strategy of the Bavarian Agency for Agriculture has funded about 30 projects. These are mostly 1 to 2 year projects on soybeans, alfalfa and other legume crops with questions addressing economics, crop production and animal nutrition.

Along with these research activities, Federal States test varieties for yield and qualitative parameters. The industry group “Union for supporting oil and protein crops” (UFOP) has conducted about 25 research projects and has delivered support to advisors and other measures relevant to the development of legume crops.

***Alfalfa** (Medicago sativa)*

***Red clover** (Trifolium pratense)*

***White clover** (Trifolium repens)*

***Bird’s-foot trefoil** (Lotus corniculatus)*

A range of research activities in Germany are supported at the European level under Framework Programmes 6 and 7 (e.g. LegSil, Leggraze, EU-COST 841, EU-COST 852, Capacities, LegumePLUS). In 2012, three relevant EU projects involve German partners. These include two projects focused on processing (gluten-free baking products, and research on meat substitutes) and the EU project titled "Legume-supported cropping systems for Europe" (Legume Futures). Legume Futures covers all legume crops and forages and is focused on developing new cropping systems for European regions. A preliminary assessment from Legume Futures of on-going research in Europe indicates that this area is characterised by fragmentation with diverse activities at the national and regional level. Much of this research is funded under programmes targeted at organic farming.

Agriculture and food research in Framework Programme 6 which ran from 2002 to 2006 was focused on food quality and other consumer-related themes. This included a large Integrated Project (IP) called the "Grain Legumes Integrated Project" (GLIP) which received funds of 14.4 million Euros from the European Commission. GLIP was focused on genomics. The project contributed significantly to the sequencing of the model legume Medicago truncatula (Barrel Medic) focused in particular on sequencing relevant to environmental and seed quality traits. The GLIP interacted with a wide range of private sector interests using the Grain Legumes Technology Platform (GL-TTP). In addition, the Paris-based "European Association for Grain Legumes Research" (AEP) provided means of networking all researchers in Europe involved in the development of grain legumes.

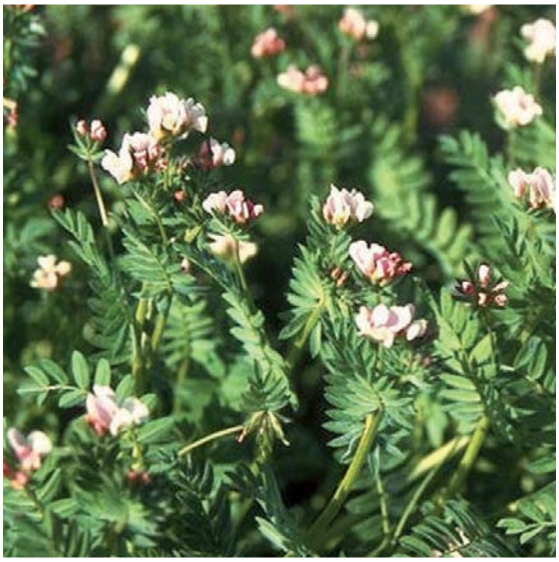
The GLIP project ended in 2008. The GL-TTP closed one year later and the AEP was disbanded in 2010. Also closed then was the internet-based service that was established by the GL-Pro project under FP5 (European Extension Network for the Development of Grain Legume Production in the EU; 2003 – 2006).

In summary, it is clear that the EU has invested significantly in research relevant to the development of legume crops. However, in many instances, the impacts of the results and infrastructure developed did not extend significantly beyond the projects themselves. A sustainable impulse for the development of legume crops

***Vetch** (Vicia sativa)*

***Lentil** (Lens sativa)*

***Sainfoin** (Onobrychis viciifolia)*



***Serradella** (Ornithopus sativus)*

4 Research priorities

Six strategic requirements and outcomes are particularly important: an increased investment in pre-breeding and breeding, the realisation of crop production potential, the valuation of ecosystem services for farmers and society, the exploitation of regional opportunities to develop supply chains, the removal of barriers to the realisation of the value of German-grown legumes as animal feed, and the development of nutritional concepts to realise the health benefits of legumes in the human diet. A strategic research programme aiming to achieve these goals should address specific interests along the supply chains for food, feed and non-food and foster broad interaction with the overarching research efforts aimed at increasing crop productivity, resource protection and socio-economics.

The account of the current situation in the production and use of legumes shows that significant action is required on several levels.

What are the strategically important challenges and opportunities that must be addressed by research to optimally support the goal of making the provision of ecosystem services from legumes more competitive? In the view of the DAFA, this research must support six strategic science and technology outcomes.

Strategic science and technology outcomes

Increased investment in pre-breeding
A sustainable extension of pre-breeding activity will provide the strategic foundation for the breeding of improved cultivars of important legume species supporting the improved productivity and potential for ecosystem services provision.

Exploitation of production potential
The genetic potential of home-grown legumes is realised by optimized crop production systems. This requires farm-level improvements in crop cultivation and protection.

Valuation of ecosystem services to support farm business decision-making
A valuation of the ecosystem performance of legumes in relation to farm business goals would support farm business decision-making. The identification, valuation and application of incentives would result in an increased cropping of legumes.

Exploitation of regional opportunities to develop supply chains
By activating regional potential, from crop production and harvesting techniques through to processing, the development of supply chains and the marketability of products will be supported.

Removal of barriers to the use of legumes in livestock feeds
A continuous supply of raw materials in sufficient quantities and quality leads to a greater use of home-grown pulse legumes in animal feed. The extension of the uses of feed grain legumes through their development, assessment and use as a source of pure protein and green meal as well as the technical improvement of forage harvesting and storage improve their economic competitiveness and increase the production area.

Implementation of dietary concepts to exploit the potential health benefits
Through the development of concepts harnessing legumes or functional components of legumes for the development of diets, public health benefits are supported.

Research needs

Achieving the science and technology outcomes presented above requires collaboration between relevant groups in society: from science, business and civil society. A strategic approach to the design of complementary activities is required. To facilitate a targeted strategy, the DAFA identified research needs in relation to the development of three value-chain areas that are key to harnessing the potential of legumes in agriculture and food in the future:

- healthy and sustainable diets;
- sustainable protein supplies for animal feeding; and
- non-food uses.

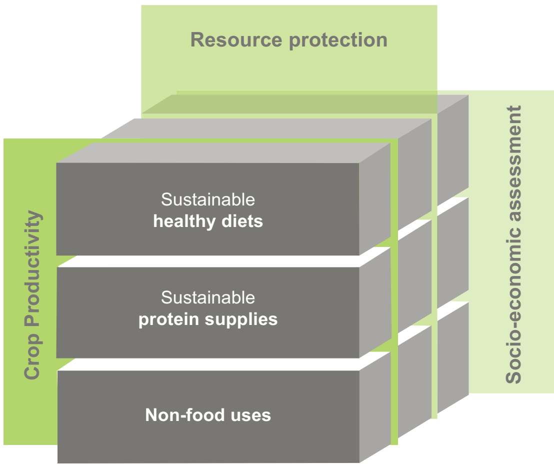
Each of these three supply chains represents a bundle of environmental, economic and societal opportunities that require specific research or other investments.

Complementing and supporting these, the DAFA has identified three research themes that underpin the functionality of these value chains and therefore have a cross-cutting character:

- plant productivity;
- resource protection; and
- socio-economics.

The inter-connection between the supply chain research activities and the cross-cutting research themes that support them form a research matrix (Fig. 8). This interaction should be kept in mind in considering each of the research needs. These six research areas are described here in detail.

Figure 8: The legumes research matrix – three cross-cutting research themes underpinning the development of supply chain orientated research activities.



4.1 Healthy sustainable human nutrition

Our current knowledge indicates that legumes could provide raw materials for foods which society will appreciate as having a regional character, as sustainable, traceable, plant-based source of proteins, and of high value in terms of health and well-being.

With their high protein content and good amino-acid profile, legumes are a valuable source of protein complementing cereal proteins and offering an alternative to meat protein. Apart from the provision of important nutritional components, legumes have important health promoting effects. The fibre in lupine and soy seeds have an extraordinary potential to bind bile acids which contributes to the regulation of cholesterol levels in patients with hypercholesterolemia. There are also the sensory properties of these fractions which allow their use in a wide range of foods.

Data are required to support the exploitation of the nutritional as well as the food technical characteristics of legume raw materials and their assessment in relation to consumers' needs. There are gaps in our knowledge regarding the suitability of legume raw materials for the production of products designed to meet contemporary consumer demands. These gaps should be filled with targeted research activity set out here.

a. Nutritional effects of foods containing legume products

Nutritional and physiological research has shown that the protein and fibre fractions of legume seeds have positive health effects.[33]

Positive nutritional effects can be delivered using innovative products.

Other positive effects can be attributed to secondary plant metabolites.[34]

- The nutritional effects of legume components or whole seeds require investigation through studies on humans. Such studies would quantify and validate these effects.
- Similar questions arise in relation to the interaction between components in the development of food products that use a wide range of ingredients. The effect of the material matrix structuring these food products on the bio-availability and thus the effect of components is not well understood.
- The role of processing, storage and preparation is also insufficiently researched. For example there is evidence that freezing and thawing during the storage of bakery products nearly eliminates the biofunctional

[33] Belski, R., Mori, T.A., Puddey, I.B., Sipsas, S., Woodman, R.J., Ackland, T.R., Beilin, L.J., Dove, E.R., Carlyon, N.B., Jayaseena, V., Hodgson, J.M., 2011: Effects of lupin-enriched foods on body composition and cardiovascular disease risk factors: a 12-month randomized controlled weight loss trial. International Journal of Obesity, 35, 810 – 819.
Schweiggert, U., Lanig, K., Eisner, P. and Hasenkopf, K., 2009: Entwicklung ballaststoffangereicherter Backwaren mit Cholesterin senken dem Potential. Symposium of Functional Food. Kiel.
Fechner, A., Schweiggert, U., Hasenkopf, K. and Jahreis, G., 2011: Lupine kernel fiber: Metabolic effects in human intervention studies and use as a supplement in wheat bread. Flour and breads and their fortification in health and disease prevention. Victor, R. P., Ronald Ross, W. and Vinood, B. P. San Diego, Academic Press: 463-473.

[34] Rochfort, S., Panozzo, J., 2007: Phytochemicals for health – the role of pulses. Journal of Agricultural and Food Chemistry 55:7981–7994.

Low-fat protein-based food ingredients can be manufactured from lupine isolates.

effects of yeast in the product.[35] The effect of process parameters such as pH, salt content, pressure and temperature on the functionality of food components requires investigation. There is generally a great need for research in this area conducted in collaboration with the food industry to identify how the nutritional and other physiological effects of legumes can be fully exploited in human diets.

b. Quality and attractiveness of legume-containing foods

Due to their high protein content and the structure of the fibre components, grain legumes provide raw material of interest for the production of protein and fibre preparations for use in food manufacturing. Such preparations, which can be used across the food industry, have the advantage of being alternatives to eggs, milk, and gelatine. Only by offering a wide selection of foods that meet the expectations of consumers with respect to organoleptic properties can legumes contribute to a sustained change in consumption patterns. These preparations must meet very high technical and sensory requirements. Protein preparations need to be able to stabilise emulsions in drinks or in products such as mayonnaise, to contribute to jellies and foams in confectionary, to bind water or oil in solid foods such as sausages or spreads, or to regulate the moisture content of bakery products. Legume-based preparations may be required to replace oils and fats. These properties are not fully developed in existing legume preparations which explains their limited use and availability. To successfully extend the use of these preparations in the food industry, research to improve organoleptic properties is required.

- In close cooperation with plant breeding, production and processing, raw materials that have functional protein fractions with few undesirable taste effects need to be identified. The latter is particularly important for the development of neutral-tasting functional ingredients incorporated into various foods without changing taste or other sensory characteristics.

- Research collaborations between research organisations and food manufacturers are required to develop procedures and processes to gain highly functional products from these raw materials. Emulsifying properties, foam forming structures and the properties required to substitute fats require consideration.

[35] Lan-Pidhainy, X., Brummer, Y., Tosh, S.M., Wolever, T.M., Wood, P.J., 2007: Reducing beta-glucan solubility in oat bran muffins by freeze-thaw treatment attenuates its hypoglycemic effect. Cereal Chemistry, 84, 512-517.

4.2 Sustainable protein sources for animal feeds

The variation in feed properties found across the legumes, as determined by species, cultivar, origin and the location of cultivation, is a barrier to increasing the inclusion of home-grown legumes in animal feeds. The development of quality assessment procedures calibrated by experiments on animals could be helpful in addressing this. Technical approaches to processing could be optimised from a cost-benefit viewpoint. Applications in aquaculture and pet food can be developed. More than other feed components, grain legumes are characterised by so-called secondary metabolites. Some of these components have, in high concentrations, adverse effects on animal health and performance, especially in pigs and poultry. These components are therefore called anti-nutritional substances (ANS). In some modern conventionally-bred grain legumes, the concentration of anti-nutrition substances has been reduced so that it is possible to have high inclusion rates without adverse effects on performance. These secondary metabolites may also have useful feed properties. For example condensed phenolic compounds are known to suppress gastro-intestinal parasites in ruminants. Investigations of such effects in other animals should be performed, not least to reduce the medical costs in animal production.

In ruminant feeding, in addition to providing protein and energy, forage legumes play a special role arising from their influence on feed intake and their structural properties. In addition to optimising their supply, research can examine how feed value can be improved through forage conservation techniques.

Grain legumes can be an important component of feed for pigs.

a. Valuation of feed ingredients

The characterisation of the feed value of all relevant legume species and their varieties using standardised innovative laboratory-based techniques and animal experiments should be developed. The goal is to provide reliable and authoritative data that can be used in feed formulation.

- Comprehensive chemical characterisation of feed ingredients is essential for optimising the inclusion of legumes in concentrate feeds and for the optimal use of those feeds in livestock production systems. Gaps in the data need to be filled and existing data need to be validated using additional tests.

- Standardised digestibility testing with respect to the energy provided by forage legumes needs to be conducted in all main farm animal species. Further questions relate to synergies between forage components as

Fresh or dried alfalfa and red clover are sources of high quality protein for cattle.

The processing of grain legumes and their mixing plays an important role in optimising use in animal feeds.

well as the synergistic effects of secondary compounds. All technical processes that could influence the value of components in feed, for example starch, need to be subject to cost-benefit analyses with respect to different animal species and age groups.

- Strategies to use newly developed protein valuation systems need to be developed to further the optimal use of protein fractions, for example through more precise combinations of protein-rich components complemented by amino acids.

- Optimal harvesting and, where relevant, grazing systems for the main forage legumes need to be developed. Their relevance to non-food uses should be considered.

- Practical means of the estimation of grain legume quality by farmers, traders and advisors considering the practices and circumstances under which grain legumes are developed, traded and processed need to be developed.

b. Processing technology to optimise value

The harvesting and treatment of forage legumes and the subsequent processes have a great influence on the efficient use of forage legumes as feed components. Conservation and, where used, chemical and hydrothermal treatments are also important. These processes used in forage and concentrate feed manufacture need to be optimised and subject to cost-benefit analyses in close collaboration with the feed manufacturers. These analyses need to focus on efficiency, the preservation and improvement of feeding value in the context of a fully functioning processing chain.

The perennial forage legumes raise specific questions. They have great potential for resource protection but, compared to grain legumes, present the feed industry with particular processing challenges. This has contributed to the decline in their use. To improve the competitiveness of forage legumes (alfalfa, red clover, other clovers, vetches and sainfoin) in the feed industry, research is required on their cost-effective use of in providing protein isolates and options for technical improvements in harvesting and conservation need to be examined.

c. Additional value chains

To increase the use of legume raw materials (in particular protein concentrates and isolates) in pet foods and aquaculture, gaps in our knowledge relating to nutritional and physiological characteristics of specific raw materials and the secondary compounds they contain need to be filled. Innovation in processing to increase digestibility needs research support.

4.3 Non-food uses

As raw materials, legume seeds and other plant parts contrast with the major agricultural crops, particularly cereals, in some special respects. This arises from the combination of high protein content, secondary plant compounds, carbohydrates that contrast with those of cereals, and a fibre fraction with some special properties. This range of constituents, particularly the combination of secondary compounds and macro-nutrients, opens up opportunities for combining food and non-food uses in interconnected and cascading supply chains. This is particularly relevant to contemporary challenges; competition for land used for food and feed production must be avoided.

Legume crop material can be used for energy with the residue of the energy conversion process use as fertiliser. This offers a technology bridging function to the expansion in the production of legumes, particularly in regions where markets are under-developed. However, the potential of legumes extends well beyond such energy uses. In parallel food, feed and bioenergy systems, co-products not needed or suitable for food, feed or material uses (e.g. chemical feedstocks) can be used for biogas production with recycling of nutrients (e.g. nitrogen, phosphorus and potassium) in digestate. Food and feed uses focused on the protein and digestible carbohydrate factions complement the extraction of secondary plant compounds (e.g. phytopharmaceuticals) thus supporting two major applications simultaneously. The development of parallel and cascading food and non-food uses increases the efficiency of land use and opens up opportunities for innovation.

Legumes for non-food uses include grain and forage legumes, legume mixtures, legumes as catch and nurse crops, and by-products from legume processing. The robinia tree (Robinia pseudoacacia) has potential to economically deliver raw materials on marginal land. These individual opportunities have not been fully explored in practice, and knowledge of impacts on resource cycles is lacking. The environmental impact of legume-based catch-cropping in comparison to that of other green manure crops is the subject of controversial debate. These considerations give rise to the research needs set out here.

The different components of lupine seed: the foundation of a wide range of uses.

Robinia *(Robinia pseudoacacia)*

a. Optimising the use of land

Processes to increase the efficiency of legume production and processing require development.

The use of legumes such as robinia as short-rotation coppice or grass-clover pastures on marginal forestry or infertile or otherwise marginal agricultural land requires research. The harvesting of woody legumes, catch and nurse crops present particular technical challenges arising from the high volume of material with high moisture contents. These challenges relate to cutting and comminution technology, innovative post-harvest logistics concepts for storage and transport, and processes up to the final energy or material uses. On the basis of pilot plants, regional crop centres or on-farm demonstration, production systems and supply chains can be assessed from crop establishment up to the use of by-products.

b. Identifying potential raw material uses

The screening of legume crops and their by-products is required in order to identify components that are potentially valuable to open up innovation opportunities. These investigations require support regarding insights into and consideration of the processing requirements and economic viability.

The composition of legumes not only has positive nutritional or physiological implications in food production. The secondary plant compounds have potential in non-food applications, particularly in the pharmaceutical sector.

In addition to isoflavins that have a high antioxidative potential (for use in preventing heart and circulatory diseases and atherosclerosis), legumes are rich in phenolic compounds that have similar pharmaceutical properties. These substances and their sites and modes of action in the human body require research in the development of plant-based pharmaceuticals.

In addition to phenolic compounds, legumes have other substances such as oligosaccharides, alkaloids and saponines that can have positive effects on health. The first laboratory investigations show that these can reduce blood pressure and inflammation. The evidence in this area is fragmented and further research is required to support product development.

In order to identify and develop pharmaceutical uses of legumes, more extensive pharmaceutical research (pharmacodynamics, pharmacokinetics, clinical trials) is required to define the most promising secondary metabolites. Breeding research that may open up opportunities to develop varieties with improved profiles or yields of these secondary materials is necessary.

4.4 Crop productivity

A wide range of legume crop species suited to different soil and climatic conditions are available to support sustainable farming systems. These include beans, grain peas, lupines, soybeans, as well as alfalfa, clover and vetch species as forage legumes. The range of site conditions that these species are suited to provides an opportunity to develop cropping systems matched specifically to local conditions and thereby providing site-specific combinations of crop production and ecosystem service provision. With this goal, research to support the development of cropping systems that exploit, maintain and enhance the diversity of legume crops is of strategic significance.

To increase the use of legumes drawing on this diversity and flexibility, healthy and productive crops are required to reliably provide adequate quantities and qualities of raw materials and to support economically viable farm businesses. These preconditions for the development of sustainable cropping systems are not always fulfilled by current legume varieties and production systems. The result is that legume crops often present higher economic risks to the farmer compared to the crops that are widely grown. As a consequence of years of decline in legume production, there is also a gap between the know-how currently available on farms and that required for the development and implementation of efficient legume-supported production systems.

To address these constraints, research is required in two areas:

a. Genetic improvement for yield and quality

The economic production and use of legumes in Germany is only possible with high-performance varieties that are well suited to local conditions and that contribute effectively to regional cropping systems. The availability of such varieties increases the attractiveness of the use of legumes to support cropping systems in general. To achieve these objectives, plant breeding is a key technology. In particular, research is needed for the improvement of faba beans, grain peas, lupines, soy, clover and alfalfa. This research requires collaboration between the plant genetics and plant breeding research communities, the plant breeding and seed sector, and companies involved in crop processing and utilisation. Four areas are identified for such collaborations.

Productivity gains from breeding are an important foundation for the cultivation and use of legumes.

Production improvements can address many of the obstacles to exploiting the potential of legumes.

- Raising yield potential, for example using heterosis, improving resistance to pod shatter, development and improvement of winter forms and development of plant breeding techniques and tools that accelerate breeding progress.

- Yield stabilisation by improving resistance to diseases and pests, increasing tolerance to stress and improving traits such as resistance to lodging, threshing characteristics and synchrony of maturity.

- Optimising crop quality with respect to secondary plant compounds.

- Accessing novel plant genetic resources (PGR). This plays a central role in the genetic improvement of legumes, including soy, for production in Germany. The use of germplasm with useful traits but which is otherwise agronomically unsuited in breeding programmes is a time-demanding process with high risks of failure. The economic risk of introducing such germplasm into breeding programmes and developing elite material from it is high. These costs are very difficult to recover in private breeding programmes. Because of this, public investment in pre-breeding is required that uses advanced breeding tools to bridge the genetic gap between novel germplasm and elite commercial breeding material. Using pre-breeding to introduce new genetic material into breeding programmes is key to sustaining and developing the use of legumes in German and European farming.

b. Improving crop production
Further improvement of crop production techniques is required to meet the needs of the various species, uses, types of production and regional conditions.

- Research is needed to optimise the role of legumes in crop rotations specific to particular farming systems considering their effects on subsequent crops, on the biological, physical and chemical components of soil fertility, and plant health effects. Concepts for conserving biologically fixed nitrogen and efficiently using this nitrogen in cropping systems need development.

- There are interactions between legume components in the crop rotation or cropping sequence that are determined by phytopathological factors. Research into these interactions that result in 'legume sickness' is required and such research is only possible within the framework of a long-term commitment to field crop research.

- The agronomic suitability of crop species and mixed-crop systems requires investigation in relation to technical requirements of different uses and regional production conditions. In this context, the relevant traits include response to sowing time, early plant development characteristics, crop establishment, irrigation needs, weed suppression, flowering time, length of grain filling phase, ripening and threshing characteristics.

- Optimal crop protection requires models and thresholds to be developed with regard to weeds, pests and diseases for each crop species. These need to be based on models of the interactions of these organisms and crops. Weeds, pests and diseases affecting yield and quality must be identified for each crop and assessed in relation to their prevalence in crops. The aim is to develop sustainable and effective crop protection measures for legume crops in both conventional and organic production systems. This includes research to support the registration of plant protection products for use in legume crops.

4.5 Resource protection

The production of legumes has many agronomic advantages such as the reduction of the use of synthetic nitrogen fertiliser, benefits for soil fertility, and other positive effects on subsequent crops that can be regarded as ecosystem services. There are further positive environmental effects. These include reductions in greenhouse gas emissions due to the reduction in nitrogen fertilisation, reduced soil tillage as well as the increased agro-biodiversity which in turn support ecosystem services.

The quantification, valuation and realisation of the provision of ecosystem services associated with legume crop production are underdeveloped. Information about the value of eco-

The soil, the foundation of all cropping systems, benefits in many ways from legumes.

The expansion of legume production will increase the diversity of crops and increase the stability of cropping systems.

system services is still too narrow and, as a result, the ecosystem services arising from innovative legume-supported cropping systems in the food, feed and non-food areas are not fully acknowledged. This leads to the need for research on the relevant processes, their valuation, and practical solutions assessed using life-cycle assessment approaches.

a. Soil and water

The potential contribution of legume production to the protection of soil resources and water are more extensive than has been recognised until now. There is a lack of data on the effect of legume crop production on the development of the humus fraction of soils and soil physical characteristics. Through elucidation and quantification of these processes, such as erosion protection and improvement of soil fertility and site productivity, positive effects for the farmer become more tangible. Moreover, such processes can be analysed with respect to provision of ecosystem services related to business risks and regulating the hydrological balance.

b. Biodiversity in agricultural landscapes

The effects of a systematic inclusion of legumes in cropping systems on agro-biodiversity require more detailed investigation. To provide a comprehensive assessment of these effects, quantitative research at the field and farm level needs to be combined with model-based investigations at the landscape and other macro levels. Findings from such research can then be incorporated into strategies to capture the socio-economic value of these ecosystem services.

c. Climate change adaptation and mitigation

Climate change in Germany is predicted to result in more extreme weather events such as torrential rain and prolonged droughts. The role of legumes in adapting cropping systems to such change requires exploration. Comprehensive evaluation of the potential of legume-supported cropping systems in reducing greenhouse gas emissions is lacking. This is a gap in the comprehensive assessment of ecosystem services.

The data needed to address the potential role of agriculture in mitigating greenhouse gas emissions are not complete and need to be extended with relevant impact models to enable the holistic assessment of the potential contribution of legume-supported cropping systems.

Assessments of the performance of legumes often only take account of the visible products, however important hidden benefits and ecosystem services arise from their cultivation.

4.6 Socio-economics

Agricultural research on legume production and use should be supported by appropriate socio-economic investigations.

a. Farming system cost-benefit assessments

Support of farm businesses must be enhanced and regional infrastructural deficiencies in the marketing and utilisation of grain legumes must be reduced. In supporting the development of value chains, the market circumstances governing the value of legumes for various markets and processes need investigation complementing development of production processes. Economic assessments must extend beyond individual crops to the longer-term economic performance of the whole farm in relation to market-based economic drivers. Crop rotations with and without legumes differ not only in terms of direct costs and overheads. Such holistic assessments need to consider whole-farm effects, taking into account effects on total labour and machinery costs as affected by the use of available machinery and labour capacity, machine configuration, depreciation and amortization. Economic assessments that take the effect of legumes on subsequent crops into account need to be developed and implemented. For this, a system-oriented farm-level economic assessment approach needs to be developed that considers all relevant costs and benefits (including within the farm business) and allocates these appropriately to the legume proportion of the cropping system. To implement such complex valuation systems, the development of decision support software to assess production and marketing strategies should be considered.

Economic benefits for farm businesses are a prerequisite for the increased cultivation of legumes.

b. Economic assessment of public benefits

Comprehensive socio-economic and wider societal assessments of the ecosystem services provided by legumes are required. The difficulties and complexity of assessing such effects, some of which are temporary (for example the improvement of soil structure), has hindered the economic valuation of ecosystem service provision.[36] What is missing includes i) science-based approaches to the detection, description and quantification of external benefits, ii) methods to adequately assess intermediate services and iii) concepts, methods und institutional solutions to enable the public support of ecosystem service provision with decision support aids to enable these to be integrated into farm management and the value chains. Two research areas are particularly relevant:

- Legume ecosystem services that are not considered in farm-level economic assessments require valuation and workable regulatory mechanisms to support them.

- The systematic and transferable quantification of actual costs and benefits of growing legumes and the resulting benefits under different site conditions and production circumstances.

c. Market development

Currently, imported soy meets the needs of feed manufacturers very well. This is a great challenge to the introduction of German-grown legumes. It is therefore important to explore the design of incentives for greater use of home-grown legumes in feed, and how such incentives impact the feed market.

[36] Matzdorf, B.; Reutter, M.; Hübner, C., 2010: Bewertung der Ökosystemdienstleistungen von HNV-Grünland (High Nature Value Grassland): Gutachten-Vorstudie ; Abschlussbericht Juni 2010 [Elektronische Ressource]; Müncheberg (Leibniz-Zentrum für Agrarlandschaftsforschung)

5 Research policy recommendations

The generation of knowledge through long-term and trans-disciplinary research combined with a suitable policy framework provides the foundation of a successful strategy for increasing the use of legumes. This strategy urges consideration of the nature of the value chains involved and the use of research results in practice aided by regional crop centres. It emphasises the role of a suitable policy framework in determining the production and use of legumes.

This strategy reflects the complex challenges have to be addressed if the ecosystem and socio-economic potential of legumes are to be realised. 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 policy and programme management framework that these research projects operate in is also important so that research projects complement each other against the background of the complex needs of the value chains and the development and implementation of policies to extract private and public benefits from legume-supported cropping systems.

For the development of research funding mechanisms, the DAFA recommends that funding organisations enable

- long-term and specific research;
- consortia to conduct trans-disciplinary research;
- integration of research to address supply chain questions and needs;
- regional crop centres to provide reference systems, pilot testing and demonstration;
- optimal exploitation of research results; and
- development of agricultural policy instruments and frameworks.

A long-term approach must be taken to planning research if it is to support expansion in cultivation.

Long-term and specific research

Experience shows that previous research funding has enabled good legume research in certain areas. However much of the research effort has had a short term perspective and is fragmented. One consequence of this is that the impact of previous research on the cultivation and the use of legumes is less than was hoped for. The research community needs to identify coherent and strategically relevant research questions and themes that can effectively support the technical and policy changes required. This must be supported by a willingness to make long-term investments in research to address these where appropriate (up to approximately 12 years). This is especially true for research that uses novel plant genetic resources to support plant breeding. Similarly, sustainable farming systems can be developed only if legume-supported cultivation systems are the subject of long-term field experiments that provide data needed for a more comprehensive assessment of effects. Research programming and programme management is required to secure and coordinate the use of strategic research resources, and to identify coherent research targets. The identification of coherent research questions is, in some cases, a research challenge in itself and should be supported, where appropriate, by research considering the European research landscape.

Consortia to conduct trans-disciplinary research

The reasons for the poor realisation of the benefits of legume production and use in sustainable development and climate protection are as complex as the effects of legume production on farm practice, markets and policy. In identifying a combination of cross-cutting research themes interacting with supply chain orientated research, this strategy recognises this complexity. Where it is useful in relation to the research questions, research needs to have a trans-disciplinary character conducted by supply chain oriented consortia. The cross-cutting research themes identified in this strategy (e.g. Genetic improvement for yield and quality) support research components needed to underpin such supply-chain oriented collaborations.

Integration of research to address supply chain questions and needs.

Research to promote the breeding, cultivation and use of legumes needs to develop solutions that are relevant to links and connections within strategically important value chains. To achieve this, research planning must be informed of the needs and aspirations of the relevant supply chain actors. No single project provides all the answers. The overall impact on value chains and the environment depends on how well a research programme on legumes fosters complementarity between projects and how well individual projects are resourced in a balanced way so that the effect of the programme as a whole is more than that of the sum of its parts. This requires a strategic alignment of research investment that goes beyond the selection of the best project proposals made in response to funding opportunities. It also means that regional value-added potentials need to be recognised so that these potential can be exploited locally.

Regional crop centres to provide reference systems, pilot testing and demonstration.

To make the potential of legumes clear to farmers, wider society and policy-makers, regional crop centres should be established after the first phase of research. These need to represent particular production regions and be based on existing production activities. They need to explore the needs of the down-stream supply chains and explore the logistical and other consequences. Support for market development and trans-disciplinary research is important to the success of regional crop centres.

The regional crop centre approach has four objectives:

- Regional crop centres provide the basis for dialogue between research and research users. They enable timely knowledge interaction and dialogue between the actors in farming, advisory services, industry, processing, marketing and science to identify and assess relevant research goals.

- The regional crop centres should serve as the basis for inter- and trans-disciplinary research projects in the various thematic areas (see chapter 3), facilitate long-term research on crop rotation and environmental effects and facilitate networking at the European level.

Regional production centers must create structures to bridge production and use.

- Within the regional crop centres, scientists should develop, test and assess innovative approaches to the many uses of legumes in collaboration with farmers and representatives of all stages of the value chains for food, feed and non-food products. This will raise the profile of legume crops and their opportunities with key decision-makers.

- The regional crop centres should awaken interest in legumes in society and the policy community and demonstrate the advantages legumes deliver for farmers and wider society.

Regional crop centres can be used to present the effect of legumes to the public in a highly visible way, for example as a contribution to diversity in agricultural landscapes ('flowering fields') or present legume-based foods. With this, legumes and their wide range of effects are made accessible to a wider public.

Research is needed, but only the use of research results in practice delivers the required progress and impact.

Optimal exploitation of research results

The communication and transfer of research results between the research community, farming, business, society and policy has until now tended to be ad hoc and embedded within individual research projects. A strategic approach to knowledge interaction and transfer is required that brings together the results of complementary research projects and professionally provides end users with access to them.

The knowledge required for the successful cultivation of legumes is complex and even the calculation of gross margins of whole crop rotations requires effort in the transfer of knowledge, training and education. The fostering of the acquisition of knowledge by farmers through various means, including training and advice, has been an essential building block for education and knowledge transfer. Therefore it is important to foster knowledge acquisition by the farmers and include advisory and educational institution in the transfer and implementation of knowledge and technology.

A significant amount of the research we identify as required relates to public goods in the form of ecosystem services that are relevant to the environment or public health. An effective strategy to implement the relevant research results must consider the development of public policy and include measures to communicate with the general public.

Development of agricultural policy instruments and frameworks

Agricultural policy is instrumental to expanding the cultivation and use of home-grown legumes. In the foreseeable future, agricultural policy will remain a major influence on agricultural land use and management. The linking of farm support funds to the delivery and protection of public goods could foster the use of legumes delivering these public goods.

The purpose of the recommendations for research policy presented here is to support the coordination of the work of scientists, farmers, business people, civil society and policy-makers to organise research so that the results will have an impact. For this purpose, the phasing of a programme with the goal of making the delivery of ecosystem services competitive may be helpful in allowing programme funders and participants to formally fine-tune the R & D activities between phases. This can be supported by updates to this DAFA strategy as appropriate.

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