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THE ENVIRONMENTAL ROLE OF PROTEIN CROPS IN THE NEW COMMON AGRICULTURAL POLICY

STUDY

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This document was requested by the European Parliament's Committee on Agriculture and Rural Development.

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Abstract:

This study provides an overview of the development and environmental effects of protein crop production in Europe. Nine policy options for supporting protein crops are presented: six inside the CAP, and three outside. We recommend an integrated policy approach combining the inclusion of protein crops into greening measures, investment in research and constraints on the use of synthetic nitrogen fertiliser. We conclude that increasing the production of protein crops would be an important contribution to the sustainable development of European agricultural and food systems.

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LIST OF ABBREVIATIONS

BNF	Biological nitrogen fixation
C	Carbon
CAP	Common Agricultural Policy
CEE	Council of the European Union
CNDP	Complementary National Direct Payments
CO_2	Carbon Dioxide
€	Euro (since 2001)
EC	European Comission
ECU	European Currency Unit (1979 until introduction of the Euro in 2001)
EFA	Ecological focus area
EU	European Union
EU-27	European Union with its latest 27 member states
GATT	General Agreement on Tariffs and Trade
GHG	Greenhouse gases
GM	Genetically modified
ha	Hectare
IPCC	Intergovernmental Panel on Climate Change
LCA	Lifecycle Assessment
M	Million
MGA	Maximum guaranteed area
MS	Member State
N	Nitrogen
N_2O	Nitrous oxide
P	Phosphorus
RDP	Rural Development Programme
SAPS	Single Area Payment Scheme
SPS	Single Payment Scheme
t	Tonne
USA	United States of America
USD	US Dollar
WTO	World Trade Organisation
yr	Year

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GLOSSARY

Acidification: a process in ecosystems that lowers the pH of soil and water in particular. It is caused by acids and compounds that can be converted into acids. In life cycle assessments, **acidification potential** arises especially from combustion processes, transport, and from some nitrogen conversions in the soil.

Agenda 2000: the term used for the CAP reform process before 2000 that built on the *MacSharry reform*. This reform placed rural development as the second pillar of the CAP and confirmed the move away from product to producer support. It also introduced the concept of 'cross compliance', which was optional then (but was made compulsory in the subsequent reform in 2003).

Amber box measures: measures that are considered by the WTO to distort production and trade. These include measures to support prices, or subsidies directly related to production quantities (Article 6 of the Agriculture Agreement). There are limits to the use of amber box measures (5% of agricultural production for developed countries), and the WTO members are commited to reduce these subsidies. Measures to encourage protein crops specifically under '*diversification'* could fall into the amber box.

Article 68: in the framework of the CAP, a clause in the regulation emanating from the *Health Check* that allows some exceptions on *decoupling* under specific conditions, including support for agricultural activities that carry environmental benefits. Some member states use this provision for support to protein crops.

Biological nitrogen fixation (BNF): the process by which a bacterium, usually in symbiosis with a plant, converts inert nitrogen from the atmosphere into a reactive form, usually ammonium. All agricultural legumes support BNF and they are the only crops that do so.

Blair House agreement: an agreement made between the United States and the European Union in 1992 as part of the negotiations in the General Agreement on Tariffs and Trade (now the WTO). It aimed to reduce subsidies to exporters and domestic producers, in particular restricting the area of oilseeds supported in Europe to 5.5 M ha.

Blue box measures: measures that would otherwise fall into the *amber box* but are designed to reduce distortion of trade. These measures include support that is not linked directly to production, but to area, and moreover are restricted to a maximum. There is no limit on spending on blue box subsidies.

Break crop: a crop species that differs biologically from the main crops grown. In cereal-based cropping systems, protein, tuber and oilseed crops are break crops.

Chickpea: *Cicer arietinum* L. A legume crop grown for direct human consumption, also known as garbanzo. It is native to western Asia.

Clovers: genus *Trifolium*, of which *T. repens* L. (white) and *T. pratense* L. (red) are most widespread. Clovers are used for forage. They are native to Europe and Asia.

Co-decision: see *Ordinary legislative procedure*

COMAGRI: the European Parliament Committee on Agriculture and Rural Development.

Common bean: *Phaseolus vulgaris* L. A legume species used mostly for direct human consumption. Its other names include "kidney bean", "navy bean" and "haricot bean". It is native to South and Central America.

Cross-compliance: the mechanism that makes most CAP payments to farm businesses dependent on compliance with rules concerning the environment, animal and plant health, animal welfare and maintainance of agricultural land in good agricultural and environmental condition.

Decoupling: separation of farm payments from production activities. This was a key part of the 2003 reform of the CAP, which packaged all farm payments related to production into a single farm payment under the Single Payment Scheme. These payments were progressively "*decoupled*" from production activities. Payments are now conditional on "*cross-compliance*".

Diversification measure: one of the "*greening measures*" within the CAP reform proposed by the European Commission. The original proposal is that in most cases, one crop species should not account for more than 70% of the cropped area of a farm, and that at least three crop species should be grown, with none less than 5%. There is a threshold for the area of arable land on the farm that triggers this requirement.

Ecological focus areas (EFAs): areas of agricultural land (excluding permanent grassland) dedicated to enhancing biodiversity, and one of the "*greening measures*" within the CAP reform proposed by the European Commission. The EC proposed that farmers manage at least 7% of their "eligible hectares" as EFAs as defined in Article 25(2) of the proposal. This means management as fallow land, terraces, landscape features, buffer strips and afforestation. Eligible areas are those that are used for agricultural activity or, where the area is also used for non-agricultural activities, predominantly used for agricultural activities.

Ecotoxicity: toxic effects on the constituents of ecosystems, including humans, animals, plants, and microbes.

Eutrophication: nutrient enrichment that disturbs ecosystems. In life cycle assessments, **eutrophication potential** considers emissions of nitrogen and phosphorus from the soil and oxides of nitrogen from combustion processes.

Faba bean: *Vicia faba* L. Primarily a feed crop but also consumed directly by humans. Its other names include "broad bean", "horse bean" and "field bean". It is native to western Asia.

Forage legumes: legumes generally fed as a whole plant, including those that are grazed directly by the animal and those that are harvested and fed (green, as silage, or as hay).

Grain legumes: those generally used for their seeds (known as pulses in some countries) for either food or feed.

Green box measures: measures that clearly do not distort trade, or at most cause minimal distortion in the view of the WTO. They must be based on public funding, i.e. general taxation, rather than on higher prices, and must not include price-support. All *decoupled* payments are in the green box. There is no limit on spending on green box subsidies.

Greening measures: part of the Commission's proposals published on 12 October 2011 setting out that 30% of direct farm payments be made in return for improvements to the environment and protection of natural resources, additional to those under cross-compliance. The Commission hopes to combine viable and diverse food production with improvements to soil, air, water and climate protection. Three measures were proposed: *Ecological focus areas*, *Diversification*, and the preservation of permanent grassland.

Gross margin: revenues (including subsidies) minus variable costs (excluding fixed and labour costs). It is often the key determinant of the attractiveness of legumes to farmers, indicating the profitability relative to other possible cropping options.

Health Check: the 2009 review of the 2003 CAP reform.

Lentil: *Lens culinaris* Medik. A food legume crop, native to western Asia.

Ley: temporary grassland which is rotated with arable crops.

Lucerne (also known as alfalfa): a forage legume, *Medicago sativa* L. It is native to Eurasia. Other species of the genus are important in Mediterranean climates and are termed "medics".

Lupin: (also spelled lupine) species of the genus *Lupinus*, of which 3 are widely cultivated, *L. angustifolius* L. (narrow-leafed or blue lupin), *L. albus* L. (white) and *L. luteus* L. (yellow). All are native to the Mediterranean basin. The plural (lupins) is used in this report since several species are included. Andean lupin (*L. mutabilis* Sweet) is a semi-domesticated native of South America that is seldom cultivated in Europe.

MacSharry reform: revision of the CAP in 1992 when public support was partly delivered using direct payments to farmers rather than just through market and price support mechanisms. These direct farm payments compensated for reduced support prices and compulsory set-aside. The area payments varied between cereal, protein and oilseed crops.

MGA - maximum guaranteed area: the area set by the European Commission as the maximum area eligible for subsidy for a particular type of crop, including protein crops and energy crops. If a crop exceeds the MGA, per hectare payments are reduced.

Monogastric animals: animals having a stomach with only a single compartment, including pigs and poultry. These animals have more specific protein requirements than *ruminants*.

National ceiling (or national budgetary envelopes): the amount of money within the EU budget that is allocated to a member state for direct payments.

Nitrogen is **reactive** when attached to atoms of other elements, particularly carbon, oxygen or hydrogen (including nitrate and ammonia), in contrast to **inert** or non-reactive atmospheric nitrogen, comprised of two atoms of nitrogen joined to each other (di-nitrogen). Reactive nitrogen is essential for life.

NUTS region: Nomenclature of Units for Territorial Statistics, geocode standard by the European Union for referencing the subdivisions of countries for statistical purposes. The NUTS regions are based on the existing national administrative subdivisions and are subdivided into four levels of hierarchy: NUTS 0 are the national states, and NUTS 1 to 3 are subdivisions into large, medium and small regions.

Ordinary legislative procedure (ex-"co-decision" procedure): the procedure that gives the same weight to the European Parliament and the Council of the European Union on a wide range of areas, including the CAP (with some exceptions). With the Lisbon Treaty it became the main legislative procedure of the EU´s decision-making system.

Organic: Chemists and biologists use the term "organic" when discussing the chemistry of carbon-based molecules. Thus "organic nitrogen" is nitrogen bound to carbon in such compounds as amino acids and proteins. The opposite is "mineral", hence "mineral nitrogen" is nitrate, nitrite, or ammonium. Decaying biological material in the soil is termed "organic matter". The term "soil organic carbon" is used to distinguish the carbon in organic matter from that in carbonate minerals such as calcium carbonate (chalk).

Organic agriculture: a production management system that aims to promote and enhance agro-ecosystem health, including biodiversity, biological cycles, and soil biological activity, by using agronomic, biological, and mechanical methods instead of synthetic materials.

Pea: *Pisum sativum* L. both a food and a feed crop. It is native to western Asia.

Pillar 1: support in the CAP since 2000 that covers all production-related payments such as the direct payments to farmers (as they were known as at the time) and market support. Pillar 1 now accounts for about 75% of EU CAP expenditure.

Pillar 2: all CAP payments related to rural development (environmental and social benefits, including the agri-environment schemes, and support for young farmers). Pillar 2 accounts for about 25% of CAP expenditure. Pillar 2 payments are co-funded by national governments. Thus shifting from Pillar 1 to 2 can result in a net increase in funding going to rural areas, but a net decrease in funds going directly to farmers.

Precrop: the crop grown before the crop in question.

Precrop effect: the impact that the preceding crop has on the crop in question.

Protein crop: a legal EU-term including only *pea*, *faba bean* and *lupins*, and used when relating to policies on protein crops. In this study, the term covers crops in the legume family that are produced to be traded in dried form, whether for human consumption or as animal feeds.

Ruminant animals: cattle, sheep, goats, deer, antelope and camels. Ruminants have a stomach of four compartments, the first of which is the rumen. They can efficiently digest cellulose which is the main constituent of forage such as grass.

Sainfoin: a forage legume (*Onobrychis viciifolia*). Native to central Asia.

Single Payment Scheme (SPS): the EU's main agricultural subsidy scheme within the Common Agricultural Policy (CAP). Farmers receiving payments from the SPS have to satisfy cross-compliance requirements, including farmers' obligations to keep land in good agricultural and environmental condition.

Soya bean (British English; "soybean" is American English): *Glycine max* (L.) Merrill. It is native to China and the seed contains 15-20% oil. A grain legume grown primarily for its high protein meal that is widely used as an animal feed protein supplement (~50% protein) and as a minor food ingredient after oil extraction.

Vetches: several members of genus *Vicia*, usually grown as forages but occasionally as grain legumes. The plural is uses in this report since several species are included.

World Trade Organisation (WTO): an international organisation that establishes global rules of trade between nations. Its main function is to ensure that trade flows as smoothly, predictably and freely as possible. WTO requirements constrain various aspects of the reform of the CAP. *Amber*, *blue*, *green* and *red box measures* refer to WTO conditions.

Yields are generally given in tonnes per hectare (t/ha) or in million tonnes per year (M t/yr), depending on context.

EXECUTIVE SUMMARY

This study was conducted for the European Parliament in early 2013 during an intense phase of the political debate about the future of the Common Agricultural Policy. The purpose is to assess the potential environmental effects of an increase in the cultivation of protein crops in the EU and to formulate a set of policy measures that could be applied under the new CAP to gain environmental benefits from increased cultivation of protein crops by EU farmers.

The background is the EU's dependence on imported protein crop commodities and the reduced cropping diversity on European farms. The EU now imports 70% of its requirement for high-protein crop commodity which in 2011 accounted for about 14% of the world-wide production of soya bean, and using about 15 M ha of arable land outside the EU. This deficit has grown mainly because of the increased demand in Europe for high-protein feed for livestock production, particularly of pigs and poultry.

Protein and protein crops

Protein is based on nitrogen-containing amino acids and is essential for growth, body maintenance and reproduction. Monogastric species, such as pigs, poultry and humans, have more specific protein requirements than ruminants such as cattle and sheep.

Though all food plants provide protein, the seeds of the members of the legume family (*Fabaceae*) are especially rich in protein. All protein crops, as the term is used in the EU, are legumes. Protein crops include beans, pea, lupins and soya bean. The legumes grown for seed are also called pulses or grain legumes. Uniquely among crops, almost all legumes perform biological nitrogen fixation (BNF) that supplies the legume plant with nitrogen and reduces the need for fertiliser nitrogen in the following crops. Like the synthesis of nitrogen fertiliser, BNF requires energy, which is provided by sugars in the legume plant. This use of plant energy for BNF is one of the reasons legumes yield less than cereals.

Our demand for plant protein has increased

Over the 50-year period 1961-2011, the production of beef, pig and poultry meat in the EU-27 has increased from 17 to 43 million t, with a particularly large increase in pig and poultry meat. This increase is tightly linked to increased consumption of meat in Europe, both in total and on a *per capita* basis. Pig and poultry diets are cereal-based and approximately two-thirds of Europe's cereal harvest is now used to feed livestock. The imported soya bean is used to enrich these cereal-based feeds with protein. This complementarity between imported soya and European-grown cereals allows this scale of livestock production.

Our production of protein crops has decreased

Protein crops are now grown on only 1.8% of arable land in the EU, compared with 4.7% in 1961. This decline is the result of a number of economic and policy factors. In contrast, they are grown on about 8% of arable land in Australia and Canada. The direct human consumption of pulses has declined. This has resulted in a reduction in the area of food legumes. Only 11-15% of pea and 9-14% of faba bean grown are now used for human consumption.

The minor role of protein crops in European agriculture reflects wider imbalances in the European agri-food system. The decline in protein crop production and the increased production of cereals is largely attributable to the comparative yield advantage of cereals over protein crops grown in Europe. The yield of wheat has increased from near parity with

protein crops in 1961 to around twice that of protein crops. Payments targeted at protein crops (coupled payments) have stalled the decline in protein crop production to some extent but have not changed the underlying economic drivers.

Recent changes in some of the economic drivers behind protein crop production may give an impetus to their cultivation. Protein crop prices have in recent years increased slightly faster than wheat prices, imported soya feed has become more costly, and fertiliser prices are also increasing significantly. As a result, the competitive position of legumes has improved in the last decade.

Protein crop yields vary more than cereals from year-to-year

Yields of protein crops are notably unstable and there are several crop management and plant breeding challenges to be overcome if European protein crop production is to compete better with cereals. Protein crops are generally less competitive than cereals against weeds. Pea in particular is susceptible to lodging (collapse of stems so the crop lies on the soil), drought stress, and pests and diseases, including the build-up of soil-borne diseases such as aphanomyces root rot.

Resource and environmental effects

Protein crops provide resource benefits to farmers

Protein crops require little or no nitrogen fertiliser and they are also efficient in using reserves of phosphorus in the soil. The nitrogen left behind in the residue of the protein crop helps to boost the yield and reduce the need for nitrogen fertilisers in subsequent crops. The organic matter content and water-absorbing capacity of the soil is often increased thus increasing the yield of following crops, reducing erosion, and increasing the soil carbon content. Protein crops break the cycles of soil-borne diseases of cereals so less pesticide is needed on the following crop. In order to increase protein crop production significantly, farmers' awareness of their long- and short-term on-farm benefits, their cost saving effects, and contribution to good agricultural practice in general, need to be improved.

Protein crops deliver environmental benefits

Local environmental benefits come from increased crop diversity and the impact of this on biodiversity. Protein crops support above- and below-ground biodiversity, including that of pollinating insects. Beyond the local level, benefits to the agri-food system include resource savings such as the reduction of fossil fuel use arising from the reduced demand for fertilisers in particular. Reduced fossil fuel use translates into lower emissions of greenhouse gases and acidic substances. Nitrous oxide emissions from protein crops are minimal, although emissions can occur following the incorporation of residues. Reducing the quantity of imported soya also reduces pressure on international land-use change. Life-cycle assessments confirm that replacing imported soya bean with European-grown protein crops reduces the resource use and environmental impacts of livestock products.

The public benefits of protein crops justify public policy intervention

Our assessment of the resource and environmental effects of protein crops indicates that public policy intervention to increase their production in Europe is justified. A range of measures including protection of the market (price support), coupled and decoupled direct subsidies, and agro-environmental schemes have been used to support protein crop production. Between 1958 and 1992 various price support schemes were available for soya bean, pea, faba bean and lupins. In 1989, area payments were introduced for chickpea, lentil and vetches. In the reform of 1992, price support was reduced and replaced with area payments. These payments varied according to crop type, with soya bean receiving less than other protein crops. In the 2003 reform, all area payments were included in the Single Payment Scheme. The "protein premium", which was a top-up payment within the single payment scheme, was used until 2012 on a restricted area basis in 17 member states, including some of the main protein crop-growing countries. In addition, Lithuania, Poland, and Slovenia use specific measures available to the new member states to support protein crops.

Policy options within the CAP

Here we present six policy options for supporting protein crops that can be considered in the reform of the CAP. These options are based on thorough analysis of the on-farm and environmental benefits of legumes and the history of the CAP with respect to protein crops.

Option 1: More stringent crop diversification meaures

The current 'greening' proposals on crop diversification (Pillar 1) are not expected to result in significant changes in cropping patterns, and almost certainly will not significantly increase the production of protein crops. Much more stringent crop diversification requirements are needed to have this effect. There is an agro-ecological case for tightening up diversification requirements to encourage more on-farm diversity in terms of crop plant families and plant genera. A flexible framework could for example particularly encourage cereal-based farms to use non-cereals in diversified cropping systems. In the context of diversification, however, there is little scientific or agro-ecological rationale to support a general requirement to produce legumes specifically. Such a requirement would conflict with WTO requirements.

Option 2: Classification of legume-cropped areas as ecological focus areas

Our review provides only limited evidence from ecology to support a policy that would allow protein crop areas to qualify as ecological focus areas (EFA, Pillar 1). There is reasonable consensus that grain legumes are superior in terms of farm-level biodiversity compared with the major cereals and maize. But there is little evidence to show that protein crops could compare well with other EFA options in terms of biodiversity, which is their purpose.

However, the simplicity of the measure gives it the potential to provide a significant boost to protein crop production in the context of the current proposals. We outline the potential of this measure to increase the protein crop area, which in turn could stimulate synergistic private sector investment in crop improvement and technical progress, especially if supported by public research. The measure provides scope for taking a flexible approach that would minimise the risks of negative unintended consequences for the effectiveness of the EFA and would underpin sustained expansion of protein crop production.

Option 3: Voluntary coupled support schemes

The current proposals include the abolition of the special support under Article 68, but include provision for voluntary coupled support schemes in response to economic and social challenges in a particular area under Pillar 1. These two factors ("economic" and "social" challenges) could be enhanced by an environmental dimension that would provide a basis for supporting protein crops. The scope for this measure is limited by WTO considerations and coupled support schemes are expensive on a per hectare basis. This is a cost borne by those receiving decoupled payments.

This option has the potential to allow regional and coupled support schemes to be developed where increasing protein crop production would be particularly beneficial. However, in these areas in particular the subsidy per hectare would need to be relatively high. We present estimates of the potential and costs of the use of coupled payments to increase protein crop production in Europe.

Option 4: Promote legumes via agri-environment schemes

In the present Rural Development Programme (Pillar 2), measure 214 may support legume cultivation at the discretion of the Member State or regional authority. Such an approach has the advantage of not conflicting with other farm interests, but the potential in terms of area affected is limited. There is also the risk that the protein crops do not perform well in agri-environment terms compared with other options under this scheme.

This option has the advantage of being based on a wide range of regulating and supporting ecosystem services provided by legumes. It is also flexible and reactive to regional needs and opportunities, as exemplified by the Entry Level Scheme working in the UK. However, the risks identified for the use of protein crops under the EFAs apply here.

Option 5: Increase support for organic farming

The use of legume crops is a practical necessity in organic farming systems. There is no doubt that expansion in organic farming leads to wider use of legumes. However, as a means of increasing protein crop production, increasing support for organic farming is an expensive option. This measure however has the merit of using established frameworks linked to distinct premium markets so that in effect consumers pay part of the cost. If the measure is used, it should be because of the other environmental and social effects.

Option 6: Investment into research, breeding, and technical progress

This review has identified two key features of protein crops: responsiveness to technical improvement and under-estimation of their on-farm benefits by farmers. Here investment in research, technical progress (which was an objective of the CAP when it was introduced in 1962) and extension can play a role.

The economic returns to public agricultural research tend to be substantial and research generates other benefits. In addition, investments in this sector are fully aligned with economic and food security goals. Investment in technical progress, especially progress which is based on crop breeding, has the potential to synergise with other measures and form an integrated policy approach.

The EU research programme (Horizon 2020) can provide substantial funding for research. The European Innovation Partnership for agricultural productivity and sustainability can complement this with work to promote technical progress based on research results.

While investment in agricultural research generally provides good long-term returns, there are risks, as shown by continued decline in protein crop production despite past research in this area. To be effective in terms of protein crop production, research must be carefully targeted.

Recommendations outside the CAP

Option 7: Strengthen climate protection policies

A protein crops policy can be seen as part of a climate protection policy, even though the benefits of protein crops go well beyond the reduction of greenhouse gas emissions and an increase in carbon sequestration in the soil. Crop production in general contributes directly to greenhouse gas emissions primarily through carbon dioxide emissions from fossil fuel use and nitrous oxide emissions from soils enriched with nitrogen. Measures to tackle these two gases could encourage the production of protein crops indirectly. Any policy that increases the cost of carbon emissions would make nitrogen fertiliser more expensive, and thus legumes more attractive. Measures that increase the price of fossil energy carriers will also make growing legumes more attractive to farmers.

Option 8: Use nutrient policies

There is a wide range of policies directly and indirectly relevant to the use of nutrients in agriculture. The best known is the Nitrates Directive, but there are others such as the Water Framework Directive and national regulations governing the use of nutrients. The Nitrates Directive has already indirectly raised the relative economic performance of clover-supported dairy systems by putting a cap on stocking rates which encourages farmers to focus on costs instead of output.

A tax specifically on the use of nitrogen in agriculture is also possible. The tax could be levied specifically on nitrogen in mineral fertilisers and on nitrogen surpluses in agriculture (e.g. the Dutch Mineral Accounting System, the Swedish tax on nitrogen in mineral fertiliser 1984-2010). Taxes on nitrogen surpluses are sound in principle but if implemented fully would consider nitrogen fixed by legumes as an input.

The environmental damage of nitrogen fertiliser has been estimated at 0.37 €/kg of N (equivalent in prices of 2013), including its effect on global warming, pollution and eutrophication. An equivalent price increase alone would hardly be sufficient to compensate the gross margin deficits of grain legumes in most production regions, but a policy that incorporates the environmental cost of the fertiliser would be an important component of an integrated policy approach that could significantly promote legume cultivation in Europe together with other measures.

Option 9: Support producer initiatives

There are bottom-up as well as state-sponsored initiatives to promote the growing of legumes, which could be supported by the European Union. The European Innovation Partnership for agricultural productivity and sustainability could support networking and knowledge dissemination.

One such state-sponsored initiative is *Danube Soya Association* aimed at growing soya bean in the Danube basin as an alternative to imported soya. It is supported by both EU members and non-member states in the Danube basin. The German protein crop strategy describes measures to support knowledge dissemination among producers (i.e. crop-specific demonstration networks) as well as support to research and development. Bottom-up private sector initiatives include product certification schemes for animal production based on on-farm or regional feed production, such as those represented by the Neuland brand in Germany and the farmer association 'Mutterkuh' in Switzerland.

Conclusions

Compared with other major agricultural regions of the world, Europe is characterised by a lower share of legumes in cropping. This is the result of preference given to using European arable land use for the production of cereals (e.g. wheat, barley and maize) and a large livestock sector that depends on imported protein crop commodities. We should not overlook the reality that the EU's protein deficit exists largely due to the demand for plant protein from a livestock sector scaled to meet our high demand for meat. Our assessment shows that increasing the production of protein crops would be an important contribution to the sustainable development of European agricultural and food systems. The direct farm and regional level environmental benefits of increased protein crop production combined with the indirect benefits arising from the better balance of EU agriculture and trade justify public intervention. We therefore recommend that policy makers focus on the public benefits in the context of a wider re-balancing of European agricultural and food systems.

Protein crops have multiple positive environmental and resource-conserving effects operating at field, farm, regional and global levels. This points to the need to recognise the potential of complementary policy measures and fostering efforts to enhance them. Such an integrated policy approach can be particularly robust if it focuses on the positive outcomes that protein crops can bring about. To make them complementary to one another, measures should be rooted in an understanding of the agroecological processes governing the benefits. With the current low use of protein crops, the promotion of legumes through greening measures can be justified from a practical policy viewpoint. Combined with investment in research and development, this could stimulate private-sector investment in crop improvement and technical progress. Increases in the price of fertiliser nitrogen costs or other constraints on nitrogen use add to this.

1. PROTEIN CROPS AND THEIR ROLE IN EUROPE

KEY FINDINGS

Protein crops (grain legume species such as faba bean, pea, chickpea, lupins and soya bean) are now grown on less than 2% of arable land in the European Union. The protein crop area as a proportion of all arable land has declined from 4.7% in 1961 to 1.8% today. Over the same period, the use of protein-rich grain in animal feed has increased dramatically. This has been enabled by imports of 37 M t of soya bean (as bean or as the cake left after oil extraction). Imports of soya bean to the EU account for 14% of the global soya harvest and about 15 M ha of arable land, mostly in South America.

Arable land is relatively scarce in Europe. Despite this, the EU is self-sufficient or nearly so in livestock products and cereals. This has been achieved by exploiting the comparative advantage of cereals which have occupied about 57% of the arable area over the last 50 years. Due to plant breeding progress combined with increased use of nitrogen fertilisers and pesticides, the yield of wheat has increased and is now about twice that of protein crops. This yield advantage for cereals is a particular feature of cropping in Europe. As a result, protein crops are less profitable than major arable crops such as wheat, but they deliver significant benefits in the cropping sequence (rotation) by increasing soil fertility and soil quality, and reducing crop diseases. Thereby, protein crops deliver substantial yield benefits to other crops, but even when these are considered, the farm-level gross margin is generally lower where protein crops are grown.

The recent reforms of the Common Agricultural Policy, in particular 'decoupling', have contributed to the decline in the production of protein crops. Most protein crop support payments were incorporated into the Single Payment Scheme.

Some underlying economic trends have been reversed in the last decade. Protein crops replace two major inputs into European agriculture: synthetic nitrogen fertiliser and soya bean imported from South America, and the cost of both of these has increased dramatically in the last 10 years. This means that protein crops have become more attractive for farmers in recent years.

This study was conducted in early 2013 for the European Parliament as the political debate about the future of the Common Agricultural Policy was going through its most intensive phase. The purpose is to assess the potential environmental effects of an increase in the cultivation of protein crops in the EU and to formulate a set of policy measures that could be applied under the new CAP to gain environmental benefits from increased cultivation of protein crops by EU farmers.

All protein crops, as the term is used in this study, are legume crops. Compared with the cereals that dominate European annual cropping, these crops deliver a unique combination of biological nitrogen fixation (BNF), high protein grain for food and feed, benefits to cropping systems in terms of reduced pests, diseases and weeds and improved soil, and improvements to the wider environment. Despite these positive features, their production has declined greatly in the European Union. The EU now has a 70% deficit in protein-rich grains that is met primarily by imports of soya bean and soya bean meal. Reversing the decline in protein crop production to improve the European environment and to address the risks arising from dependence on imported protein crop commodities presents a complex challenge to policy-makers charged with delivering public goods for public funds. Our goal here is to serve this policy community in its widest sense.

We have written this report to convey the current understanding of the key agro-ecological processes, their impacts, and policy options to a wide audience. The report presents an overview of the production and use of protein crops and reviews the environmental and resource impacts of their production. It is to be noted that these crops have unique effects on resource use and the environment which are often confused, so we make a clear distinction between resource use and environmental impacts. This is followed by an analysis of policy instruments that are currently used or were used in the recent past. Together, the understanding of processes, the assessment of their impacts and the insights on current and past policy measures provides the foundation of our strategic recommendations.

1.1. Protein crops – a basic introduction

All food crops provide plant protein but seeds of the members of the legume family (*Fabaceae*) are especially rich in protein, and these are therefore called protein crops. The legume family is the third largest family of flowering plants. The species of agricultural significance belong to the sub-family *Papilionoideae.* These are characterised by flowers with five unequal petals (Fig. 1). A common feature of legumes is that their seeds form inside pods. These legumes include beans, pea, clovers, lupins and soya. The legumes grown for seed are often known as pulses or grain legumes. Forage legumes, like clover, are not the focus of this report but are discussed in Annex 3.

Figure 1: Bee on a narrow-leafed lupin flower

The **multi-purpose nature** of legumes, described in detail later, is widely recognised and valued (e.g., Beste and Boeddinghaus 2011). The agricultural function that is unique to legumes is biological nitrogen fixation (BNF), performed by almost all legumes and a characteristic of all agricultural legumes used in Europe. In BNF, nitrogen (N_2) in the atmosphere is fixed to reactive forms (reactive nitrogen) essential to biological processes (Annex 2). In natural ecosystems, such biologically fixed nitrogen is the primary source of reactive nitrogen. Like synthetic nitrogen fixation (N fertiliser manufacture), BNF is an energy-intensive process. Unlike fertiliser manufacture, this energy is supplied by the growing legume plant.

Nitrogen is the key limiting building block of protein synthesis in the plant. The plentiful supply of nitrogen from BNF provides the basis of **the high protein content** of the seeds and the key role in our protein supplies, either directly through our consumption of pea, beans, lentils etc., or indirectly through the provision of high-protein animal feeds. The protein content of legume seeds varies ranges from 23 to 40%, compared with 9 to 13% for cereals such as wheat and barley.

In addition to protein, legume seeds contain a diverse range of carbohydrates and some are relatively rich in oil (e.g. soya bean and lupins). There is also a range of secondary plant compounds, a fibre fraction, and additional nutritional or health benefits from a certain protein fraction (Sirtori et al. 2012). This all means that legumes play a particularly important role in sustainable, healthy diets.

Protein crops in European farming systems

Grain legumes are generally grown as sole crops, but sometimes are grown in mixtures called "intercrops" with cereals, in which case the mixture is often ensiled for feed rather than harvested as a grain product.

Many of the effects of leguminous protein crops described here derive from processes operating within the cropping systems in which they are grown. The multiple benefits of legumes are only fully evident and optimised when whole farming system-wide effects are considered. This includes the very important **precrop** and **break-crop effects** of legumes. Grain legumes are grown as components of crop rotations, often providing a 'break' from pests and diseases of the dominant crops (usually cereals) as well as supplying nitrogen to the following crop (Robson et al. 2002, Kirkegaard et al. 2008). Yields of subsequent crops are higher than would otherwise be the case (even when they are fertilised, see Chapter 2.1.2). A recent analysis of trends in wheat yields in France suggests that the decline in the use of legumes has adversely affected the yield of wheat crops (Brisson et al. 2010). Legumes play a particularly important role in farming systems that are valued by consumers, including organic and low-input systems, certified quality meat production, and traditional systems that characterise certain regions, such as in the Alps.

In **organic agriculture** (which covers 2% of the EU agricultural area), restrictions on stocking rates, the exclusion of synthetic fertilisers and some requirements for producing animal feed locally all make legumes essential. They provide the soil with nitrogen and deliver valuable animal feed components. Therefore the rules of organic production include the premise that "the fertility and biological activity of the soil shall be maintained and increased by multiannual crop rotation including legumes and other green manure crops". The effectiveness of fertility maintenance on organic farms depends upon the balance of nitrogen-fixing legumes and nitrogen-depleting non-legumes in the rotation (Watson et al. 2002). Legumes are considerably more widespread on organic than on conventional land. In Germany, for example, grain legumes occupy 7% of organic arable land compared with 0.8% of total arable land (Böhm 2010). Across the EU, 20-40% of the major grain legumes are produced on organic farms. For forage legumes, this share is much higher.

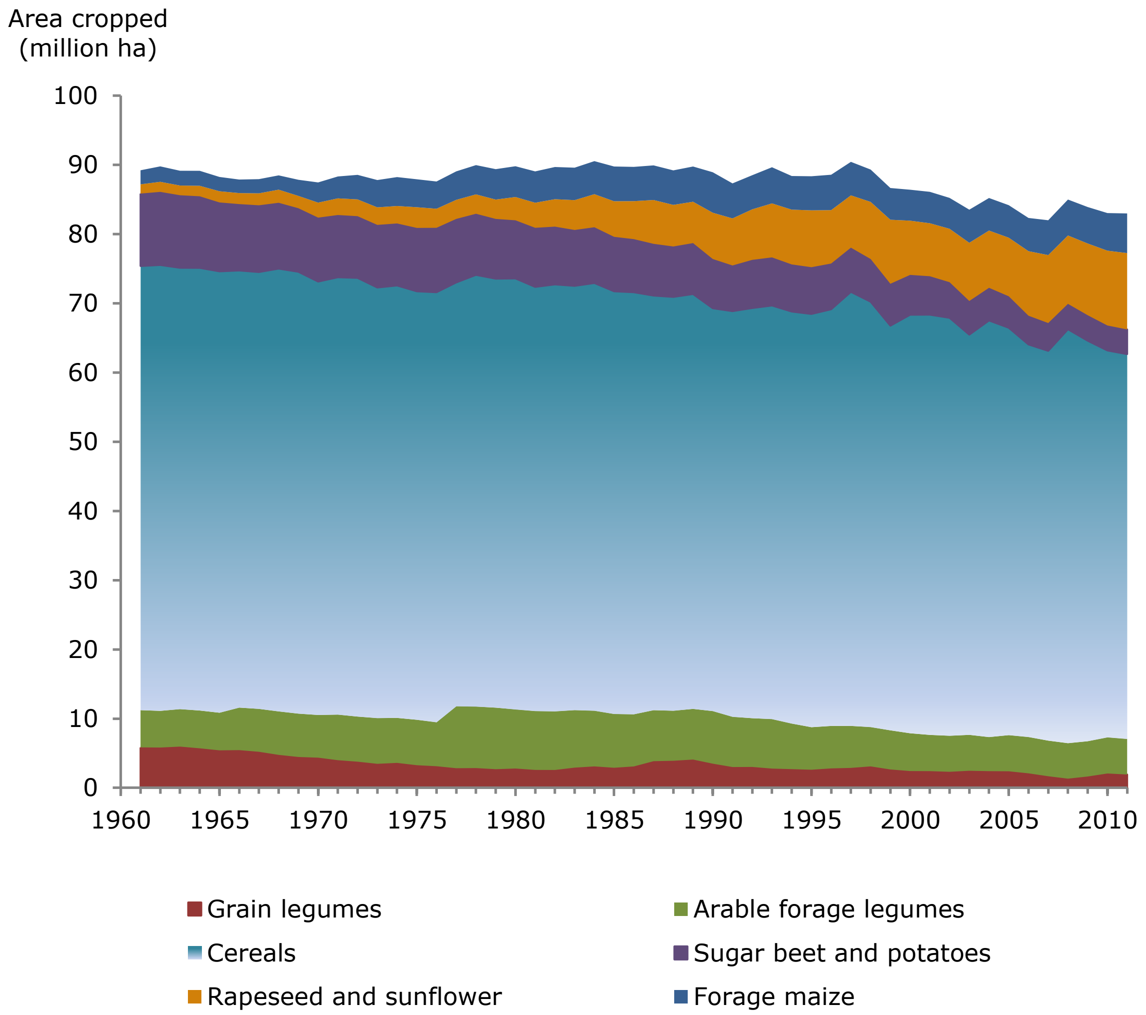
1.2. History of protein crop production and consumption

When the CAP was initiated fifty years ago, farm production in Europe was based to a large extent on self-sustaining mixed farming systems. Technical progress and a wide range of other drivers have resulted in increased crop productivity relying on synthetic fertilisers and pesticides used within specialised systems. To a significant extent, livestock production which has increased dramatically has been decoupled from the land used to provide the feed needed. As a result, some synergies between livestock and crop production have been lost. The side effects of this include environmental problems, degradation of soils, and a 10-fold increase in the import of soya bean and soya cake. These changes and their relation to the decline in the role of protein crops are described in detail in the following sub-sections.

1.2.1. Arable crop production

The changes in the area of the major arable crops over the EU-27 between 1961 and 2011 are shown in Fig. 2. The area allocated to these major crops dropped from 91 M ha in 1961 to 83 M ha in 2011 in line with declines in the total arable and agricultural area. The proportion of the EU arable area (excluding permanent crops) under cereals (including forage maize) has remained remarakable stable at about 57%. The major changes in terms of the proportion of land to crops have been in the decline in potatoes and sugar beet (due to productivity growth), the growth in the production of oilseeds, and the decline in forage and grain legumes. Grain legumes (protein crops) declined from 5.8 M ha in 1961 (4.7% of the arable area) to 1.9 M ha in 2011 (1.8% of the arable area).

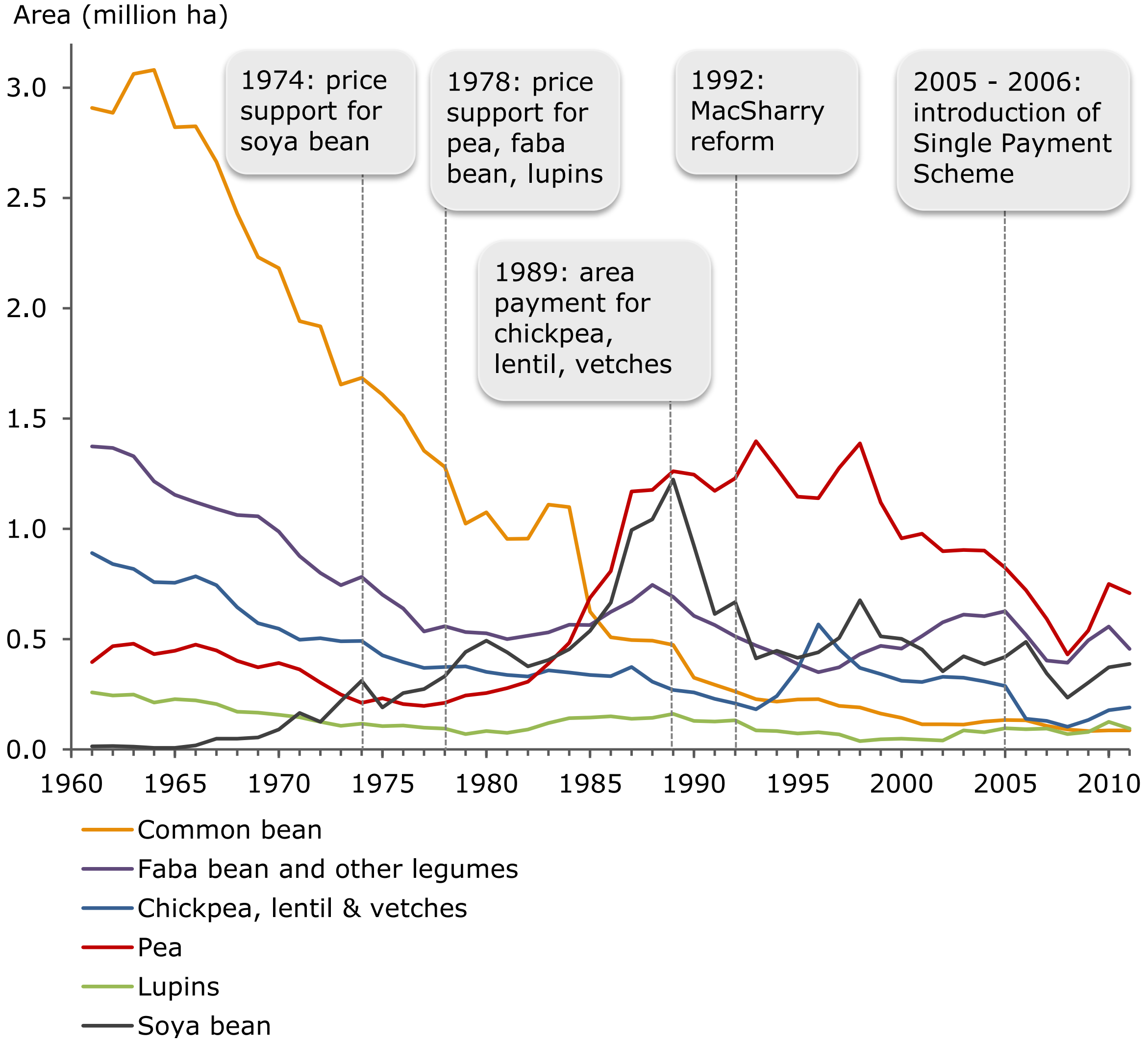
Figure 2: Change in areas of production of key arable crops in the EU-27 (1961 – 2011)



Source: FAOstat (2013). Pre-1992 data do not include data on crops grown in the Czech Republic, Estonia, Latvia, Lithuania, Slovakia, and Slovenia.

These changes have occurred for a variety of reasons. Increased yields are a major factor. Between the 1970s and the 1990s, wheat production in north-western Europe benefited from an annual yield increase of about 0.15 t/ha/yr (Supit 1997). The expansion of wheat production in Europe has been facilitated by the switch to autumn sowing, the availability of inexpensive nitrogen fertilisers, investment in plant breeding, and a wide range of pesticides from a well established European pesticides sector. Specialisation and intensification effects driven by comparative advantage resulted in more concentrated production and more homogeneous farming systems (Brouwer 2006). The combination of availability and low costs of synthetic nitrogen fertilisers relative to farm product prices (e.g. cereals, milk, beef) and imported feed protein has been another major enabler of this process.

Figure 3: Production areas of different protein crops in the EU-27 in relation to policy events[1] (1961-2011)



Source: FAOstat (2013)

In 1961, nearly 6 M ha were cropped to various species of grain legumes (Fig. 3). More than half of these crops were for direct human consumption and common bean was widely cultivated. Pea and soya bean (the majority being used as animal feed) became the most widely grown protein crops following the introduction of policy support for protein feed crops in the 1970s.

Pea production peaked between 1987 and 1999 (peak area almost 1.4 M ha, peak yields above 4 t/ha in 1990). Since then and particularly associated with the 2003 reforms, the area under pea has continued to decline in all member states except Spain (ca. 700 000 ha in the EU in 2011). Similarly, soya production surpassed 1 M ha in 1988, but after 1989 it declined again and has fluctuated around 400 000 ha since. In Romania the land area of soya bean declined by 75% between 2006 and 2008 (FAOstat 2013) due to the decision to stop production of GM soya (Dinu et al. 2010). Lupin production has fluctuated over time and has now stabilised at a low level (around 100 000 ha in 2011). The small area of all

[1] EU-wide aggregated data may mask regional effects of policies. For a regional breakdown of policy effects refer to Chapter 3.1. For a breakdown of production areas by country, see Annex 1.

grain legumes in 2008 is partly explained by low yields in 2007. Production of protein crops within organic production systems is currently important: 40% of lupin and faba bean and 20% of pea production areas are certified organic (EUROSTAT 2013).

The production area of the main protein crops in the individual member states of the EU is listed in Annex 1.

1.2.2. Changes in consumption

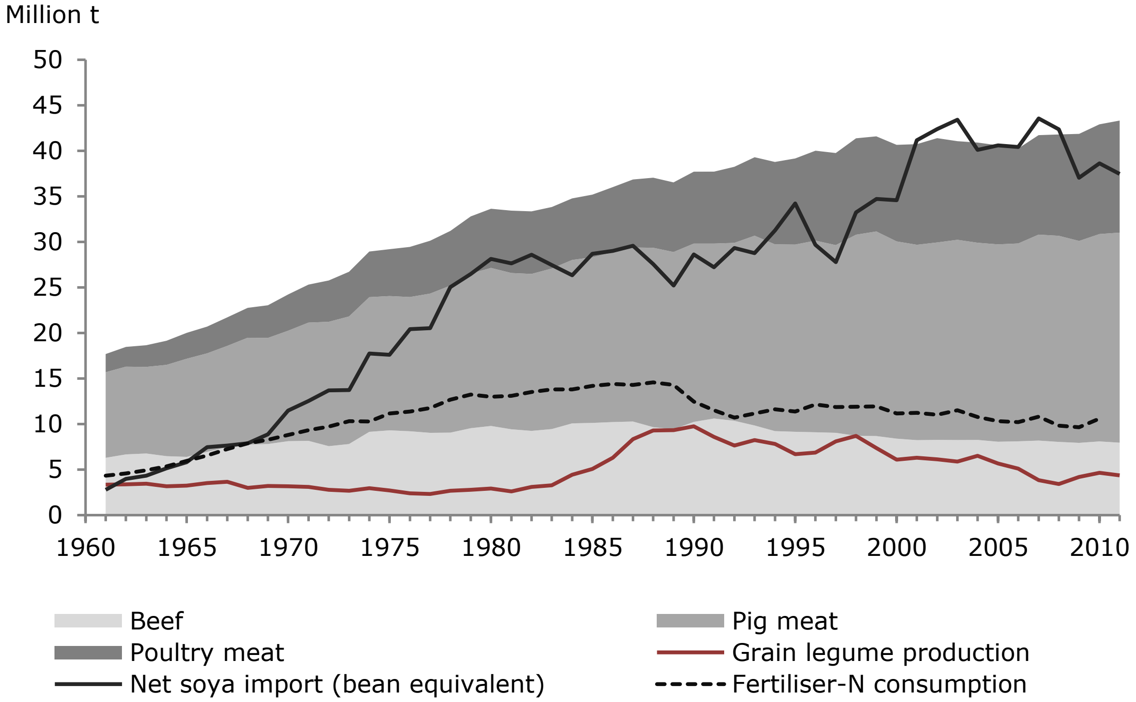
The consumption and production of livestock products are closely linked in the EU. The combined production of beef, pig and poultry meat in the EU has increased from 17 to 43 M t from 1961 to 2011, and demand for protein-rich feed has grown accordingly. This demand has been met by a higher production of grain legumes (an increase from 3.3 to 4.3 M t and a larger share being used as animal feed) and greatly increased import of soya bean (increase from 2.7 to 37 M t) (Fig. 4). The **higher consumption of meat** has been met by increased production of pig and poultry meat rather than by beef. Pig and poultry diets are cereal-based and approximately two-thirds of Europe's cereal harvest is now used to feed livestock. This scale of production based on European-grown cereals is made possible by the complementary qualities of soya bean meal that provides the necessary protein enrichment for cereal-based feeds. The EU imports the equivalent of 37 M t of soya bean, about 14% of the worldwide soya production. Imported soya accounts for about 15 M ha of land outside the EU and is the largest cause of the EU net 'virtual' land import (von Witzke and Noleppa 2010).

This **dependence on imported protein** has stimulated discussions about Europe's approach to plant protein provision and the consideration of possible options to replace imported soya by protein crops grown in Europe.

In 1961, grain legume crops that are used exclusively for **human consumption** (chickpea, cowpea, groundnut, lentil, and common bean) dominated grain legume cropping in Europe with 67% of the area. This dropped to 22% by 2010 (FAOstat 2013). Currently, 11-15% of pea and 9-14% of faba bean produced are used for human consumption (PROLEA 2011). In the Mediterranean countries in particular, pulses in human diets have largely been replaced by meat (e.g. in France, Cavaillès 2009). Of the food grain legumes consumed in Europe today, only 57% are produced within the EU (FAOstat 2013).

Forage legumes are outside the focus of this report, but some of their features are relevant so information on them is provided in Annex 3. In some areas of Europe, particularly where grass grows well, forage legume production may be more important than protein crops as an alternative to imported soya. The production of forage legumes has become more attractive to farmers recently due to increasing nitrogen fertiliser prices.

Figure 4: Changes in the production of meat and corresponding changes in fertiliser N use, protein crop production and net soya import for the EU-27 (1961 – 2011)



Source: Calculations based on data from FAOstat (2013).

1.3. Drivers behind the reduction in the protein crop area

The changes in area and production of a given crop are the result of the effects of different drivers on the relative profitability of the crop compared with other production options that farmers have for their land. An account of the drivers that have contributed to the decline in the area of protein crops is provided here.

1.3.1. The comparative advantage of growing cereals in Europe

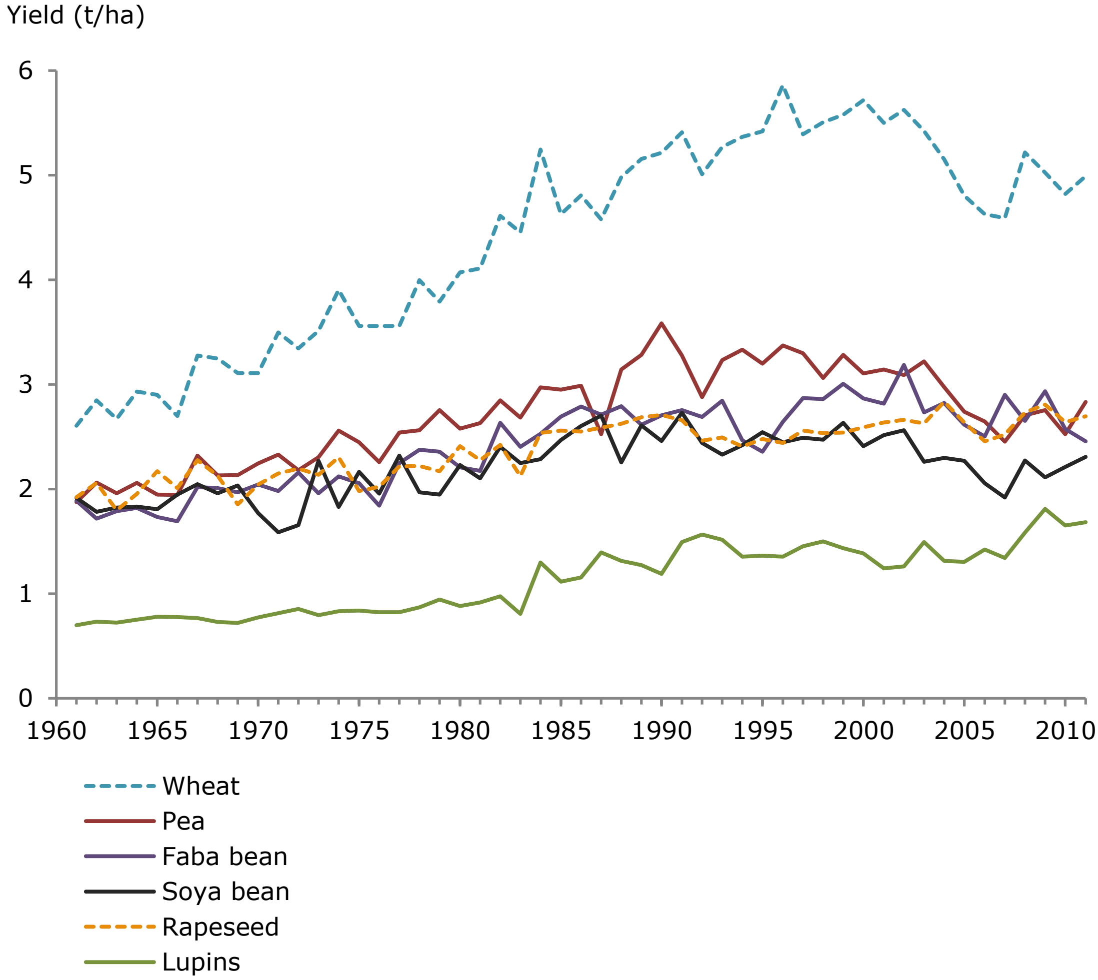
A major underlying driver behind the reduction in the proportion of arable land used for protein crops is the increased comparative advantage in the production of starch-rich cereals in Europe over the production of protein-rich grain legumes. The yields of soya bean and other protein crops are closely aligned in Europe (Fig. 5), so soya is representative of protein crops for the purpose of this comparison. Fig. 6 shows the changes in the yield of wheat and soya bean in the EU (using France as an example) and the USA from 1961 to 2011[2]. Soya bean yields in Europe have been similar to soya bean grown in the USA since 1971 (data not available for France prior to that year). While US wheat yields are similar to US soya bean yields, wheat outyields soya in Europe (Fig. 6). Furthermore, wheat yields in Europe have increased steadily and are now double those of soya bean. The comparative advantage of using European land to grow wheat instead of protein crops has increased.

In addition to higher yield potential of cereals in Europe, farmers who grow protein crops are confronted with a range of **agronomic challenges**. Protein crop yields are considered

[2] Reliable and comparable data are available for only soya bean and wheat in both Europe and the USA, and France is a country where both are grown widely.

unstable, as pointed out in many studies (von Richthofen et al. 2006a, Sass 2009, Flores et al. 2012). Some are not as competitive as cereals against weeds (Corre-Hellou and Crozat 2005). Pea in particular is susceptible to lodging (collapse of stems so the crop lies on the soil), drought stress, and pests and diseases (Gueguen et al. 2008 in Mahmood 2011). Where pea has been grown intensively, build up of aphanomyces root rot, which is a serious soil borne disease, has reduced yields. Yield instability is partly due to the indeterminate or continuous growth of most legume stems, which allows them to take advantage of good mid-season growing conditions, but delays their ripening and harvesting periods. Cereal crops, in contrast, flower and ripen much more uniformly. Determinate faba bean and non-branching lupin cultivars have been developed to circumvent this problem, and have gained some market share in regions with short seasons.

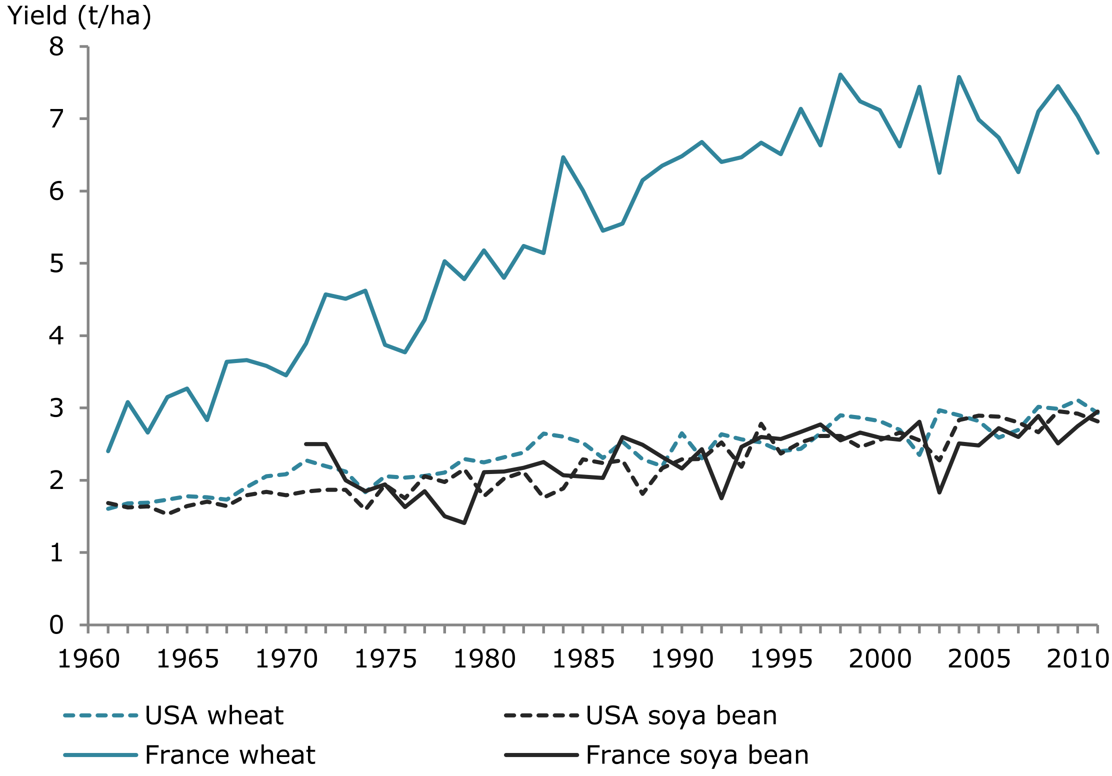
Figure 5: Average yields of wheat and the main grain legumes in the EU-27 (1961 – 2011)



Source: FAOstat (2013)

These agronomic challenges highlight a need for research to support crop development in order to increase and stabilise yields in relation to those of other crops. Breeding has been successful in raising the nutritional quality of faba bean and lupins, opening up new food uses and marketing options. Nevertheless, breeding, research and development or even certified seed production are often not commercially viable due to the small production areas (LMC International 2009). The crops competing particularly with legumes are rapeseed (also a break crop in cereal-dominated cropping systems), cereals, potatoes, and sugar beet (in Germany, Belgium, Switzerland, and Spain; von Richthofen et al. 2006a).

Figure 6: Yields of wheat and soya bean in the USA and France (1961 – 2011)



Source: USDA National Agricultural Statistics Service (2013), and EUROSTAT (2013) France represents an example of EU production.

The differences in yields between cereal and protein crops are reflected in effects on farm gross margins. Per hectare **gross margins of different protein crops** were shown to be between 55 and 622 €/ha less than those of cereals and oilcrops in several case studies across Europe, although gross margins increased in response to using legumes in five case studies (Annex 4). This shortfall compares with the protein premium of 57 €/ha which was paid in most EU member states. However these estimates generally do not take account of savings of nitrogen fertilisers and pesticides used in subsequent crops, and the higher yields of those crops. These benefits that are attributable to the legume crop can be the equivalent to more than 100 €. On a rotational basis, the average gross margins of legume-supported rotations are reported in case studies to be about 40 €/ha less per year compared with the dominant cropping systems without legumes. Extreme reductions of up to 181 €/ha per year as well as slight increases in gross margins up to 7 €/ha per year are reported (Annex 4). In considering these data, it must be remembered that small reductions in rotation gross margin may arise from a large reduction at the legume crop level, as the crop level reduction is averaged over the other crops in the system.

1.3.2. Reduced support under recent reforms of the Common Agricultural Policy

The production, use and trade in protein crops have been the subject of measures in the Common Agricultural Policy since the 1970s (Fig. 3).

The reduced support for protein crops reflects the general development of the CAP which moved from a system of price-support to decoupled income support for Europe's farmers.

The main protein crop support mechanisms used in the past include the price support for soya bean (introduced 1973), pea, lupins and faba bean (introduced 1979), and area payments for certain other grain legumes (introduced 1981). These measures supported increases in areas under protein crops, especially pea and soya bean. The 1992 MacSharry reform replaced price support with area-related direct payments for protein crops, cereals and oilseed crops. Payments for pea, faba bean and lupins were higher than for other crops, whereas payments for soya bean were lower, which resulted in a decline in soya production area. The 2003 reform introduced decoupling, replacing direct payments by an EU-wide uniform single payment scheme that is not linked to production. The earlier advantage for pea, faba bean and lupins was maintaned to some degree by introducing the protein crop premium for these crops that was paid until 2012 in most member states. Today, legumes are supported in the CAP under voluntary direct support measures and by agro-environment schemes. These are measures applied voluntarily by member states and are short-term in nature.

Other policies have affected the attractiveness of legume crop production indirectly. The biofuels blending mandate has, in effect, provided a subsidy for oilseed rape which is used for biodiesel and produces rapeseed meal as a byproduct. In Germany, the Renewable Energy Law indirectly subsidises the production of maize used as a substrate for biogas production, resulting in a large increase in the silage maize crop that competes with other uses of arable land in Germany.

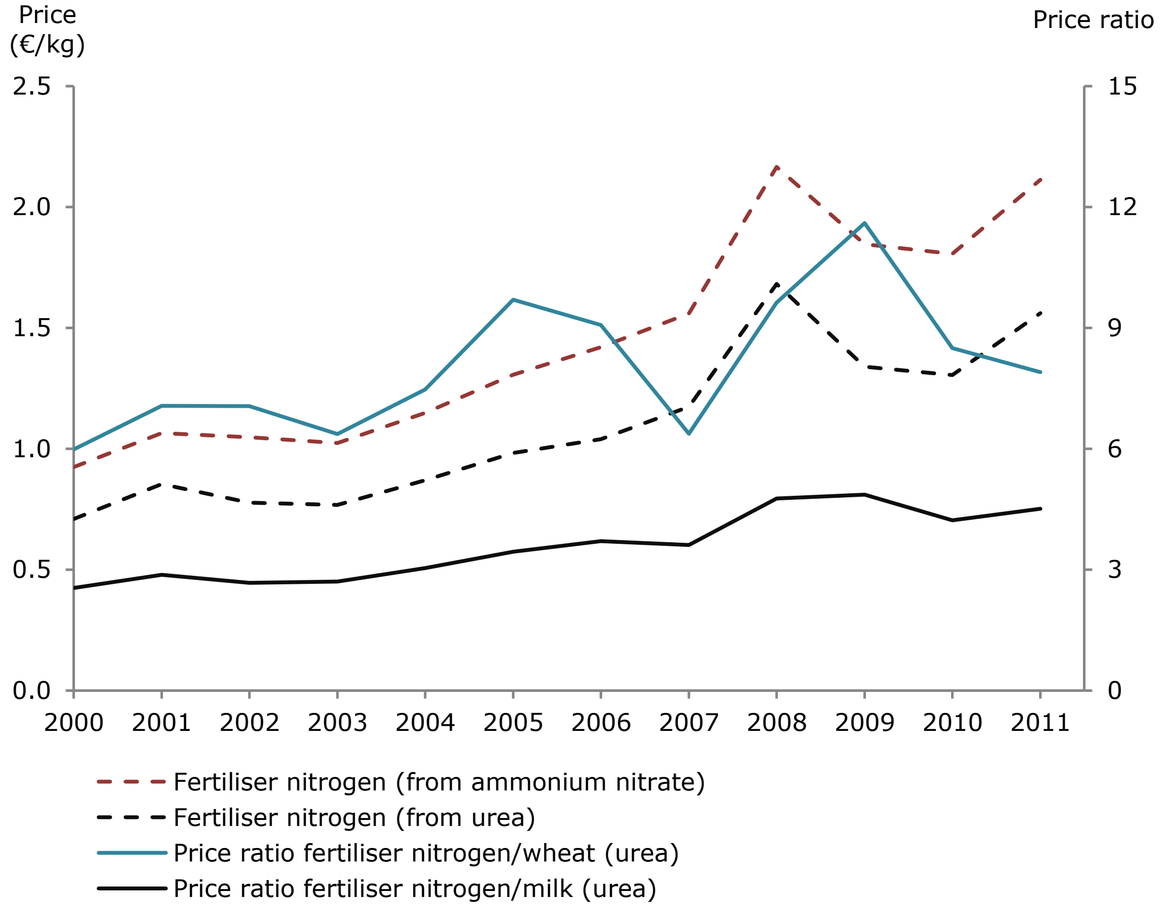
1.4. Recent drivers supporting revival in protein crop production

The previous section has set out the drivers behind the decline in the area of protein crops over the last 50 years. Recent market developments in the last decade provide some countering effects.

1.4.1. Nitrogen fertiliser has become more expensive

Nitrogen fertiliser prices have more than doubled since 2000 (Fig. 7) and the costs of fertiliser N relative to farm prices for wheat and milk have increased by 78% and 63%, respectively. Thus, the economic benefit of nitrogen provision through legumes is increasing.

Figure 7: Changes in the price of mineral nitrogen fertilisers, wheat and milk in the EU-27, and the associated feriliser/product price ratios (2000-2011)



Source: Calculations based on data from: EUROSTAT (2013). The urea-N/wheat-milk price ratio is the amount (kg) wheat or milk required to pay for one kg of nitrogen in urea fertiliser.

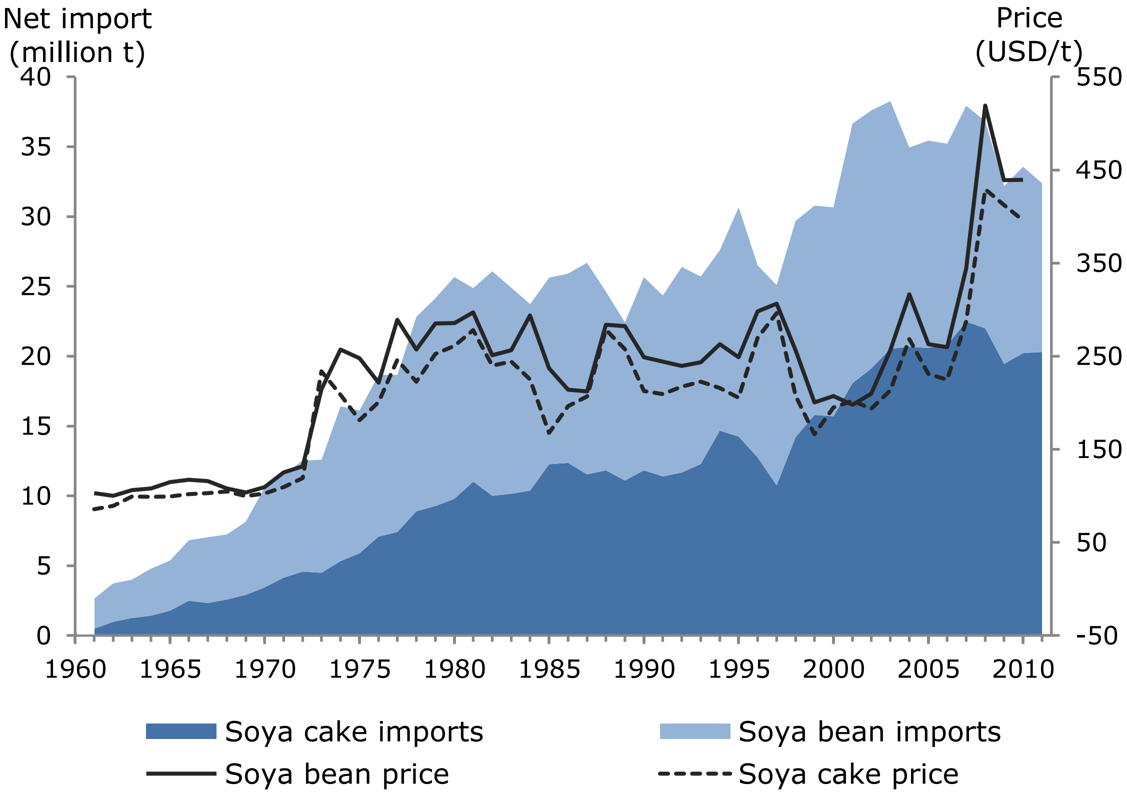
1.4.2. The price of soya on the world market is increasing

The price paid for imported soya has increased steadily since 2007 and the import quantities have fallen (Fig. 8). Soya feed prices are expected to continue to increase due to growing international demand. If the EU were to have one quarter of its soya imports GM-free, the increased demand would raise the price of GM free soya by 55 €/t (Aramyan et al. 2009).

1.4.3. Increasing producer prices for protein crops in Europe

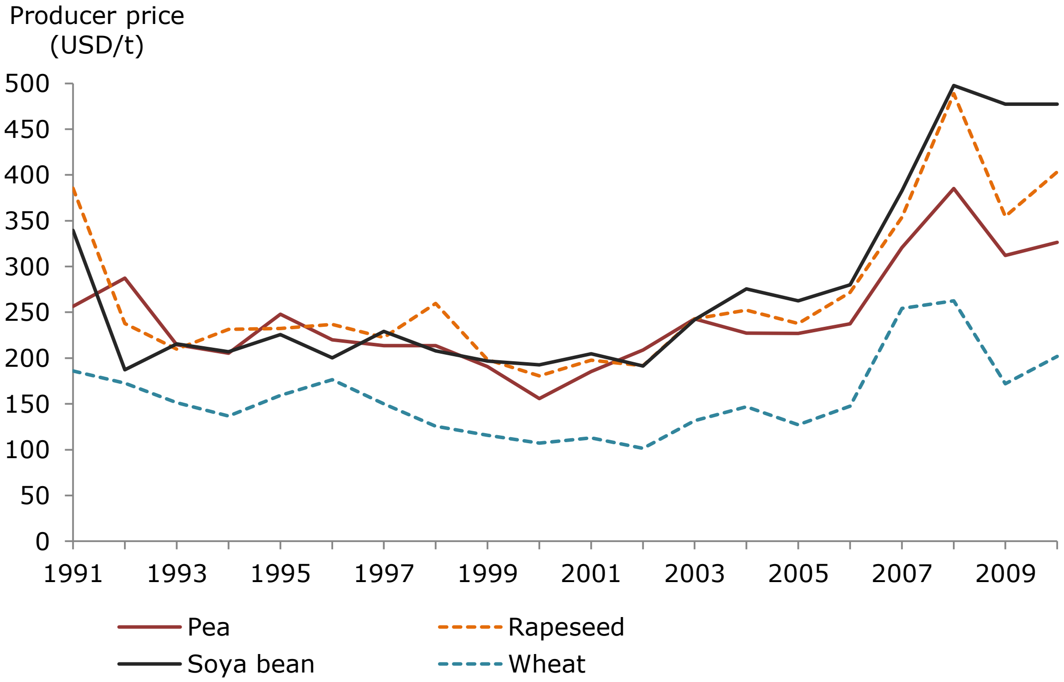
The prices of European-grown protein crops used for animal feed are closely correlated with the price of imported soya bean. Accordingly, the producer prices of European-grown soya bean, pea and faba bean have increased in line with the increase in international soya prices (Fig. 9). Most importantly, the price advantage of protein crops over wheat has increased slightly, reducing the comparative advantage of wheat (and cereals in general) over protein crops in competition for European land.

Figure 8: Changes in soya feed imports and import prices (1961 – 2011)



Source: Calculations based on data from 1961-2010 - FAOstat (2013), 2011 - EUROSTAT (2013).

Figure 9: Changes in producer prices for main protein crops, rapeseed and wheat in major producer countries (1990-2010)



Source: Calculations based on data from FAOstat (2013). Prices are averages for major EU producer countries: Bulgaria, France, Poland, Spain and the UK.

1.5. Conclusions

Arable land is relatively scarce in Europe. Despite this, Europe is self-sufficient, or nearly self-sufficient, in most crops and crop products that can be produced in Europe. European farms also produce enough livestock to support a high level of consumption of livestock products. This has been achieved by exploiting the comparative advantage of cereals. The area used for cereals has remained remarkably stable at about 57% of the arable area over the last 50 years. This remarkable agricultural productivity is enabled by two external inputs in particular: synthetic nitrogen fertiliser manufactured from fossil energy sources, and soya bean and soya cake imported from South America.

The reduction in protein crop cultivation from 4.7% of the arable crop area in 1961 to 1.8% in 2011 is part of a wider change to more specialised and intensive production. It is also due in part to reduced demand for grain legumes for direct human consumption, which is associated with the increase in livestock product consumption. It can therefore be concluded that the minor role of protein crops reflects wider imbalances in the European agri-food system.

Agricultural policy has not realised its potential to mitigate the decline in protein crop production, and several policies have even played a role in driving these changes. However, the history of protein crop production over the last 50 years shows that payments targeted at protein crops (coupled payments) have stalled the decline in protein crop production but have not changed the underlying economic drivers. Despite the success of these interventions in temporarily increasing soya bean, faba bean and pea production, long-term trends were not reversed. However, the market developments of the last decade represent more fundamental change. Farmers are now looking carefully at the value of BNF and European-grown protein crops are increasing in value faster than the wheat with which they compete for land.

2. ENVIRONMENTAL AND RESOURCE IMPACTS

KEY FINDINGS

The production of protein crops leads to several positive resource and environmental effects.

Due to the nitrogen-fixing capacity of legumes, the need for synthetic nitrogen fertiliser is significantly lower for protein crops compared with other crops, and the nitrogen fertiliser needs of the farm as a whole are reduced. Reductions in disease levels and improvements in soil properties such as organic matter content and structure cause an increase in the yields of subsequent crops, particularly if legumes are included in cereal-dominated rotations.

The main environmental effects of protein crops are:

- Industrial carbon dioxide emissions are reduced due to reductions in fertiliser use.
- Emissions of the greenhouse gas nitrous oxide are very low or zero.
- The flowering habit of protein crops is beneficial to biodiversity through effects on pollinating insects, especially bees.
- The over-wintering of cereal stubble prior to the spring sowing of protein crops and some other aspects of protein crop production, which also apply to other crops, support increased populations of small mammals, birds and some beneficial insects.

Protein crops can decrease or increase emissions of nitrates to ground water, depending on the management of crop residues and the use of other crops to reduce nitrate leaching.

The combination of these effects generally reduces product life-cycle fossil energy use and environmental impacts of cropping systems and of the products of animals fed with European-grown protein crops compared with animal products using imported soya bean.

Chapter 1 outlines the characteristics of protein (legume) crops. These characteristics and the associated processes (described in detail in Annex 2) determine their interaction with on-farm flora and fauna and the nitrogen cycle. Here we examine the effects of protein crops on the environment and resource use. We review life-cycle assessments that examine the system wide impacts of protein crops – on whole cropping systems and on products that use protein crops.

We emphasise here a distinction between effects on resource use, which are at least partly farm internal effects, and effects on the environment, which are entirely external. Resource use effects include the beneficial effects on soil fertility and soil structure. These effects generally result in benefits for the farm business through, for example, higher yields and reduced use of fertilisers and pesticides. True environmental effects arise from processes that impact outside the crop, particularly those affecting emissions of pollutants to water and air, and those that impact on biodiversity.

Table 1: Resource (R) and environment (E) effects of legumes arising from key agroecological processes operating at four levels of scale. Source: This consortium

Process	Protein crop	Farm	Agri-food system	Global
Biological nitrogen fixation (BNF)	R: No N fertiliser required. E: Reduced N_2O emissions. E: Below ground biodiversity changes.	R: Reduced N fertiliser requirement.	R: Reduced fossil energy (natural gas) use. E: Reduced CO_2 emissions from industry.	E: Reduced global GHG emissions.
Grain protein synthesis	R: Lower crop yield (compared with cereals) due to resource demands of protein synthesis.	R: Increased on-farm supply of protein.	R: Increased diversity of 'protein' crop commodity supplies.	R: Reduced demand for globally traded soya. E: Reduced direct land-use change pressures.
N transformations in soil	E: Reduced N_2O emissions.	E: Effects in both directions on nitrate leaching.		E: Reduced global GHG emissions .
Soil development		R: Improved water infiltration, reduced cultivation energy, increased crop yields.		
Phosphorus transformations	R: Increased mobilisation of soil P.	R: Reduced optimum levels of plant-available P.		R: Reduced mining of phosphate rock (minor effect).
Soil carbon transformations	R: Positive soil carbon balance.	R: Increased soil organic matter, higher and more stable crop yields.		E: Increased soil carbon sequestration (minor effect).
Weed, pest and disease development		R: Increased cropping system yield. E: Reduced emissions of pesticides to water.		
Species interactions	E: Increased pollen and nectar provision. Increased soil fauna diversity.	E: Larger population of insects supporting wider wildlife.		

Table 1 details both **resource and environmental effects** of legumes arising from key agroecological processes operating **at four scales**. First, there are effects within the crop. Above this, at the farm level, benefits for following crops grown in sequence (crop rotation) arise from nitrogen-related processes and the interruption of the build up of diseases and pests in particular. At the agricultural-food system scale, impacts arise from the effects on energy consumption, particularly the use of natural gas in fertiliser nitrogen production. At the global scale, protein crop production in Europe has effects on global trade in protein crop commodities, particularly from soya bean and underlying landuse changes.

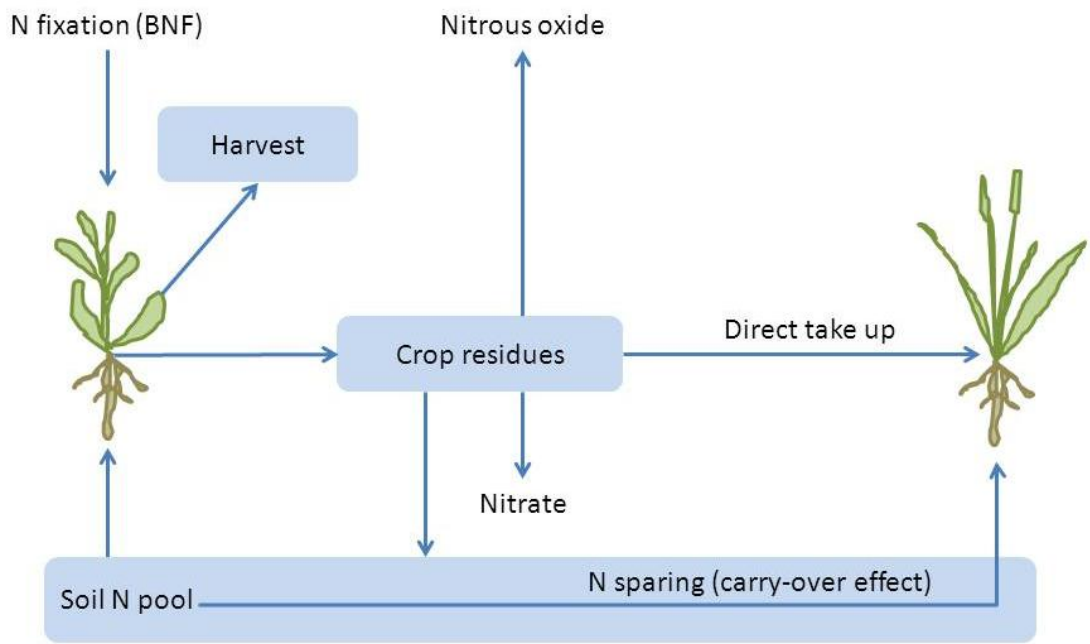
Based on the understanding of processes set out in Annex 2, this chapter assesses the overall impacts with an emphasis on the life-cycle of the commodities and products involved.

2.1. Crop and farm-level impacts

2.1.1. Reduced use of synthetic nitrogen fertiliser

Protein crops require almost no N fertiliser to express their yield potential while the cereal crops they normally replace typically receive 100-200 kg N/ha. As a result, the production of protein crops directly reduces nitrogen fertiliser use. Furthermore, the large quantity of nitrogen in the residues of legumes allows the saving of considerable amounts of nitrogen fertiliser in the following crops (Fig. 10).

Figure 10: The on-farm nitrogen cycle, showing the effect of legume pre-crops



Source: This consortium.

The residual N combined with other precrop effects such as the reduction in root diseases that reduce nitrogen uptake can be expressed as a **fertiliser nitrogen equivalent**. This is reported to be as much as 120 kg N/ha (Chalk 1998; Köpke and Nemecek 2010). However, the beneficial effect of this depends on how well farmers take it into account when fertilising the following crops. A survey of agronomic experts for the Legume Futures project reported that the savings made in practice are significantly less (Table 2). It appears that many farmers fertilise the crop after legumes as they would after other crops and treat the legume-derived N as a bonus that supports the higher yield and protein content normally achieved in these situations. This means the full potential environmental and resource benefits of protein crops are often not realised. Forage legumes fix significantly more nitrogen than grain legumes due to their high biomass production and longer growth period (Annex 3).

Studies using nitrogen labelled with non-radioactive isotopes (^{15}N labelling methods) show that only a relatively small proportion of nitrogen residue from protein crops is used by the next crop through direct take-up (Fig. 10). As much as 75% of the total residue enters the soil reserve, providing a resource for the longer-term supply of other crops. Thus there is a resource impact for the farm and an environmental impact due to reduction in fertiliser manufacture.

Table 2: Fertilisation practices for major protein crops and winter wheat in five case study regions across Europe[1]

Crop[2]	Yield (t/ha)	Regional average mineral fertiliser applied (kg/ha)			Experts view of mineral N fertiliser saved in farm practice in succeeding wheat (kg N/ha)
		N	P	K	
Faba bean	1.6-5	0	15-20	25-45	0-20
Pea	1.2-4	0	15-20	25-40	0-20
Lupins	2.5-3	0-30	15-35	30-35	0-20
Forage legumes, dry matter	6-15	0-65	0-15	0	0-20
Winter wheat	3.2-8	135-200	25-30	20-60	0

[1] Location and soil type: Scotland (Eastern, grade 3), Italy (Calabria, loam), Sweden (Västra Götalands, silty clay loam), Germany (Brandenburg, sandy clay loam) and Romania (Sud-Muntenia, Chernozem)
[2] IT (faba bean, pea and lupins), SE (faba bean and pea), SC (faba bean and pea), RO (pea), DE (faba bean, pea and lupins)

Source: Legume Futures survey in five case study regions across Europe.

2.1.2. Increased yields of subsequent non-legume crops

Crops following a legume in rotation yield more than after other precrops. Even where all crops are fertilised for optimum yield, cereal crops following 'break' crops are reported to yield 15 to 25% more than cereals grown continuously (Peoples et al. 2009, see also Annex 4). This is due to reductions in diseases and improvements to root growth. This is a significant resource benefit and is greater after protein crops than after other break crops. Part of the yield benefit is caused by changes in soil microbiology, particularly the enhancement of growth of beneficial soil micro-organisms.

In addition, the nitrogen effect of protein crops increases yields of subsequent crops further where they receive low or moderate levels of fertiliser. The size of this nitrogen-related yield benefit also depends on the species of the legume crop; high-biomass crops such as faba bean generally give a greater effect than low-biomass crops such as chickpea. Similarly high biomass legumes grown only for the residue (green manuring) provide a greater effect than the residues of legumes harvested for grain. This positive yield response persists and may affect a second or even third cereal crop (Evans et al. 2003). The size of the break-crop effect varies also with site characteristics, and is generally lower where growth of the break crop is restricted due to poor availability of water or nutrients (Bachinger and Zander 2007, Kirkegaard et al. 2008).

2.1.3. Nitrogen transformations

Nitrous oxide (N_2O) is a powerful greenhouse gas. The IPCC (Intergovernmental Panel on Climate Change) provides an emission factor of 1.25% of fertiliser or crop residue nitrogen released as nitrous oxide. Most of the emission arises from the process of denitrification, which is the progressive conversion of nitrate into di-nitrogen, usually in conditions of low oxygen. In protein crops that are growing and fixing nitrogen, **little or no nitrous oxide is released**, and this is a significant and positive environmental impact. However, the crop residues degrade after harvest and the mineral nitrogen released from them contributes to nitrous oxide emissions in the same way as those from the residues of other crops.

Some of the nitrate dissolved in soil water **leaches into groundwater**. Since protein crops are generally not fertilised with additions of mineral or organic nitrogen fertiliser, leaching in the year of growth is reduced. However, nitrate released from the breakdown of their nitrogen-rich residue can contribute to leaching in the following season. Some very deep rooting legume crops such as lupins reduce nitrate leaching by taking up nitrates from deep layers of soil (Dunbabin et al. 2003).

Growing of short-season catch crops after legumes can capture the nitrate and minimise both leaching and nitrous oxide release. Thus the environmental impact of legumes on nitrate leaching and nitrous oxide release can be both positive, in the year of the crop, and negative, depending on the management of the crop residues.

2.1.4. Biocide applications

Reduced biocide (pesticide) use has a resource impact at the farm level and an environmental impact at agri-food system and global level. Reductions in overall biocide use can be expected as a consequence of the break-crop effect. However, the use of pesticides in protein crops should not be overlooked. Most broad-leaved break crops, including protein crops, receive as much pesticide as mainstream cereals (Kirkegaard et al. 2008).

Economic analyses by von Richthofen et al. (2006b) assumed that pesticide application in cereals grown after legumes can be reduced, leading to a 20-25% reduction in pesticide costs for the succeeding crop. Nevertheless, assessed over whole cropping sequences, the amount of pesticides used in sequences with and without protein crops is about the same. The environmental impact depends on the specific pesticides used. In one out of four case studies (in Saxony-Anhalt, Germany), the terrestrial ecotoxicity potential was 7% lower for the rotation with protein crops due to lower amounts of problematic pesticides used (von Richthofen et al. 2006b).

2.1.5. Impacts on biodiversity

By providing nectar and pollen, the mass-flowering of protein crops contributes to the maintenance of populations of **wild and domesticated bees** (Westphal et al. 2003, Köpke and Nemecek 2010). This is the basis of much of the above-ground benefit to biodiversity. Protein crops have little effect on larger fauna. Kopij (2008) noted that there was little change in the bird fauna from a zone in southwestern Poland where faba bean and clover disappeared from cultivation. Increases in populations and diversity of small animals involved in the degradation of plant residues, including earthworms and springtails, have been noted under perennial forage legumes (Eisenhauer et al. 2009, Sabais et al. 2011, Annex 3) and the Legume Futures project is assessing whether the same happens under annual legume protein crops.

Little research attention has been given to the biodiversity effects of legumes in whole rotations and at farm level. An LCA on rotations with and without grain legumes highlighted the positive **biodiversity impact of the legume-supported rotation** (Nemecek and Baumgartner 2006), but without setting out the mechanisms. Very favourable impacts were found for the species richness of wild flora, small mammals and wild bees. Some of the effect is attributable to the different sowing times of different crops. Protein crops are generally sown in spring rather than in autumn, in contrast to cereals, particularly in north-western Europe. Over-wintered stubble provides combined forage and cover for small mammals, birds and insects that is not found in low-growing winter cereal crops (Potts 2003, Evans et al. 2004).

2.1.6. Effects on soils

Soil organic carbon

Protein crops and forage legumes make larger contributions to soil organic matter (Table 3) than most other crops, **providing short-term carbon storage as well as benefits to soil structure and composition**. This provides an environmental benefit from sequestering some CO_2 from the atmosphere, with resource effects from higher crop yields due to improved soil quality.

Table 3: Soil organic matter balance effect of major legume and non-legume crops derived from long-term experiments in Germany

Crop	Organic matter balance (t/ha/yr)[1]
Potato	-1.80
Silage maize	-1.35
Cereals, sunflower, maize (grain)	-0.70
Grain legumes (straw harvested)	0.35
Grassland	1.05
Lucerne[2]	1.80
Clover-grass[2]	2.10

[1] 1 t of organic matter containing 50 kg N and 580 kg C
[2] In the first year of production

Source: Leithold et al. (1997)

Switching from cereal monoculture and conventional soil cultivation (e.g. ploughing) to a combination of protein crops in rotation with cereals and reduced tillage stimulates the accumulation of 0.5-1.0 t of soil organic carbon per hectare per year. Where the practice is continued, such an accumulation of soil organic matter continues for a number of years until a new equilibrium is reached, with the legume component of the cropping sequence contributing up to 20% of the carbon gain (West and Post 2002, Wu et al 2003, Hernanz et al 2009). Nevertheless, this effect is not always found. The legume effect was not detected in a comparison of continuous wheat with wheat-faba bean rotation in a Mediterranean system (Lopez-Bellido et al 2010), and the effect of the legume can be negative if it is a low dry-matter producer such as lentil, or if the crop replaced in the rotation is a high dry-matter producer like maize (Lemke et al. 2007). Soil organic carbon content is reduced by bare fallow as the organic matter is oxidized by microbes and there is little input from fresh plant matter. The effect of soil carbon sequestration is more clearly shown for forage legumes than for protein crops, primarily because forages are in the ground 365 days per year, often for more than one year, and tend to have a high root biomass (Annex 3).

Soil phosphorus

The ability of legumes to **solubilise phosphate** from insoluble forms reduces the need for phosphorus fertiliser in the year the legume crop is grown and also benefits the phosphorus uptake of a cereal grown in mixture with the legume (Li et al. 2007). Fertiliser recommendations seldom take this effect into account. Our assessment is that this mobilisation has little effect on the overall long-term use of phosphorus at farm level and on losses of phosphorus causing water pollution. There is thus a small resource benefit for the farmer but little environmental impact beyond the farm gate.

2.2. European and global impacts

The described environmental impacts of protein crops at the crop level have the potential to reduce the overall environmental impacts of agricultural production more widely and improve the environmental profile of food products. **Life Cycle Assessment** (LCA) is a method that considers the environmental effect of processes within a production system and provides a means for comparing the environmental impacts and resource use of commodities, products and processes. LCA has particular strengths in assessing impacts at the continental and global levels as it rigorously quantifies the GHG emissions and other environmental consequences (such as eutrophication and acidification) associated with a product throughout its life-cycle, from 'cradle to grave' (Brentrup 2004). Results are expressed in relation to impact factors, including fossil energy use, GHG emission, eutrophication, acidification, ecotoxicity, and land use. It is now widely used to inform policy development. The LCAs reviewed here assessed the environmental impact of protein crops in relation to the land used and the commodity output.

2.2.1. Assessments of crop products and cropping systems

Several studies have compared the life cycles of domestically produced pea and faba bean with imported soya bean and with other European crops (averages of rapeseed, cereals, potatoes; Cederberg and Flysiö 2004, Eriksson et al. 2005, Van der Werf et al. 2005, Nemecek et al. 2005). In order to take into account the effects of growing protein crops on the cropping system, Nemecek and Baumgartner (2006) compared crop rotations with and without protein crops (mostly pea) at four sites. These LCAs also consider the legume's effect on subsequent crops and on the choice of crops that are replaced when protein crop production is increased.

It should be noted that the reviewed studies over-estimate GHG emissions from legumes due to applying pre-2006 methodologies that assumed direct emissions of nitrous oxide during legume growth. Based on recent research findings, it is now accepted that there is little or no nitrous oxide emission from a legume during its growth, but there are emissions from the residue (See Section 2.1 and Annex 2).

In most cases, European-grown protein crops (mostly pea) are associated with significantly **reduced fossil energy use, GHG emissions, ozone formation and acidification** compared to imported soya bean and other crops on a per unit product basis (Table 4). Reductions in nitrogen fertiliser use were the main reason for the reduction in energy inputs and associated emissions. However, the results for cropping systems were greatly affected by the assumptions about the crop being replaced by the protein crop. For example, the displacement of grain maize with the avoidance of the large amounts of energy used in drying the maize grain dominated the environmental benefits of the switch to the protein crop in a Swiss study. In a case in Spain, the protein crop replaced an unfertilised crop (sunflower), so no fertiliser savings occurred, and small or even negative environmental effects resulted from the inclusion of protein crops in the cropping system.

However, the environmental benefits of protein crops are **constrained by low yields** which limits the environmental benefits on a per unit product basis (see also the contrasting impacts on landuse, Tables 4 and 5). Low yields led to non-significant effects on energy use and negative effects on GHG emissions and ozone formation per kg product in a Swiss case (Nemecek et al. 2005). In the comparisons of crop rotations, such yield differences are not factored into the assessment but reduced environmental benefits due to low yields have also been noted (Nemecek and Baumgartner 2006, Baumgartner et al. 2008).

Many studies show that the effects of protein crops on **eutrophication**, i.e. the abundant accumulation of nutrients, are the result of two counteracting processes: nitrate emissions to water from the legume crop itself are low, which leads to very favourable effects of pea and faba bean compared to other domestic crops, but emissions in the subsequent crop are frequently reported to be higher due to losses from the N-rich legume residues, combined with longer uncropped periods before or after legume cultivation due to their shorter growth periods in comparison with autumn-sown crops. Therefore, the outcome of the assessments of protein crops range from very positive to very negative, and the comparisons of crop rotations reveal non-significant to somewhat negative effects of including protein crops (Table 4).

The effects of including protein crops in crop rotations on **ecotoxicity**, i.e. the negative impacts of biocide applications, could not be determined due to differences between assessment methods (Nemecek and Baumgartner 2006). The study assumed that the diversification of the rotations, leading to lower shares of cereals (including maize), would reduce disease pressure and pesticide applications in cereals, but the application of insecticides in legumes off-set this benefit.

It can be concluded that the production of protein crops generally has very favourable effects on most environmental impacts of crop production, except for eutrophication which may be differently affected. However, the effects may be reduced by the frequently low yields and by associated changes in cropping systems.

Table 4: Comparison of the results of LCA studies of protein crop products compared to other crops (%)

Region	% change in environmental impact						
	Energy demand	GHG emission	Ozone	Eutrophi-cation	Acidi-fication	Ecoto-xicity	Land-use
Comparison of European-grown pea to other crops[6] (per kg produce)							
Sweden[1]	-27	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Sweden[2]	-35	n.s.	n.s.	75	-12	n.s.	n.s.
Switzerland[4]	n.s.	11	25	-52	-48	n.s.	n.s.
Comparison of European-grown pea to imported soya meal/cake (per kg produce)							
Sweden[1]	-70	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Sweden[2]	-78	-57	n.s.	-50	-87	n.s.	32
France[3]	-64	-44	n.s.	-17	-67	n.s.	-58
Comparison of crop rotations with protein crops to those without (per ha land)							
Germany[5]	-14	-12	-10	n.s.	-17	(-)[7]	n.s.
France[5]	-11	-8	-6	n.s.	-18	(-)	n.s.
Switzerland[5]	-31	-9	-15	10	-14	(+)	n.s.
Spain[5]	n.s.	13	6	15	n.s.	n.s.	n.s.

Colour coding[4]	very favourable	favourable	n.s., not significant	unfavourable	Very unfavourable

Source: Calculations based on data from: [1]Cederberg and Flysiö (2004), [2]Eriksson et al. (2005), [3]Van der Werf et al. (2005), [4]Nemecek et al. (2005), [5]Nemecek and Baumgartner (2006), [6]other crops: average of wheat, barley, rapeseed, [7]conflicting results of different assessment methods.

2.2.2. Assessments of protein crop-based animal production

As the vast majority of protein crop commodity is **used in animal feeds and provides an alternative protein source to imported soya bean**, the question arises as to how the increased use of European-grown protein crops affect the environmental performance over the life cycle of animal products (meat, milk, eggs) based on such feeds.

The role of feed crop production on the life-cycle effects of animal products is high. In the life-cycle of livestock commodity products (carcass meat, milk etc), feed production accounts for:

- 50-75% of energy consumption,
- 47-88% of greenhouse gas emissions,
- 50-98% of eutrophication,
- 28-98% of acidification,
- >90% of ecotoxicity, and
- >96% of land use

(Blonk et al. 1997, Eriksson et al. 2005, Van der Werf et al. 2005, Ellingsen and Aanodsen 2006, Nemecek and Baumgartner 2006, Katajajuuri 2007, Baumgartner et al. 2008).

The comparison of animal products based on different feeding regimes is not simply a function of the environmental benefits of legumes, but also depends on the different feeding values of the components and associated changes in feed composition required to maintain a high animal performance. In many studies, inclusion of pea in feed formulas partially replaced both soya and cereals, since pea contain large amounts of starch as well as protein. There are nutritional constraints on the extent to which soya protein can be replaced by other protein crop sources in conventional commercial farming systems[3]. In addition, changes in animal productivity and excretions of nitrogen compounds are considered.

Besides crop production, the transport-related environmental impacts can in some cases be significantly reduced by replacing soya bean meal with European grain legumes (Baumgartner et al. 2008), but often the difference between overseas imports by sea and EU inland transport by canal, rail and road to feed compounding industries is smaller than one might expect. Differences in transport have generally minor effects on the overall environmental impacts of end products[4].

In most studies, the **fossil energy use** required for the production of a unit of animal product **and the associated GHG emissions decreased** where European-grown protein crops are used (Table 5). The reductions were caused by reductions in transport and partial replacement of cereals in feeds (see above). Nevertheless, Houdijk et al. (2013) found that emissions per unit of meat product were similar for soya and the European-grown grain protein based diets. However, incorporating land-use change (deforestation and destruction of grasslands in South America) into the LCA resulted in the European-grown protein diets having an advantage over the soya-based diets in terms of GHGs (Topp et al. 2012).

[3] Pea and faba bean have lower protein concentrations and different protein qualities than soya, so their inclusion at 10-24% of feed is required to replace soya that is included at 8-13% of feed (Cederberg and Flysiö 2004, Eriksson et al. 2005, Nemecek and Baumgartner 2006, Baumgartner et al. 2008, Köpke and Nemecek 2010, Houdijk et al. 2013).

[4] Transport contributes 4-27% of energy demand, 2-15% of GHG emissions and around 18% of acidification in the studies listed hereafter.

Table 5: Comparison of results of LCA studies of animal products produced using different feed compositions (%)

Region	% change in environmental impact						
	Energy demand	GHG emission	Ozone	Eutrophi-cation	Acidi-fication	Ecoto-xicity	Land-use
Comparison of soya-based to domestic legume-based feed (per kg end-product)							
Sweden, pork[1]	-16	-13		-31	-40	-36	n.s.
Sweden, pork[2]	-19	-10		n.s.	n.s.		24
Germany, pork[3]	n.s.	-5	n.s.	n.s.	n.s.	(+)[5]	n.s.
Spain, pork[3]	-6	n.s.	n.s.	17	n.s.	(+)	32
France, chicken meat[3]	-6	-10	n.s.	n.s.	n.s.	(+)	n.s.
France, eggs[3]	-4	-10	-5	n.s.	n.s.	+	n.s.
UK, milk[3]	-9	n.s.	n.s.	n.s.	n.s.	n.s.	n.s.
Comparison of soya-based to farm-produced legume-based feed (per kg end-product)							
Germany, pork[3]	-19	-16	-25	-11	-10	n.s.	n.s.

Colour coding[4]	**very favourable**	**favourable**	**n.s., not significant**	**unfavourable**	**Very unfavourable**

Source: Calculations based on data from: [1]Cederberg and Flysiö (2004), [2]Eriksson et al. (2005), [3]Baumgartner et al. (2008), [4]Nemecek and Baumgartner (2006)[5] conflicting results of different assessment methods.

Feeding European-grown protein crops has shown **little effect on ozone formation, eutrophication, acidification, ecotoxicity and land-use** (Table 5). Ozone formation and acidification were positively affected in one case. Eutrophication was in one case negatively and in one case positively affected, and ecotoxicity effects depended on the assessment method. The amount of land required for feed production was very negatively affected in two case studies, but not significantly so in all others.

On-farm feeding of home-grown legumes increases benefits further, as shown in one case study that considered **on-farm production** (Table 5, Baumgartner 2008). In this case study, greatly reduced transport led to lower energy demand, and greater advantages in terms of GHGs, ozone formation and acidification (Baumgartner et al. 2008). However, an on-farm feed producer may not achieve the efficiency of animal feed manufacturers, leading to higher feed costs and lower animal performance from farm-produced feeds.

Further optimisations of feeding systems with respect to environmental impacts are possible. As the production of roughage feed such as arable grass-clover leys or hay from meadows may have much lower environmental impacts than that of concentrate feed crops, increased roughage feeding of dairy cows may improve environmental effects, but may also lead to higher GHG emissions from digestion processes. Improved nutritional qualities (through plant breeding) of grain legumes would reduce environmental impacts from manure management. Baumgartner et al. (2008) suggested that feed optimisation models (defining the most cost-effective feeds) should be extended with environmental optimisation criteria, which would require research into the development of such models[5]. European-grown grain legumes can also provide environmental benefits in other end-uses, such as human nutrition (partially replacing meat in diets) or in feeds for farmed fish (partially replacing soya feeds or fish meal)[6].

It is concluded that a greater inclusion of European protein crops in feed improves the environmental performance of animal products, especially with respect to fossil energy use and GHG emissions, as well as other impact categories in some cases. Improvement of yields through research and agronomic innovations could greatly increase these environmental benefits. However, the European production of protein crops, even if it were significantly increased, can only satisfy a small share of the European feed demand at current levels of crop yield, animal production and consumption[7].

2.3. Conclusion

This assessment of the scientific evidence shows that increasing protein crop production in Europe would bring benefits for the environment and resource use at a range of scales, from the field to the global. Protein crops require little or no nitrogen fertiliser and they are efficient in using reserves of phosphorus in the soil. The organic matter content and water-absorbing capacity of the soil is often increased, thus increasing the crop-production capacity of the soil, reducing erosion and runoff, and potentially storing carbon for decades. They break the cycle of soil-borne diseases of cereals so less pesticide is needed on the following crop. The benefits in terms of fertiliser and pesticide use and the yields of other crops on the farm are significant. This results in a range of benefits for the farm which have wider environmental benefits through reduced fertiliser production in particular.

Protein crops provide several direct environmental benefits, independent of resource effects, balanced by some risks. The emission of nitrous oxide from protein crops is generally low. The clear benefits for biodiversity are detected above-ground and in the soil. Protein crops support populations of wild and domesticated bees, other pollinating insects, and beneficial soil bacteria.

The provision of protein is the source of a large proportion of environmental impacts arising from food production (Westhoek et al. 2011). This is due to the intrinsic connection between protein synthesis and the nitrogen cycle which is the source of emissions to water and air, and energy consumption in nitrogen fertiliser production. In this context, the production of protein crops would be an important component of a range of measures to raise the environmental performance and resource use efficiency of our agri-food systems.

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[5] Models that take the environmental effects of feedstuff production into account do not seem to exist. Castrodeza et al. (2005), Dubeau et al. (2011) and Oishi et al. (2011) described feed formulation models that enable an optimized nutrient composition that reduces N and P excretion. Lara (1993) developed a feed formulation model that aims not only at low cost, but also at a maximised inclusion of the ingredients available in the farm.

[6] Faba bean, pea, lupin and soya bean exudates can be used in aquaculture feeds to reduce the use of fish meal with faba bean and pea giving the best results for Atlantic salmon (Aslaksen et al. 2007) and white lupin and pea being equally good for rainbow trout (Zhang et al. 2012). Supplementation with amino acids is sometimes required when feeding plant proteins to fish.

[7] When we consider the total compound feed production in the EU (150 million tonnes, EUFETEC 2010) and the average pea yield (see Chapter 1), an EU-wide replacement of only 1% of the average compound feed by European fodder pea would require an increase in production areas to their historic peak in the late 1980s.

3. THE CAP AND RELATED POLICIES

KEY FINDINGS

In general, the development of the Common Agricultural Policy (CAP) of the EU from direct price support to area-based support decoupled from production has contributed to drivers causing decline in protein crop production. Under the current CAP, Article 68 and the Complementary National Direct Payment (for new member states) constitute the main direct support schemes for legumes under Pillar 1. Under Pillar 2 (the rural development programme), agri-environmental schemes are the main measure. They are Member State specific and not all countries use them to support protein crop production.

Against this background (as of March 2013), the Commission Proposal (issued in 2011) sets out that direct coupled support for legumes should be possible under the reformed CAP. The Commission proposal also sets out measures to "green" decoupled payments which are relevant to protein crops: crop diversification and Ecological Focus Areas (EFA).

In response, the mandate for negotiations concerning direct payments adopted by the European Parliament on 13 March 2013 proposes that land used for legumes should be counted as a contribution to a farm's Ecological Focus Area. The Parliament also proposes that the EFA should be set at only 3% of the farmed area until 2016. The Parliament also called for a European protein strategy and called for improvement of the conditions for providing coupled support for legumes.

The subsequent Council statement proposes that 5% of farmed land be allocated to EFAs from the outset, including land used for legumes. It agrees with the Commission proposal on direct coupled support.

Negotiations continue.

The Common Agricultural Policy (CAP) of the EU has been the central driving force of agricultural development since its inception in 1962. Being one of the first common policies for several European countries, it aimed at fostering food security and stabilising agricultural markets by introducing product and price support. Consequently, as the environmental costs of production became more apparent, various reforms of the CAP emphasised environmental and rural development measures and greater exposure to market conditions to halt over-production. This was achieved largely by decoupling farm subsidies from production activities and output. This chapter discusses the most important steps in the development of the CAP relevant to protein crops, the current CAP and outlines the current reform process.

3.1. A short history of protein crop support in the CAP

The changes in the support of legumes in the CAP reflects the general development of the CAP towards a support system decoupled from production. Protein crops have, over long periods of time, been subject to special support measures to overcome competitive disadvantage compared with cereals in particular. Table 6 outlines various policy mechanisms used to support protein crops in the CAP.

Table 6: Development of EU-wide policies to support protein crops

Cereals	Soya bean	"Protein crops": pea, faba bean, lupins	"Specific grain legumes": chickpea, lentil, vetch grain
Begin of support for legumes			
Since 1958: Price support provided as "deficiency payments" to producers	1974: Price support provided as "deficiency payments" to producers (Council of the European Communities 1974) 1979: payments directed to processors	1978: Price support for animal feed as "deficiency payments" to the first processor (Council of the European Communities 1978)	
	1986: MGA[1] set	1982: Inclusion of protein crops for food 1988: MGA set	1989: Uniform area payment of 75 ECU/ha for a MGA of 300 000 ha (Council of the European Communities 1989)
1992: MacSharry Reform (Council of the European Communities 1992)			
Reduction of price support, replacement with regionally uniform area payment: basic amount multiplied with regional reference yield, this led to area payments of several hundred €/ha			1995: 150 ECU 1996: 181 ECU for MGA 400 000 ha
1993: 25 ECU/t 1995: 45 ECU/t 2000: 59 €/t 2001: 63 €/t	1993: 63 ECU/t Inclusion of soya bean with "Oilcrops"	1993: 79 ECU/t 2000: 73 €/t	2000: Council of the European Union (2000): separate MGA for vetches and for chickpea and lentil, since reduced payment for vetches due to exceeded MGA
2003: Introduction of SPS[2] (Council of the European Union 2003)			
Inclusion of all area payments into SPS between 2005-2006, only France and Spain retained 25% of coupled payments			
-	-	"Protein premium" - uniform area payment: 56 €/ha with MGA in 17 MS, complementary national payments in 3 MS	-

[1] MGA - maximum guaranteed area, [2] SPS – single payment scheme.

Sources: LMC International (2009), Cavaillès (2009).

The first Europe-wide policy on legumes was introduced after 1973, when the US placed an embargo on soya bean exports due to production shortages and overall high global commodity prices. Consequently, the European Economic Community sought to reduce its dependency on imported soya by introducing price support for home grown soya in 1974. Furthermore, price support was introduced for the "protein crops" pea, faba bean and lupins grown for livestock in 1978 and for the same crops grown for food uses in 1982. The support was granted in the form of a "deficiency payment" to producers, i.e. a payment based on the difference between a set minimum price and the price of soya bean imports. This support led to an expansion in the areas cropped to pea and soya bean, whereas faba bean and lupins were little affected. It also caused, at least for some years, strong competition between feed and food end uses, because the subsidy for lupin, pea and faba bean was tied to feed use between 1978 and 1982. To alleviate competition between legume species, support for chickpea, lentil (both for food) and vetches (for feed) was introduced in 1989 in the form of uniform area payments that were continued until 2005/06. Several grain legume species such as common bean, as well as forage legumes in general, did never receive EU-wide support under the CAP.

In 1992, the **MacSharry reform** started shifting price support to direct support of farmers. Area-based direct payments were introduced for protein crops, cereals and oilseed crops to compensate for the decrease in price support. The area-based payment was calculated using regionally specific reference yields for categories of crops such as "cereals" and "other cereals" (including protein crops and soya). The reference yield was multiplied with a specific amount determined in ECU/t, resulting in a per hectare support that was uniform within a region but differed between regions and between crops. For protein crops, this area-based payment was introduced with the basic amount set at 65.00 ECU/t, whereas soya bean was classified as an "oilcrop" and received 16.50 ECU/t less. The region-specific reference yield was the same for both the oilcrops and the protein crops (LMC International 2009). Partly due to this lower support for soya bean, the area grown declined sharply.

In addition, the 1992 reform introduced agri-environment programmes as compulsory component of member states' rural development plans. Within these, many member states included the support of legumes (see below).

The 1992 **Blair House Agreement** between the EU and the USA placed a number of restrictions on the support of certain oilseeds, including soya bean. This Memorandum of Understanding was negotiated during the GATT Uruguay Round of multilateral trade negotiations. It limited the supported area to 5.5 M ha, including the cultivation of oilseeds for non-food purposes on set-aside land (EC-DG Agri 2011). In 2000, intervention prices were lowered further and direct payments increased. Protein crops then received 9 ECU/t more than cereals and oilcrops. The Blairhouse agreement is now redundant, although it remains in force (see below).

Decoupling was introduced in the **2003 reform**. Decoupling means that payments were no longer linked to the production of a specific product. Instead, direct payments are now made to farmers on the basis not of what they produce but on the basis of subsidies they received in the past. Full implementation varied between member states and occurred between 2005 and 2007. All previously existing direct payments were replaced by an EU-wide uniform Single Payment Scheme (SPS). Each farm payment was made conditional on farmers' compliance (cross-compliance) with existing environmental and animal welfare legislation and a set of good agricultural and environmental practices. In the case of legumes, the individual member states were given the **option to continue specific support** using the following measures (LMC International 2009):

- Complementary national direct payments (CNDP, details see below) within national budgetary envelopes in new member states. Lithuania and Slovenia use this specifically for legumes but Hungary, Estonia and Poland provided support within a larger group of crops (LMC International 2009).

- The protein premium provided special aid of 56 €/ha to protein crops on top of the SPS subject to a maximum guaranteed area of 1.65 M ha for the EU. This measure was used by Austria, Belgium, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, Malta, the Netherlands, Portugal, Slovenia, Spain, Sweden, and the UK. It was phased out in 2012.

- Option to continue 25% of the coupled payments for cereals, oilcrops and protein crops, and reduce the SPS payments accordingly. This was applied by France and Spain, on top of the special aids. This measure was phased out in 2010.

Therefore, 20 of the 27 EU member states continued support for protein crops after the 2003 reform. The payments were reduced overall. The total coupled aid budgets of EU member states for protein crops dropped from more than 500 M in 2004 to 70 M € in 2005 (LMC International 2009). In France, the direct payment premium for protein crops amounted to a 15% higher payment compared with payments given for oilcrops and cereals (which at that time were still partly coupled), but even this amount is regarded as not to have compensated the economic disadvantages of pea as compared to cereals (Cavaillès 2009). For the whole of Europe, the relative profitability of pea did not change significantly as a result of the 2003 reform, but production decreased in areas suited to pea and increased in lower yielding areas (LMC International 2009, Kamp et al. 2011), and pea output changed accordingly (see also section 1.3.2). It remains uncertain as to how much of the reduction in pea production is attributable to the reforms and how much is due to agronomic causes.

In the context of the **Health Check** (2008), it was decided that coupled direct payments for plant products should be decoupled completely in order for the sector to become more market oriented. The protein premium was decoupled across the EU by 2012 and integrated into the single payment scheme. The Health Check resulted in specific regulations on phasing out market intervention and on helping farmers adjust to the consequences.

3.2. Support for protein crops under the current CAP

The CAP has been based on two pillars since 2000. Pillar 1 includes market measures and direct payments, whereas Pillar 2 covers rural development measures aimed at improving living conditions in rural areas, including but not restricted to agriculture. Pillar 1 is still the main component of the CAP in financial terms, but efforts have been made to shift resources from the first to the second pillar.

3.2.1. Pillar 1: Market measures and direct payments

Market measures (Council of the European Union 2007)

In international trade policy, soya bean is classified as an oilseed, not a protein crop. There are no import tariffs (Council of the European Communities 1987) on oilseeds. Hence, soya bean and soya bean meal may be imported duty-free. The ready availability of soya bean at low cost on the world market is a major factor behind the decline of legume cultivation in Europe and the dependence on imported vegetable proteins. The only protein crops on which there is a tariff are faba bean (3.2%) and sweet lupins (2.5%) (EC-DG Agri 2011). Decoupling following the reform in 2003 and the abolition of specific payments for energy crops effectively made the Blair House Agreement redundant, although it remains in force. There is currently no restriction of the production of oilseeds in the EU.

Direct payments (Council of the European Union 2009)

Direct payments under Pillar 1 include all payments to farmers which are not made under the rural development scheme. They therefore include all payments mentioned in Table 7 unless otherwise specified. Under the current CAP, **Article 68** is one of the most widely used options for direct support for legumes under Pillar 1. It states that member states may choose to provide direct payments for specific crops of up to 10% of their national ceiling under the single payment scheme (SPS), for a defined set of purposes (EC-DG Agri, no date). These include support for:

1. protecting or enhancing the environment;
2. improving the quality of agricultural products;
3. improving the marketing of agricultural products;
4. practising enhanced animal welfare standards;
5. specific agricultural activities entailing additional agro-environment benefits;
6. payments for disadvantages affecting farmers in specific sectors (dairy, beef and veal, sheep and goat, and rice) in economically or environmentally sensitive areas as well as for economically vulnerable types of farming;
7. top-ups to existing SPS payment entitlements in areas where land abandonment is a threat;
8. risk assurance in the form of contributions to crop, animal and plant insurance premiums; and
9. mutual funds for animal and plant diseases and environmental incidents.

Six countries currently use Article 68 to support protein crops: Finland, France, Lithuania, Poland, Slovenia and Spain (EC-DG Agri 2010).

The **complementary national direct payments** (CNDP; Article 132 in EC 73/2009, Council of the European Union 2009) provide a further mechanism for the support of protein crops. These are available to the twelve member states that joined the EU after 2003. On accession, they could apply the transitional Single Area Payment Scheme (SAPS), a simplified decoupled income support scheme. CNDPs are a top-up payment linked to production to increase the direct support level. Most of the new member states use the CNDPs for the livestock sector or other sectors where the standard EU support scheme would be much higher than the SAPS area payment (EC, no date). Only Lithuania and Slovenia opted for CNDP payments specifically for legumes, but Hungary, Estonia and Poland provided support within a larger group of crops (LMC International 2009). Table 7 presents details of support for legumes under Pillar 1 per country.

3.2.2. Pillar 2: Rural development policy (Council of the European Union 2005)

The second pillar of the CAP supports rural development. Three objectives lie at its core: (1) improving the competitiveness of the farming and forestry sectors, (2) enhancing the environment and the countryside and (3) improving the quality of life in rural areas. These objectives are implemented through components called axes, with a fourth one added for bottom-up approaches with the same three objectives. For each of these axes, a set of activities (called measures) is available to member states out of which they or regions within them can choose and include them in their regional rural development programmes. The costs of these activities are shared between the Member State, the EU, and third parties. The following activities are potentially relevant to the promotion of legumes.

Axis 1 is concerned with the **competitiveness of agriculture**. Some member states interpret this as including investments that increase the environmental sustainability of agriculture, but no evidence has been found that these are actually used for the support of protein crops. Specific measures under axis 1 can be used for information campaigns on legumes (111 and 114) or for supporting cooperative schemes for developing legume cultivation (124 and 141). We have no detailed information about the content of individual programmes.

Table 7: Support to legumes under Pillar 1: Article 68 and CNDP

Country	Details	Details
Finland	Support under Article 68: 6.5 M € for protein and oilseed crops in 2011. With an area of 83 000 ha (in 2009), this amounts to approximately 78 €/ha.	Maa- ja Metsätalousministeriö (2011), EC-DG Agri (2010)
France	Support under Article 68(1)(a)(i), 2010 and 2011 in total: 80 M € Pea, faba bean, lupins (100 €/ha in 2010, €140 in 2011) Forage legumes: lucerne, clover, sainfoin (Onobrychis spp.); payment of 14 €/ha in 2010, 16 €/ha in 2011	EC-DG Agri (2010), Ministère de l'Agriculture, de l'Alimentation, de la Pêche, de la Ruralité et de l'Aménagement du Territoire (2011)
Lithuania	Support provided under Article 68 and under CNDP	LMC International (2009), EC-DG Agri (2011)
Poland	Support provided under Article 68 (total 2010-2011: 21.6 million € - 163.89 €/ha per hectare in 2012 Or support provided under CNDP for pea, faba bean and lupins. In 2012, this payment for protein crops was 52 €/ha	Communication with the Polish Ministry of Agriculture (2013)
Slovenia	Support under Article 68 and under CNDP	LMC International (2009)
Spain	Support under Article 68 (1)(a)(ii): National quality legume programme; 2010 and 2011: 1 million €/yr	EC-DG Agri (2010)

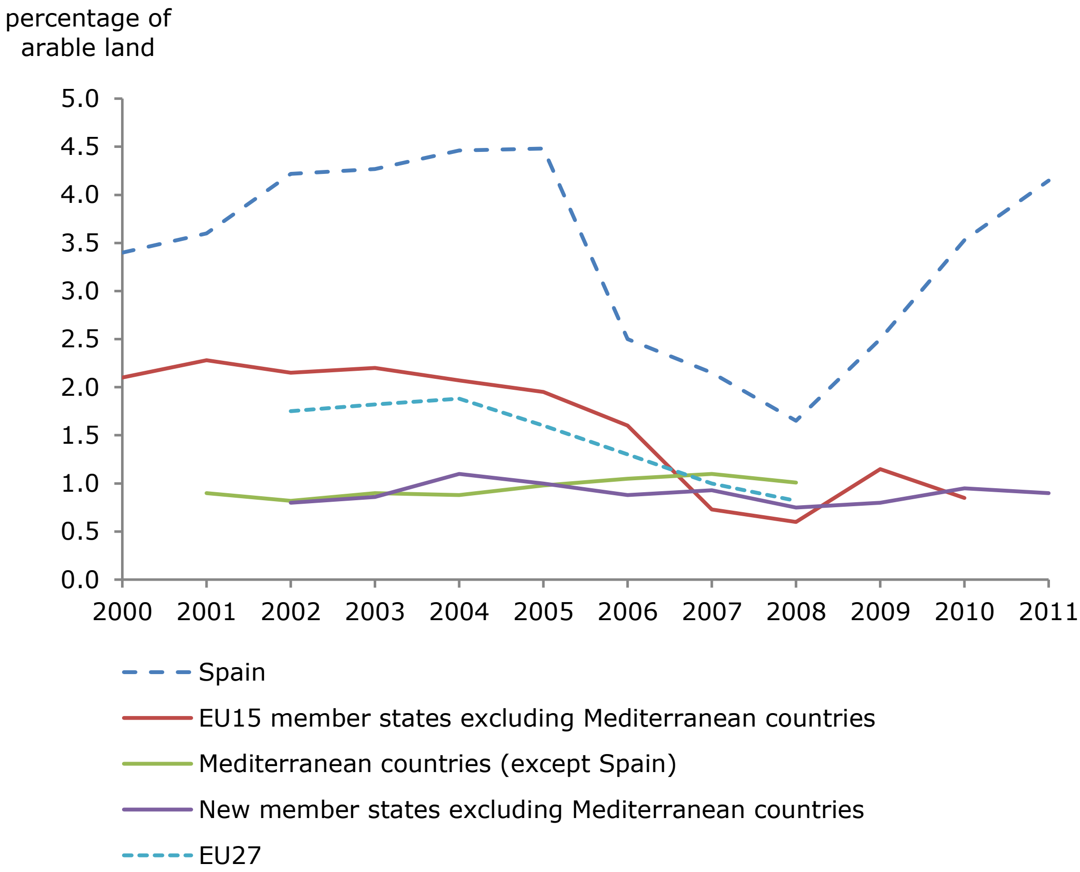
Axis 2 is the **environmental axis**. Measures 211 and 212 cover support paid to farmers in less favoured areas. In order to qualify, farmers must fulfil certain conditions which may include the use of crop rotations. Probably the most frequently used measure for promoting legumes in Pillar 2 is the agri-environment schemes under measure 214 (Article 39, Council of the European Union 2005). As for all measures in Pillar 2, their design is up to the member states at national or regional level. The core conditions, however, apply EU-wide. Farmers applying to an agri-environment scheme offered by their Member State need to commit to a specific set of management practices favourable for the environment or animal welfare for a period of five years. In return, they receive an annual payment to compensate for the income foregone, additional costs and transaction costs that the measure implies. Annex 5 provides various examples of agri-environment schemes in different countries.

3.2.3. Impact of CAP policies

This section assesses the effects of the policies described above. Perman et al. (2003) gives various indicators for doing so: goal achievement, cost-effectiveness, long-term effects, and implications for other objectives. We shall focus here on the principal indicator, namely the impact of the policies on the areas under legumes, in different parts of the Union.

In the following section, we focus on the **percentage of grain legumes** (not including soya bean) relative to total arable land. In the EU as a whole (i.e. all present member states), grain legumes except soya bean covered about 2 M ha, or 1.8% of all arable land, in the period 2002-2004. By 2008 this had declined by more than half, to 900 000 ha or 0.8% of arable land. In 2009 grain legume cultivation (except soya bean) slightly recovered, to 1.3 M ha. At first sight the reduction up to 2008 appears to be a **reponse to decoupling**. The protein crop premium paid in recent years was not sufficient to stimulate recovery of cropping to the 2002-2004 level.

Figure 11: Area under grain legumes as percentage of arable land in the EU-27 (2000-2011)



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

Nevertheless, the situation differs between countries, and this provides insights into the effectiveness of other measures to promote protein crops: Article 68, the CNDPs, and measure 214 of the RDPs. Three groups can be identified (Figure 11):

(1) **The EU-15 member states other than Mediterranean countries** (Austria, Belgium, Denmark, Finland, France, Germany, Luxembourg, the Netherlands, Ireland, United Kingdom, Sweden). There was a sharp decline in the area of protein crops between 2003 and 2008, undoubtedly as a result of decoupling. Decoupling was introduced in different countries at different times, beginning in 2004 and completed in 2007, so the decrease was not simultaneous in all countries. The sharpest decline occured in 2007. This happened especially in UK, France, Austria, Denmark and Germany that had relatively large areas under cultivation. In some countries with lower proportions of arable land under protein crops, particularly Sweden and Finland, the area under cultivation dropped with decoupling, but recovered after 2008. In Finland this followed the introduction of protein crop support under Article 68 combined with contract growing of protein crops for feed processors. In Sweden the recovery may be attributed to the importance of organic farming in that country. Protein crop production remains important in the UK and Austria.

(2) The **Mediterranean countries** (Cyprus, Greece, Italy, Malta, Portugal and Spain). In general, the area of protein crops in these countries declined less than in other EU regions. This is partly attributable to the prominent role of food legumes in the regional diet, so the percentage of arable land under grain legumes reflects local demand for high value food grain legumes rather than high support payments. Cyprus, Greece, Italy and Portugal all have about 1% of their arable land under grain legumes, and this percentage has remained relatively stable. The situation in Spain is different where there was a decline in the area under grain legumes from 4.5% of arable land in 2006 to 1.7% in 2008, followed by a recovery to 3.5% by 2010. This can partly be explained by considerable yield losses caused by drought in 2007, which may have discouraged farmers from production. In addition, Spanish protein crop production was especially affected by the end of support for chickpea, lentil and vetches (which are not eligible for the protein premium). Vetches grown for grain for animal feed have been an important crop in Spain and have accounted for a about one third of the relatively large protein crop area in the past.

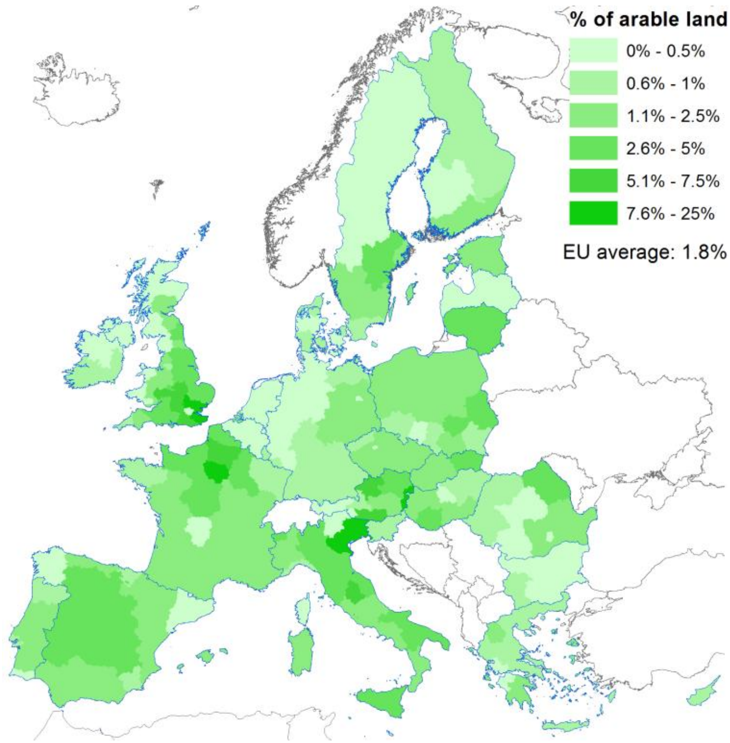
(3) **New member states other than Mediterranean** that joined the EU in 2004 and 2007 (Bulgaria, Czech Republic, Estonia, Hungary, Latvia, Lithuania, Poland, Romania, Slovakia, Slovenia). The availability of the protein crop premium of 56 €/ha increased the attractiveness of these crops compared with support prior to joining the EU. Although there was no immediate increase after these countries joined the EU, there was a gradual rise in cultivated area, with a particularly large increase in 2009 in Lithuania and Poland, and to a lesser extent in Estonia. In contrast, the cultivation of protein crops declined in Romania and Bulgaria continuing a trend that started long before they joined the EU.

The area of protein crops in the EU recovered from 2008 to 2009 and evidence suggests that this recovery can be attributed to the Rural Development Programme introduced in 2007. The availability of support under **Article 68**, introduced by Regulation (EC) 73/2009 (Council of the European Union, 2009) seems to have had an impact in Spain, Finland, Lithuania, and Poland where cultivation clearly increased from 2009 onwards. The decline continued in Slovakia. In France there was only a brief rise in 2009. That country has experienced a drastic increase in the incidence of *Aphanomyces* fungus that reduced the yield of pea in the main production areas (LMC International 2009) and this might explain the lack of recovery in cultivation there.

Figures 12 and 13 show the cultivation of grain legumes (this time including soya bean) per NUTS 2 region. The proportion of arable land under protein crops for NUTS 2 regions is presented in Figure 12. Figure 13 shows the percentage changes in these areas between 2000 and 2010 (or from 2003 for those countries where there was no data available for 2000). Most of the largest percentage changes are from very low initial values, where the choices of a few farmers can make a large difference (see Bulgaria, Denmark, Finland and Ireland). Figure 12 and 13 indicate that:

- There are large regional differences both in areas under legumes and in rate and direction of change. In some countries, there has been a sharp decrease in regions where legume cultivation was important (Eastern Germany, Veneto in Italy, Picardy in France).
- Several countries with a high proportion of grain legumes provided extra support under either Pillar 1 (Art. 68 or CNDP) or Pillar 2 (measure 214 of the RDP) or both. In Poland and Ireland, these measures appear to have resulted in increased cultivation of grain legumes, and also in Slovenia, most of Central and Southern Italy, and Northwestern Spain (León) – but not in other parts of Spain, and not in most of France.

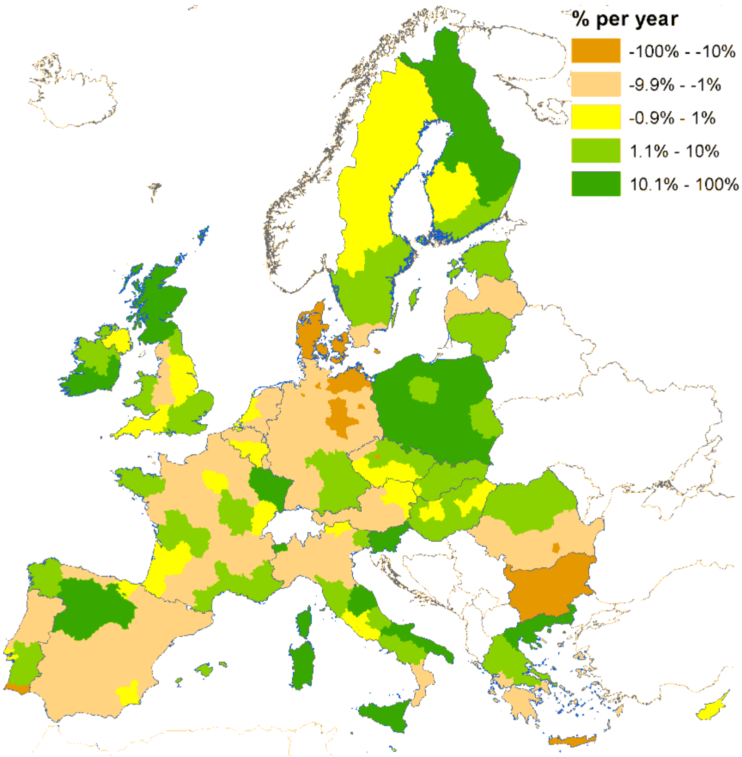
Figure 12: Proportion of EU-27 arable land used for protein crops in 2010[8] (%)



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

[8] Grain legumes as used here and in the following figures refer to the EUROSTAT definition which include field pea, broad and field bean, sweet lupin, and other dried pulses such as lentils and vetches.

Figure 13: Change in the proportion of EU-27 arable land used for protein crops (2000-2010) (%)



Source: Calculations based on EUROSTAT (2013)

3.3. Negotiations on the new CAP post-2013

At the time of completing this report, the negotiations between the European Commission, the European Parliament and the Council were progressing in response to the CAP reform proposals published by the Commission in 2011.

3.3.1. Proposals from the European Commission

The CAP reform proposals presented by the EC on 12 October 2011 for the period 2014-2020 aim to support food security, sustainable management of natural resources and rural territorial balance in the EU (EC 2011). The reform is presented as "a new partnership between Europe and farmers". Enhanced competitiveness, the environment and living conditions in rural areas are in its focus. Revenue from farming is among the lowest of all labour sectors in Europe, and Europe's farmers have to respect some of the world's strictest sets of rules regarding food safety, the protection of the environment and animal welfare, so the continuation of income support for Europe's farmers is considered justified (*ibid*.). An important objective of the Commission is the maintainance of farming as a viable economic sector, which also helps to take care of the environment as well as maintaining rural communities and landscapes.

While addressing income and food security, the reform seeks to increase emphasis on protecting and improving the environment. It is proposed that the system of two pillars remains in place, and **Pillar 1** (encompassing direct support and market mechanisms) would include a **"greening" component**. This means that 30% of direct payments would be paid to farmers only if they comply with three specific practices with a focus on environment and climate (EC 2011):

- ***Crop diversification**:* For farm holdings with more than 3 ha of arable land, at least three crops shall be cultivated, with each covering an area between 5% and 70% of the arable land.

- ***Maintaining permanent grassland**,* applying to grassland that has not been reseeded for at least five years.

- Establishment of ***ecological focus area*** applying to **7%** of the eligible area[9], excluding permanent grassland. This would include land left fallow, terraces, landscapes features, buffer strips and afforested areas.

According to the Commission proposal, the greening measures would apply to the whole area of a land-holding eligible for direct payments. Organic farms automatically benefit from the greening payment, but farmers in Natura 2000 areas would have to abide by the regulation to the extent that they are consistent with Natura 2000 legislation (EC 2011). These greening requirements come on top of cross-compliance, which remains a condition for all beneficiaries of the Single Payment Scheme.

Furthermore, the Commission proposal makes provision for a **voluntary coupled support scheme** (Article 38) "for specific types of farming or specific agricultural systems which are experiencing certain difficulties and which are particularly important for economic and/or social reasons" (EC 2011, p.8), including protein crops and other grain legumes (but not forage legumes, Article 38). This scheme can amount to 5% of the annual national ceiling (i.e., the maximum amount of agricultural subsidies per country), but can go beyond this in particular cases.

Pillar 2 will continue to include measures for rural development and use **agri-environment measures** as its main instrument. Pillar 2 will also include specific measures to support young farmers, rural networks and rural markets, and promote stronger links between farmers and consumers (EC 2012).

3.3.2. Response from the European Parliament[10]

On March 13, the European Parliament agreed on four mandates for negotiation on the CAP reform proposals (direct payments; rural development; financing, management and monitoring of the CAP; and single Common Market Organisation (CMO)).

The Parliament's response (EP 2013) to the Commission proposal addresses the use of **EFA** to support protein crop production by proposing that where the arable land covers more than 10 ha, (...) 3% of the eligible area shall become EFA. Additionally, EFA shall also include "land planted with nitrogen-fixing crops", thus including areas planted with legumes. This position differs from the Commission proposal in that it proposes a smaller total area of EFA and allows land used for legumes to qualify.

The Parliament also proposed that a **strategic plan for protein crop production** should be prepared: "In order to improve the environment, combat climate change and improve agronomic conditions, the Commission should, without delay, submit a strategic plan for

[9] Article 25(2) of the Commission proposal defines the term 'eligible area' as any agricultural area of the holding that is used for an agricultural activity or, where the area is used as well for non-agricultural activities, predominantly used for agricultural activities; or any area which gave a right to payments in 2008 under the single payment scheme or the single area payment scheme« (EC 2011, p. 36)

[10] In 2002, the European Parliament adopted a "Resolution on the cultivation of protein crops" (EP 2002) and in 2011 a Resolution on "the EU protein deficit: what solution for a longstanding problem?" (EP 2011), calling for measures to tackle Europe's protein deficit.

the supply of vegetable proteins, which will also enable the Union to reduce its very heavy dependence on external sources of supply. The plan should provide for more oil-protein crops and legumes to be grown under the common agricultural policy and should encourage agronomic research into suitable and productive varieties" (Amendment 104, Recital 29 a (new), EP 2013).

The Parliament also responded to the Commission's proposal to set up a **voluntary coupled support scheme** for specific types of farming, including protein crop production, the Parliament's statement elaborates it further. Instead of 5% (in justified cases, 10%) of the national ceiling that may be used for this specific support, the Parliament proposes to allow member states to use up to 15% of the national ceiling. Furthermore, the Parliament's position refers directly to protein crops: "**This percentage may be increased by three percentage points for those member states which decide to use at least 3% of their national ceiling in order to support the production of protein crops**" (Amendment 19, Recital 33, EP 2013). Furthermore, the Parliament statement proposes to justify this on "environmental" grounds.

3.3.3. Response from the Council

On March 19, the Council adopted its position[11]. The main positions regarding protein crops are the following:

- **EFA**: For holdings with an eligible agricultural area larger than 15 ha (excluding permanent grasslands), 5% of the eligible area from 1 January 2014 shall be ecological focus area (Council of the European Union 2013a). The 5% level is an increase on the Council's previous position which was 3%. Member states should decide whether or not to consider nitrogen-fixing crops as ecological focus area (Council of the European Union 2013b).
- The Council agrees on the Commission proposal to establish **coupled support** for specific crops, such as protein crops (Article 38 of the proposal).

3.4. Conclusions

Policy instruments are an important factor influencing the cultivation of protein crops in Europe. The area grown declined between 2003 to 2008 in the old member states. Since 2008, the area under grain legumes has slightly increased, although not to the previous level. This can partly be explained by the introduction of Article 68, a system of direct support for protein crops. This shows that the area grown responds to monetary incentives. Cropping in the Mediterranean countries is generally more stable because of domestic demand for grain legumes for direct human consumption.

Despite the importance of policy factors, legume cultivation is also affected by their economic and agronomic characteristics (see Chapter 1). In recent years, grain legumes have suffered from poor harvests in some countries due to regional disease problems and weather conditions and these factors have played a role in the decline in cultivated area (LMC International 2009).

The current CAP reform proposals include five elements relevant to protein crops:

- inclusion of nitrogen-fixing crops (i.e. legumes) in ecological focus areas;

[11] Latest Council documents: 7539/13, 7183/13, 7183/13 ADD 1, 7182/13 COR 1, 7183/13 ADD 2, 7539/13, 7539/13 ADD 1. Council documents can be assessed at http://register.consilium.europa.eu/

- continuation of voluntary coupled support, applied by member states in the context of Article 38;
- continuation of agro-environment schemes, negotiated and applied by member states;
- a call from the European Parliament for the Commission to prepare a strategic plan for the production of oil-protein crops and legumes to be grown under the common agricultural policy; and
- a proposal from the European Parliament that the EU should invest in relevant crop research.

4. STRATEGIC OPTIONS

4.1. Agroecological processes, environmental impacts and policy

Chapter 1 documents the decline in the production of protein crops in Europe since 1990. It identifies reasons for this decline: technological changes in agriculture, international trade, and policies. Chapter 2 describes resource and environmental effects of growing protein crops. Taken together, Chapters 1 and 2 show that the trend of decreasing protein crop cultivation coupled with increasing plant protein consumption by livestock has led to a large protein deficit and a range of resource and environmental challenges.

The processes that underlie protein crop production (Annex 2) and their impacts on resource use and the environment (Chapter 2) contrast with other crop types in a wide range of respects of relevance to public policy. They interact with the nitrogen cycle and with soil in ways unique in agriculture. The co-evolution with pollinating insects results in characteristics that have specific **effects on biodiversity**.

Our study of the agroecological and resource protecting processes in protein crops provides some guidance on where policy levers can act. Protein crops have far-reaching effects on agricultural systems through biological nitrogen fixation and the provision of organic nitrogen to succeeding crops, changes to soils from the deep rooting character of some legume species, net carbon accumulation, the mobilisation of soil phosphorus, diversification of cropping, suppression of weeds, pests and diseases, and protein synthesis and yield development. Here we describe the most important of these processes in terms of their relevance to the development of policy measures.

Biological nitrogen fixation (BNF) receives a great deal of attention from scientists and the policy community involved in cropping system development. In nature, BNF provides reactive nitrogen which is necessary for life. A shortfall of reactive nitrogen restricts growth of plants and animals but an excess can cause damage to the environment. Biological nitrogen fixation is the natural and renewable equivalent of synthetic nitrogen fixation in fertiliser manufacture.

Capturing and transforming fixed nitrogen within and between crops conserves reactive nitrogen in the soil-plant-farm system and therefore reduces the need for nitrogen inputs. There are several relevant policy levers, the overall purpose of which is to reduce the flow of reactive nitrogen into the agro-ecosystem. Our analysis of crop- and farm-level economic data shows that, due to the rising cost of fertiliser nitrogen, the nitrogen 'carry-over effect' of legume crops is a potentially significant factor in farmers' economic assessments. Research in Ireland has found that the Nitrates Directive has effectively put a constraint on stocking rates on grassland farms by capping the amount of organic nitrogen that the farm can use. This limitation makes it attractive for farmers to reduce grassland production costs using clover instead of maximising grassland yield using fertiliser nitrogen.

The most significant environmental benefit of BNF is the **reduction in nitrous oxide** emissions. There is now consensus that the protein crop itself results in little or no emissions of nitrous oxide and this, together with reduced carbon dioxide emissions from fertiliser manufacture, reduces total greenhouse gas emissions from the cropping systems.

Deep rooting and the increased mobilisation of soil phosphorus do not have significant environmental benefits in themselves. The main effect of deep rooting is to improve soil properties resulting in **increased yields of subsequent crops**. Similarly, mobilisation of fixed phosphorus may enable the legume crop to be grown in soils that are low in plant-available phosphorus but we found no evidence to show that this will significantly change phosphorus fertilisation practice at the cropping sequence and farm level.

The **positive carbon balance of protein crops** compared to cereals and maize compensates in the short term for other crops in the rotation with negative balances. The overall environmental effect depends on a long-term increase in stable soil carbon. This depends largely on wider farm-level soil carbon management strategies that may be the subject of carbon-related policies.

The effect of protein crops on **on-farm crop diversity** is one of the most direct and legume-specific effects on the environment, with impacts arising directly from increased insect activity. There are also indirect effects, for example from changes to cropping systems otherwise dominated by autumn-sown cereals. Overall, an increase in protein crop production will bring a range of benefits for biodiversity, but these vary greatly from site to site.

The yield and protein formation processes in legume species have profound effects on the economic competitiveness of protein crops and their role in protein supplies, especially in supporting intensive animal production. Particularly in Europe, protein crops are disadvantaged compared with the cereals and this is at least partly due to plant resources (photosynthate) used to 'fuel' biological nitrogen fixation combined with the superior performance of cereals under European, notably north-western European, conditions. Nevertheless, protein crops are responsive to investment in research and technical change, and this too is the subject of potential policy measures.

4.2. Developing policies: some science-based considerations

An integrated policy approach

Our study has identified a range of environmental and resource benefits from expanding protein crop production in Europe. We can say with considerable certainty that protein crop expansion will result in a **wide range of public benefits** with very low risks of unintended negative consequences. These crops are truly multi-purpose across the full range of ecosystem services: providing very high quality food and feed, regulating greenhouse gas emissions, and supporting soil development processes. These services interact with each other within systems operating at the field, farm, agri-food, and global scales. This range of services and the complexity of systems in which they deliver impacts present a great challenge to policy-makers charged with delivering public goods for public funds.

There are three major consequences of the multiple benefits of protein crops for policy: a range of complementary policy measures requires consideration; we need to consider how these policy measures interact within complex systems at the farm, agri-food and global system scales to deliver the full range of benefits sought; and we need to examine the potential for interaction of measures with other policy areas, particularly those relating to the nitrogen cycle and biodiversity.

This points to the need to recognise the **potential of complementary policy measures** and fostering efforts to enhance them. Such an integrated policy approach can be particularly robust if it focuses on the positive outcomes that protein crops support with the development of measures rooted in an understanding of the agroecological processes affected. With the low use of protein crops currently, the promotion of legumes through greening measures can be justified from a practical policy viewpoint. This combined with investment in research and development could stimulate private sector investment in crop improvement and technical progress. All increases in the price of fertiliser nitrogen costs or other constraints on nitrogen strengthen these incentives.

We recommend that policy-makers develop integrated policy approaches rooted in understanding of how protein crops affect agricultural and food systems. This integrated approach would foster synergies between complementary measures, for example between those presented below as Option 2 (allowing protein crops to contribute to ecological focus areas) and Option 6 (investing in research and technical progress). This integrated approach would also for example consider all the drivers of the growth in the plant protein deficit.

Obligation and sanctions

The agroecologial processes affected by protein crops and the resulting environmental and resource benefits provide a rationale for public intervention to boost protein crop production. However, these do not justify a policy that obliges farmers to produce protein crops specifically. The benefits of protein crops are developed by optimising cropping systems, and this is achieved by focusing on the outcomes protein crops support. Protein crops can be indirectly supported by raising taxes on some farming practices. The use of nitrogen fertiliser in particular justifies attention. Price mechanisms can be used in a way that expresses the environmental cost of nitrogen use and of greenhouse gas emissions associated with nitrogen fertiliser applying the "polluter pays principle".

We recommend that policy-makers avoid measures that oblige farmers to produce protein crops specifically. Instead, policy intervention generally should seek to support the outcomes protein crop support. Sanctions should be aimed at undesirable practices by inclusion of public costs into resource usage such as introducing a tax for nitrogen fertiliser. Also, climate protection policies could play a central role and would indirectly support the production of protein crops.

Incentives

Incentives make protein crops more attractive. Options 3-5 below set out three different approaches to incentivising the cultivation of legumes. The challenge we are faced with in designing such incentives can be formulated as one of **public goods**, although some of the resource effects benefit the farmer (lower need for fertiliser nitrogen in subsequent crops, reduced incidence of pests due to rotation in general, and better soil structure). However, these benefits for the farm business are not sufficient to compensate for the **lower economic returns** that protein crops offer in most situations, compared to competing crops such as wheat.

There are also **incentives that could indirectly encourage farmers** to grow more protein crops. An obvious one is the support for organic farming (Option 5), which, as explained in Chapter 1, entails a larger share of legumes in both forage and arable-based farms. Furthermore, mechanisms to provide payment for agricultural techniques that reduce emissions of N_2O or lead to increased carbon storage in the soil can also be designed. Such policies would make legumes more attractive to farmers.

Incentives in the form of coupled payments have been important in maintaining protein crop production in some parts of Europe in recent years. Removal of this incentive now would undermine confidence in the protein crop sector as a whole. We recommend retaining the use of coupled payments, particularly where protein crops currently provide a range of significant environmental and resource benefits within cropping systems.

Raising the economic performance of legumes is a long-term robust approach

Our work shows that legumes are responsive to investment in research and development (see Option 6). Given the rarity of legumes in many regions, it is reasonable to speculate that production would respond well to knowledge transfer activities and technical support. The German Agricultural Research Alliance (DAFA) has identified research targets for legumes (DAFA 2012). These include investment in crop breeding and cropping system improvement to raise yield and quality. The European Commission, with a large budget for research, is in a position to steer research funds towards increasing the productivity of legumes, which will help to improve their competitive position vis-à-vis other crops. The Commission is developing new instruments such as the European Innovation Partnership on Agricultural Productivity and Sustainability. There are examples of effective crop specific technical support initiatives such as the Danube Soya Association that can bundle technical advances and target them at farmers on a regional basis.

We support the recent and planned investments by the EU and some EU countries in research, development and technical progress on protein crops. We also expect a positive interaction between an increase in area of legumes e.g. in the context of the ecological focus area and the investment into breeding as the larger market for protein crop inputs (especially seeds) will stimulate further private investment in research and technical progress generally.

The protein deficit presents challenges beyond legume production

The expansion of legume cultivation in Europe is sometimes seen as a means of addressing Europe's plant protein deficit. Europe accounts for the consumption of about 14% of the world's soya crop and European consumption of soya on a per capita basis is amongst the highest in the world. However, when the increase in demand for soya for pig and poultry production is considered, the decline in the production area of legumes in Europe has played only a minor role in the growth of this protein deficit. The protein deficit in Europe is caused by a combination of factors that need to be addressed.

We recommend that the European Union develops a comprehensive protein strategy that considers all the drivers and impacts of protein production and consumption if the political objective is to reduce Europe's dependence of imported plant protein.

4.3. Policy options for supporting protein crops

Our work shows that a combination of circumstances can tip the balance in favour of protein crops. However, our results also indicate that **the European Commissions proposals** for the CAP for the period 2014-2020 (EC 2011) **are unlikely to reverse the trend** towards decreasing areas under protein crops. This means that Europe will continue to forfeit the range of environmental and agricultural resource benefits protein crops bring. Additional proposals are therefore necessary and these should be integrated to turn the scale towards a greater use of protein crops on arable farms.

Against the background set out above, here we present and assess specific options that could be included in the new CAP to support the cultivation of protein crops. Any promoting measures should have the ambition of increasing the area under protein crops on present arable land because expansion of protein crop production at the expense of grassland or nature areas would have negative environmental consequences that exceed the benefits of growing legumes. The options are not listed in order of priority. We provide a brief impact assessment for each of the options. In the context of this study, the options can only be assessed in broad qualitative terms.

Option 1: More stringent crop diversification requirements

Our assessment and those of others (Westhoek et al. 2012, European Society of Agronomy 2012) is that **the current proposals on diversification will not result in significant changes in cropping patterns**, and almost certainly will not incentivise the production of protein crops. Much more stringent crop diversification requirements are needed to have this effect. The challenge is to develop requirements that are equally effective in terms of locally relevant outcomes in highly varied cropping circumstances across Europe. There are two obvious gaps in the current proposal: it does not encourage rotation of different crops which is beneficial in annual arable cropping systems, and related to this, it does not give additional weight to diversification between different families or genera of crops, for example diversification between cereals, brassicas and legumes.

There is an environmental case for tightening up the diversification requirements generally. Farmers could respond to the current requirements for example by growing wheat, rye and triticale which in many ecological respects is a cropping system that is similar to a wheat monoculture. Providing incentives to grow **species from different plant families** (cereals, mustard/cabbage, potato and legume families) would be particularly beneficial. However, the case for obliging the production of legumes specifically in the context of diversification is less clear. The one-size-fits-all approach now proposed is simply not appropriate. More flexibility and greater recognition of diversification in crop types from an agroecological viewpoint is required.

Although a quite different measure, the United Kingdom's Environmental Stewardship Scheme (a Pillar 2 instrument) uses a points system to assess a farm's compliance with whole farm agreements use more than 60 management options (Defra 2013). While not directly relevant to CAP diversification proposals, the principle is useful. It is a model for a more **flexible approach** that allows farmers and regional authorities to match qualifying measures to local environmental needs with points awarded for various degrees of compliance. This would offer farmers flexibility in relation to regional differences and the option of gaining additional recognition for rotation, diversity between crop families, and diversity in relation to the dominant crop in the region. This flexibility could provide a framework for accommodating regional demands and priorities.

Tightening diversification requirements has the advantage of a clear link to relevant agroecological processes that have both environmental and long-term resource benefits.

Impact assessment: Tighter diversification requirements could increase the area under legumes, provided that benefits for diversification between plant families (cereals, legumes etc.) are recognised. If effective in this way, it will have positive environmental effects through changes to greenhouse gas emissions, energy use, biodiversity, water quality, soil quality and non-renewable resources (see Chapter 2). To comply with WTO requirements, the production of legumes should not be specifically obliged.

There are **social and economic costs**. On the social side, the option will lead to a reduction of the freedom of individual farmers and an increase in their administrative burden. On the economic side, there is a cost to the farmer of having to grow a crop that yields a lower return than the alternative.

Option 2: Classification of legume cropped areas as ecological focus areas

In response to the Commisson's proposal (EC 2011), the European Parliament has proposed that legume-cropped land be regarded as a contribution to the EFAs (EP 2013). Our review provides **limited evidence from ecology to support such a policy**. There is reasonable consensus that legume crops are superior in terms of farm-level biodiversity compared with the major cereals and maize, but this advantage unique to legumes is limited to the effect of the flowering habit and associated interactions with insects. The question here is not the comparison with the dominant crop type (usually cereals) which is the focus of most agroecological studies of legumes, but the comparison between legumes and the management of land for biodiversity purposes proposed for the EFAs. In the Commission proposal, these are described as 'fallow, terraces, landscape features, buffer strips and afforested areas', but exclude permanent grassland (EC 2011). The question thus arises as to under which conditions would legume crops bring about similar benefits for biodiversity.

A political advantage of this option is that it softens the impact of the EFA measure on intensive arable farms. There are also some built-in **synergistic effects**. It is reasonable to assume that the most intensively cropped farms are characterised by a lack of diversity in existing cropping and a low proportion of land that already qualifies as EFAs. Offering the opportunity to count legumes towards EFA may be particularly relevant to these businesses and offer a **productive option for cropped land** that contributes directly to crop diversification. The measure has the further advantage of stimulating a significant increase in the current legume cropping area on advanced arable farms, thereby stimulating investment in technical progress and processing infrastructure. So it may have a role to play in a wider and longer-term strategy in line with an integrated policy approach, particularly if it stimulates investment in crop development.

Nevertheless, there are clear **risks of unintended consequences**. First, the measure would nullify the effect of EFAs in regions where grain or arable forage legumes are already grown. More importantly, the measure might even legitimise or stimulate further reductions in non-cropped areas, reducing the area of wild and semi-wild crop margins, hedgerows etc. The measure could also stimulate the production of legumes in areas already characterised by excess nitrogen due to intensive and concentrated livestock production.

The measure is amenable to a **flexible approach** which could be used to minimise these risks. This could be done by for example preventing the whole of a farm's EFA requirement being met in this way and by building feedback into the measure as the protein crop area in a region expands. If the measure was successful and protein crop production also became more economically competitive through market changes, a scaling factor could be introduced that for example would set down that a larger area of protein crops equates to one hectare of conventional EFA use. In this way, the momentum in expanding the protein crop area is maintained if market prices and other considerations support expansion. It is very important that the measure has a long term perspective and that it encourages expansion of legume cropping beyond the scope of the EFAs.

Impact assessment: This option will certainly cause protein crops to be grown in some areas where at present they are not grown, with the environmental benefits as described above. The overall environmental effect will depend upon the percentage of arable land to be under EFA – which is yet to be determined. The economic cost of this option in terms of farmers' revenues is likely to be lower than Option 1, but so is the environmental benefit. The impact on free trade will be small.

Option 3: Voluntary coupled support schemes (direct support under Pillar 1)

Under the new CAP as proposed, the special support under Article 68 will be abolished, but the Commission proposal includes provision for voluntary coupled support schemes in order to respond to economic and social challenges in a particular area. These two factors ("economic" and "social" challenges) could be **enhanced by an environmental dimension** that could allow for the support of legumes. In this case, the EU should provide direct incentives for member states to adopt such coupled support schemes for legumes.

Impact assessment: This option has the potential to allow regional and coupled support schemes to be developed where increasing protein crop production might be particularly beneficial. However, in these areas in particular the subsidy per hectare would need to be quite high to produce the intended effect – typically several hundred euros per hectare (see also Annex 4).

A rough estimate suggests that an additional 3-6% of the total arable area of the EU-27 could be planted with protein crops (i.e. 5-8% including the current area) if all member states decide to make use of the option to use 3% of the national ceiling for coupled protein crop support, as proposed by the Parliament (see Chapter 3). If member states decide to use even more, e.g. 8% of the national ceiling, which would be possible under the Parliament proposal, this would result approximately in an additional 10% (i.e. 12% in total) **increase in area planted with protein crops**. However, this decision by member states would depend on local policy developments and would be at the expense of other coupled support measures. In any case, the area would have to be tied to a maximum to comply with WTO requirements.

The cost in terms of the subsidy to be paid would be about €1.2 billion per year if member states decide to use 3% of the national ceiling for protein crops. However, since these subsidies are to be paid out anyway, there is no net cost to the taxpayer – only to those farmers who would otherwise have received decoupled payments.

Option 4: Promote legumes via agri-environment schemes (Pillar 2)

According to the Commission proposal, agri-environmental schemes will be continued. In the present Rural Development Programme, measure 214 may include legume cultivation at the discretion of the Member State or regional authority. The purpose of the agri-environment schemes is to support compliance with key objectives on biodiversity and landscape, so the inclusion of protein crops must be assessed in this context.

This option has the advantage of being relevant to a wide range of regulating and supporting ecosystem services provided by legumes. It is also flexible and reactive to regional needs and opportunities, as exemplified by the Entry Level Scheme working in the UK (see Option 1). However, the risks identified for the use of protein crops under the EFAs apply here.

Impact assessment: This option offers similar benefits to Option 1, but without the social cost of loss of freedom for farmers. A difference is that the **cost** of implementing the measure is not borne by the farmer, but **by the taxpayer**. However, the impact in terms of an **increase of the area under legumes will be much smaller** than in the preceding policy options for three reasons: firstly, it is up to member states to include this scheme in their Rural Development Programmes (RDPs); secondly, it will never be more than a fairly small component of the overall RDP; and thirdly, Pillar 2 as a whole is much smaller than Pillar 1.

Option 5: Increase support for organic farming

The use of legumes either as grain protein crops or forages is practically a necessity in organic farming systems as legumes provide the only means whereby significant quantities of reactive nitrogen can be obtained. There is no doubt that expansion in organic farming leads to wider use of legumes by excluding synthetic nitrogen fertilisers forcing dependence on nitrogen fixed by legumes. This option has the merit of **using established frameworks** linked to distinct premium markets so that in effect consumers pay part of the cost of the environmental benefits gained, but it does not get legumes onto conventional farms.

Impact assessment: Certified organic crops were grown in the EU on 3.7 M ha in 2011, or 2% of the total agricultural area (FAOstat 2013). Organic farming has expanded by 14% since 2004 and continues to expand quite rapidly in some areas of Europe e.g. France, Poland, Spain, Czech Republic, Portugal, Sweden, and Germany (FAOstat 2013). Increased support as was recently announced in Lower Saxony in Germany reinforces expansion. If we assume that 5% of organic farms will be planted with grain legumes (as the European average on certified organic arable land, EUROSTAT 2013) and 15 % with forage legumes or legume grass mixtures as is the case in Germany in 1998 (Hof and Rauber 2003), an expansion of organic farming by 1 M ha would lead to 50 000 additional hectares under grain legumes and 150 000 additional hectares under forage legumes. Based on estimates that specific support to organic farms costs 100-400 €/ha depending on the country (Lehner 2010), it is clear that this is an **expensive way to increase the area under legumes**. If this measure is selected, it should be because of the whole mix of environmental and social effects.

Option 6: Investment into research, breeding and technical progress

This review has identified two key features of legumes, especially of grain legumes: **responsiveness to technical improvement and under-estimation of the farm benefits**. Our results indicate that the whole-farm economic performance of protein crops is underestimated and that there is scope for extracting more of this on-farm value. Therefore, we can expect protein crop development and production to respond well to investment in research and technical progress. Further, the EU research programme (Horizon 2020) is available to provide substantial resources.

Impact assessment: The economic returns to public agricultural research are usually substantial (Fuglie and Heisey 2007), but hard to quantify and by definition impossible to predict. Nevertheless, research generates other benefits in addition to useful knowledge: skills, networks and spinoff companies among them. In addition, investments in research **are fully aligned with economic and food security goals**. There is consensus in the scientific and agri-business communities that **plant breeding** in particular is a key technology for the development of protein crops (e.g. DAFA 2012). Key research targets include the genetic improvement of the major grain legume species with priority on yield level and stability, supported by agronomic research for a better extraction of the value of legumes within cropping systems. There is market failure for research supporting genetic improvement in particular because commercial plant breeding generates insufficient returns to justify the level of investment that these critical targets require (Moran et al. 2007).

Despite the high rate of return generally to investment in agricultural research, there are potential downsides. The investment is long-term, particularly in underpinning technologies such as plant breeding, and there are trade-offs between scientific impact on the research community and commercial impact on breeders, farmers and processors. These risks are evident in the substantial investments in relevant research already made by the EU and national authorities, which has not prevented a decline in the production of legumes. Counter to this, we can see from other countries, especially Canada and Australia, that vibrant legume sectors are associated with very substantial investments in public research. It is important therefore that the research investment is **carefully targeted, sustained over a sufficient period, and supported by complementary innovation activities** to generate impact in terms of crop production and use. The new European Innovation Partnership in agricultural productivity and sustainability is relevant here.

Options outside the CAP

Option 7: Strengthen climate protection policies

A protein crops policy can be seen as part of a climate protection policy, even though the benefits of **protein crops** go well beyond the **reduction of greenhouse gas emissions** and an **increase in carbon sequestration** in the soil. Crop production contributes directly to greenhouse gas emissions primarily through carbon dioxide from fossil fuel use and nitrous oxide emissions from soils enriched with nitrogen. Measures to tackle these two gases could encourage the production of protein crops indirectly. Any policy that increases the **cost of carbon emissions would make nitrogen fertiliser more expensive**, and thus legumes more attractive. There are many ways of achieving this. At present, a **cap-and-trade policy** exists in the form of the emissions trading system. For a variety of reasons, the results achieved in terms of emission reduction have been disappointing. More restrictive allowances are an obvious answer, but probably not easy to impose. An alternative would be a **carbon tax**, which has a number of advantages (Taschini et al. 2013). An assessment of the relative merits of these mechanisms is beyond the scope of this study but it needs to be pointed out that measures that increase the price of fossil energy carriers will also make growing legumes more attractive to farmers.

Option 8: Use nutrient policies

There is a wide **range of policies** directly and indirectly relevant to the use of nutrients in agriculture. The best known is the Nitrates Directive, but there are others such as the Water Framework Directive and national regulations governing the use of nutrients. The Nitrates Directive has already indirectly raised the relative economic performance of white clover-supported dairy systems by putting a cap on stocking rates which encourages farmers to focus on costs instead of output.

A **tax** specifically on the use of nitrogen in agriculture is also possible. A justification for this would be the environmental problems caused by nitrogen losses in addition to the greenhouse gas emissions from nitrogen fertiliser manufacture. The tax could be levied specifically on nitrogen in mineral fertilisers and on nitrogen surpluses in agriculture (e.g. the Dutch Mineral Accounting System (MINAS) described by Ondersteijn et al. 2002). The first would be the easiest to implement, but would penalise arable farms while leaving the livestock industry (the largest user of reactive nitrogen) not directly affected (Berntsen et al. 2003). Sweden had a tax on nitrogen in mineral fertiliser from 1984 to 2010, but abolished it because it had negative effects on the competitive position of Swedish farm businesses compared with those of other European countries.

Taxes on nitrogen surpluses are sound in principle but if implemented fully would consider nitrogen fixed by legumes as an input. The use of **nutrient balancing** could incentivise legume production. An expansion of legumes from such a measure might be an artefact of the nitrogen accounting mechanism in which biologically fixed nitrogen is under-estimated as a nitrogen input.

Impact assessment: It is possible to put a price on the environmental benefits of legumes to a limited extent. The **costs of the environmental damage of nitrogen fertilisers** has been estimated at 0.31 €/kg of N (Blottnitz et al. 2006), including its effect on global warming, pollution and eutrophication. That is equivalent to 0.37 €/kg of N in prices of 2013. If we assume that growing protein in a rotation will reduce the amount of fertiliser nitrogen needed for the next crop by 75 kg/ha, this yields a social benefit of 27.50 €/ha for the pre-crop effect alone. A policy that would add 0.37 €/kg N to the current price of nitrogen fertiliser (now about 1.50 €/kg urea N) would incorporate the environmental cost of the fertiliser. An equivalent price increase alone would hardly be sufficient to compensate the gross margin deficits of grain legumes in most production regions[12], but has the potential of tipping the balance in favour of forage legumes. Larger fertiliser price increases would be required to lead to a substantial increase in protein crop cultivation in Europe through this measure alone. However, a policy that incorporates the environmental cost of the fertiliser would be an **important component of an integrated policy approach** that could significantly promote legume cultivation in Europe together with other measures.

Option 9: Support producer initiatives

There are bottom-up as well as state-sponsored initiatives to promote the growing of legumes which could be supported by the European Commission with funds or **by encouraging networking and knowledge dissemination**.

One such state-sponsored initiative is Danube Soya Association, aimed at growing, processing, and marketing soya bean with sustainable techniques in the Danube basin as an alternative to imported soya. It is supported by both EU members and non-member states in the Danube basin. The German strategy to promote protein crops describes measures to support knowledge dissemination among producers (i.e. crop-specific demonstration networks) as well as support to research and development[13]. Bottom-up private sector initiatives include product certification schemes for animal production based on on-farm or regional feed production, such as the Neuland brand in Germany and the farmer association 'Mutterkuh' in Switzerland.

4.4. Conclusion

Compared with other major agricultural regions of the world, the EU is characterised by a low level of protein crop production. The dominance of cereals in European arable cropping combined with the import of large quantities of soya bean and meal enables self-sufficiency in livestock products. Our assessment shows that increasing the cultivation protein crops would be an important contribution to the sustainable development of European agricultural and food systems. It would contribute directly to several targets set out in the Commission's proposals: climate change mitigation, 'greener' production and a territorially and environmentally balanced EU agriculture. The direct farm, regional, and global level environmental benefits of increased legume production, combined with the indirect benefits arising from the better balance of EU agriculture and trade, justify public intervention using

[12] According to own calculations based on gross margin data of Mahmood (2011) and von Richthofen et al. (2006b).

[13] The strategy was launched in 2012 by the German federal ministry of food, agriculture and consumer protection (BMELV 2012a). The strategy is partly based on the 'The Legumes Expert Forum' which is a research strategy of the German Agricultural Research Alliance (DAFA 2012) including leading experts in legume agronomy, breeding, economics, processing, animal nutrition etc. The strategy is the basis for calls of several research and development proposals (one proposal per crop and region) which shall be strongly connected with demonstration networks for both lupins and soya bean (BLE 2012), faba bean and pea (in preparation) and forage legumes in future.

direct and complementary policy measures. We therefore recommend that policy makers focus on the public benefits of protein crops in the context of a wider re-balancing of European agricultural and food systems. This requires an integrated approach to policy development, which sees legumes expansion as a component of a wider effort to develop a more sustainable agriculture and food system. We recommend that policy development on protein crops takes such a systems approach and is rooted in an appreciation of the agroecological processes.

ANNEX 1. PRODUCTION AREA OF MAJOR PROTEIN CROPS IN EU-27 MEMBER STATES (2011)

	Pea		Lupins		Faba bean and other grain legumes		Soya bean		Common bean		Chickpea, lentil & vetches	
	ha	%[1]	ha	%	ha	%	ha	%	ha	%	ha	%
Austria	11715	**0.86%**	147	0.01%	9409	**0.69%**	**38123**	**2.80%**			1451	0.11%
Belgium	962	0.12%			468	0.06%			168	0.02%		
Bulgaria	1082	0.03%			87	0.00%	600	0.02%	954	0.03%	**3589**	0.11%
Cyprus					520	0.62%			200	**0.24%**	177	**0.21%**
Czech Republic	17189	0.54%			6828	0.22%	7584	0.24%			79	0.00%
Denmark	5900	0.24%			1900	0.08%						
Estonia	8457	**1.34%**							93	0.01%		
Finland	4800	0.21%										
France	**250000**	**1.36%**	**3486**	0.02%	**93243**	0.51%	**41571**	0.23%	3216	0.02%	**13961**	0.08%
Germany	**55800**	0.47%	**21500**	**0.18%**	21217	0.18%	1000	0.01%				
Greece	384	0.02%	50	0.00%	2320	0.09%	2000	0.08%	**9062**	**0.36%**	**9885**	**0.40%**
Hungary	18286	0.42%	50	0.00%	847	0.02%	**41009**	**0.93%**	632	0.01%	31	0.00%
Ireland	900	0.08%							2000	0.19%		
Italy	7270	0.11%	3000	**0.04%**	**43800**	**0.64%**	**165955**	**2.44%**	**6320**	0.09%	**13604**	**0.20%**
Latvia	1100	0.09%	0	0.00%					2200	0.19%	10	0.00%
Lithuania	26500	**1.21%**	**6000**	**0.27%**	6900	0.32%			4000	0.18%	2000	0.09%
Luxembourg	203	0.33%			65	0.11%			44	0.07%		
Malta					232	**2.58%**			132	**1.47%**	215	**2.39%**
Netherlands	437	0.04%			521	0.05%			1335	0.13%		
Poland	14287	0.13%	**52508**	**0.47%**	**69699**	0.63%	208	0.00%	**17541**	0.16%	2782	0.03%
Portugal			0	0.00%	20279	**1.85%**			3365	**0.31%**	1180	0.11%
Romania	**28535**	0.32%			429	0.00%	**71861**	**0.80%**	**24105**	**0.27%**	85	0.00%
Slovakia	5771	0.41%	65	0.00%	1215	0.09%	16997	**1.22%**	106	0.01%	1191	0.09%
Slovenia	321	0.19%			226	0.13%	107	0.06%	289	0.17%		
Spain	**200000**	**1.60%**	**7900**	**0.06%**	**55443**	0.44%	700	0.01%	**9875**	0.08%	**140000**	**1.12%**
Sweden	18819	0.72%							739	0.03%		
United Kingdom	**30000**	0.49%			**120000**	**1.98%**						

Source: FAOstat (2013), [1] percentage of arable land, bold values are the 5 highest of the respective column.

ANNEX 2. AGROECOLOGICAL PROCESSES IN PROTEIN CROPS

Protein (legume) crops directly support a number of distinct agroecological processes that simultaneously affect resource use and the environment at the different levels set out in Table 2 (Chapter 2).

Biological nitrogen fixation

From an agronomic viewpoint, biological nitrogen fixation (BNF) is a distinguishing feature of legume crops. Legumes maintain a symbiotic relationship with alpha- or betaproteobacteria collectively called rhizobia. The rhizobia convert inert atmospheric di-nitrogen (N_2) into reactive nitrogen forms, initially ammonium. As a result, the legume plant itself requires little or no nitrogen from soil reserves or fertiliser. In addition, the legume plant residues left after harvest (roots, straw, leaves etc) are rich in organically bound N that can contribute to the nutrition of the following crop. The so-called 'precrop effect' of legumes, however, includes much more than the effect of this organic nitrogen.

The formation of the association between the plant and the bacterium involves a chemical recognition process between the partners so that the "right" bacterium gains entrance to the "right" plant. For European legumes, the most important bacteria species are *Rhizobium leguminosarum* on pea, faba bean, lentil, vetches and most clovers, *Sinorhizobium meliloti* on lucerne, *Bradyrhizobium "lupini"* on most lupins, and *B. japonicum* on soya bean. Selections (symbiovars) of *R. leguminosarum* have been identified that optimize the amount of N fixed by each host species (Lindström 1984, Stoddard et al. 2009).

For pea, faba bean and clover, rhizobia native to European soils are generally regarded as sufficient to establish symbiosis, but inoculation of seed with improved rhizobial selections can increase BNF, particularly when a crop is new to a region, or where the soil pH is low (van Kessel and Hartley 2000, Lindström et al. 2010). The compatible rhizobia enter the plant via plant-derived infection threads and occupy root cells to form the N-fixing nodule. The nitrogen-fixing enzyme nitrogenase is produced within the bacterium, and red leghaemoglobin (a molecule similar to the haemoglobin of vertebrate animal blood cells) in the cytoplasm of the root nodule cell controls the flow of oxygen to the bacteria, so an active nodule always has a characteristic pink centre. Nitrogenase is active as long as the plant is metabolising, even close to 0°C (Lindström 1984).

As in all symbiotic relationships, there is an exchange of resources between the host and bacterium with costs and benefits for the host. BNF requires considerable energy input from the host (legume) plant. Each molecule of atmospheric nitrogen, N_2, converted to 2 ions of NH_4^+ (ammonium) requires 16 molecules of ATP (the molecule that transfers energy within cells), representing a net cost of 10-15 g glucose per g N fixed (Hay and Porter 2006). The sugar is provided by the host plant and its provision is a trade-off between BNF and grain yield. This energy costs ultimately has consequences for the competitiveness of legumes compared with cereals, and thus the development of support policies.

There are, however, benefits to the legume plant in terms of energy, compared with plants such as wheat that take up reactive nitrogen from the soil. Legumes relying on BNF do not need to reduce nitrate from the soil to ammonium, at an average cost of 4-5 g glucose per g N (Hay and Porter 2006). In faba bean, this avoided cost (a benefit to the plant) was found to be 10 g glucose per g N (Schilling et al. 2006) which is nearly as much as that of BNF.

A vital question for the overall effect of BNF on yield is the reaction of the plant to the demand for energy from nodules. This crop physiological response depends on whether the growth of the plant is limited by its ability to photosynthesise or by its ability to use the photosynthate for new plant tissue. In faba bean and soya bean, rhizobial symbioses use 4-16% of the host plant photosynthate, but this is generally compensated by an increase in photosynthetic rate as the plant responds to the demand, so the net yield penalty of BNF is zero (Kaschuk et al. 2009). In pea, however, yield was found to be limited by overall photosynthetic activity, and a significant yield penalty to BNF was shown (Schulze et al. 1994). Corresponding datasets on more minor grain legumes, such as chickpea or any of the lupins, are limited. Crops subjected to stresses are limited in their ability to photosynthesise, and in these cases there is a negative effect of BNF on yield. In general, the scientific literature indicates that BNF has a yield penalty in pea and in stressed crops, but not in unstressed faba bean or soya bean.

Use and transformation of fixed nitrogen

Estimating the quantity of nitrogen fixed is of interest to farmers, environmental scientists and policy-makers. In crops that have a mixture of legumes and other plants, including grass-clover pastures, the non-legume plants tends to take up the available soil nitrogen, forcing the legume to rely on BNF. This stimulates BNF and increases the proportion of nitrogen in the legume that is derived from the atmosphere (Carlsson and Huss-Danell 2003, Peoples et al. 2009, Li et al. 2011). It has been estimated that the most widely grown grain legumes in Europe, pea and faba bean, derive on average 60% and 74% of the nitrogen in their shoot biomass from BNF (Peoples et al. 2009). Using these data in a per hectare estimate based on grain yield requires reliable estimates of the partitioning of total plant biomass and nitrogen between root, shoot and seed, along with the amount of soil N, the presence of appropriate rhizobia, the cultivar, and growing conditions. Our calculations based on literature averages show that pea, faba bean and lupins fix 50-69 kg of N for every tonne of seed produced. On-farm measurements are, however, usually lower than experimental ones (Peoples et al. 2009).

Estimates of BNF are primarily based on above-ground plant material. The difficulty in accounting for N in below-ground plant biomass leads to an underestimation of BNF. Complete extraction of roots from soil is difficult, and the separation of roots of species in mixtures is even more difficult, so estimates of the amount of BNF in below-ground matter are rare. Our calculations based on root-shoot ratios and root N content suggest that below-ground N is only 8-14% of above-ground N in pea, faba bean and narrow-leafed lupin. Others have estimated that 30-60% of total plant N may be below the soil surface (Peoples et al. 2009), representing up to 100 kg N/ha for faba bean (Jensen et al. 2010). Some of the difference between these two methods of estimation may be due to rhizodeposition, meaning N left in the root zone from root exudates, shed cells, and dead root fragments. Rhizodeposited N represented 12-16% of plant N, or 80% of below-ground N, from pea, faba bean and white lupin (Mayer et al. 2003). A meta-analysis put rhizodeposition at 16% of total plant N (Wichern et al. 2008), or 10-14 kg below-ground N per tonne of seed, representing 8-11 kg nitrogen derived from the atmosphere per tonne of seed. Rhizodeposition is included in the above estimate of 50-69 kg N fixed per tonne of grain legume seed harvested.

Protein synthesis and supply

The synthesis of 1 g of protein requires about twice as much plant energy as that required for the synthesis of 1 g of starch (Penning de Vries et al. 1974). This means that 1 t of a crop (e.g. pea) containing 25% protein is equivalent in photosynthetic energy terms to 1.12 t of a cereal crop with 12% protein.

Grain legumes differ in protein content, from 20-25% in common bean, lentil and pea, to over 40% in soya bean and yellow lupin. The quality of the protein, as measured by the amino acid composition, also varies. Because of its amino acid profile, soya bean is particularly highly valued for inclusion in many animal feeds. Furthermore, batches of soya bean and soya meal are consistent in quality, partly because they are mixed several times in transport and when passing through the large–scale oil pressing facilities. In contrast, the several species of locally produced protein crops are likely to be grown on smaller scales. Batches are therefore smaller and vary considerably in composition.

Nitrogen transformations in the soil: denitrification and nitrification

Reactive nitrogen, as distinct from inert atmospheric nitrogen, is essential for life but is also an environmental hazard.

In anaerobic (low-oxygen) soil conditions, many micro-organisms use nitrate (NO_3^-) instead of oxygen for respiration, thereby reducing nitrate to nitrogen in the process called denitrification. One of the intermediate products of this process is nitrous oxide (N_2O), which is a greenhouse gas that is 298 times as potent as CO_2 over 100 years. Denitrification is decreased in the root zone of some plants, particularly in the presence of sugar-rich root exudates (Henry et al. 2008). Some rhizobia and other bacteria produce enough nitrous oxide reductase that N_2O release cannot be detected (Sameshima-Saito et al. 2006), showing another way in which this environmental hazard can be reduced.

Within the nitrogen cycle, nitrification (the process whereby ammonia is oxidized to nitrate) also causes some N_2O release. Nitrification is less important than denitrification in terms of N_2O emissions (Philippot and Hallin 2011).

The IPCC (Intergovernmental Panel on Climate Change) uses a default emission factor of 1.25% to estimate the N_2O emission from non-legume crops on the basis of nitrogen supplied as either fertiliser or crop residues. In annual legume crops, or in the year of establishment of perennial legume crops, little N_2O is released, and this continues in a perennial grass-legume mixture (Rochette and Janzen 2005) where most of the mineralised nitrogen is taken up by the grass component as fast as it is released by the breakdown of legume residues. Other sources confirm that N_2O release is lower in a legume-supported rotation than in a legume-free rotation, but that measurements have to continue for at least 2 years to make reliable assessments (Lemke et al. 2007, Dusenbury et al. 2008). Jensen et al. (2011) reported average direct N_2O emissions from legume fields of 1.29 kg N_2O–N/ha compared to 3.22 kg N_2O–N/ha from non-legume crops. Emissions differ between species and even between cultivars (Pappa et al. 2011).

Leaching

In the process of mineralisation, much of the organic (carbon-linked) nitrogen (including proteins, amino acids and urea) taken up by microbes is metabolised to inorganic (not linked to carbon) ammonium, NH_4^+. This can then volatilise to be released to air as ammonia (NH_3), be taken up by plants, or be metabolized by nitrifying bacteria to nitrate, which is mobile in soils and moves with water through the soil and potentially into groundwater, in the process called leaching.

Reductions in leaching help protect water resources from elevated nitrate levels and to conserve nitrogen in the soil/plant system to support the growth of subsequent crops.

Leaching can be minimized by the use of catch crops. These are short-lived, rapid-growing crops, such as fodder radish, that are sown as soon as possible after the previous crop is harvested. They take up nitrate and other nutrients during the short fallow, and are tilled in shortly before the next main crop is sown. This is particularly beneficial after legumes to protect the nitrogen reserve from loss. As the catch crop breaks down, it releases the captured nutrients and they are taken up by the main crop.

Phosphorus transformation

The roots of many crops release exudates. Most legumes release carboxylic acids that solubilise phosphate ions from bound forms such as calcium and iron phosphates that are otherwise unavailable to plants and immobile in the soil. The process is to an extent self-regulating: the lower the phosphorus concentration in the soil, the more acid is released, and depending on the species, up to 8 acids are released (Egle et al. 2003). In 50 faba bean varieties, phosphorus uptake ability ranged 3-fold, and the difference in release of soil phosphate was detectable in wheat sown immediately after the beans were harvested (Rose et al. 2010). The solubilised phosphorus is considered poorly mobile in the soil and likely to be fixed to the soil matrix in a short time (Shen et al. 2011). In legume-cereal crop mixtures, the release of soil P by legume exudates promotes the P uptake and growth of the non-legume crop (Li et al. 2007). One side-effect of the release of acids by legume roots is a gradual acidification of the soil, usually countered by periodic applications of lime, and partially countered by the alkalinity of the crop residues.

Although P can be mobilised by legume crops, and they are known to need less P input than cereals or oilseeds (Bolland et al. 1999), legumes still receive considerable amounts of P in farm practice as either mineral fertiliser or manure. In a study of farm practice in Sweden, Italy and Scotland, grain legumes were reported to receive 14-37 kg P-fertiliser per ha, which is more than cereals, whereas in Finland the recommendation for grain legumes is the same as for wheat, rye and rapeseed. Legume-grass mixtures generally receive no P-fertiliser and sole cropped lucerne and clover in Italy receive P fertiliser and animal manure.

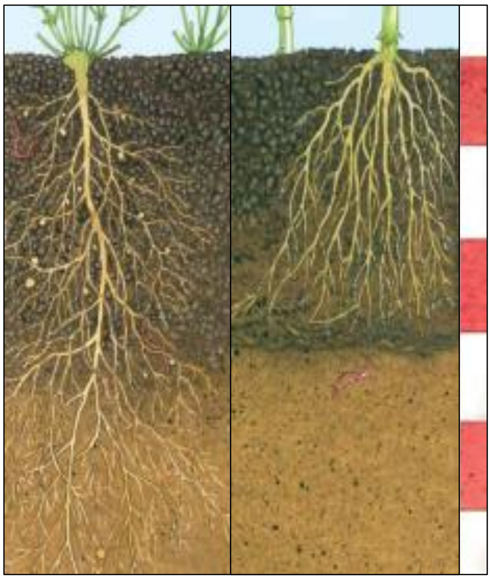
Soil development

There is a wide range of soil development processes influenced by legumes and these have both resource and environmental impacts. These relate in particular to effects on soil organic matter (carbon) and effects arising from deep rooting.

Hydrogen gas is a by-product of BNF and it supports the growth of bacteria within a few centimetres of the legume nodule (La Favre and Focht 1983) adding 1 kg of soil organic carbon for every 8 kg of nitrogen fixed (Dong and Layzell 2001). These bacteria also have plant growth-promoting properties (Maimaiti et al. 2007). They enhance the elongation of roots, primarily by inhibiting the production of ethylene by the plant when subjected to stresses such as transient drought (Maimaiti et al. 2007, Golding and Dong 2010). The result is a yield-promoting effect for succeeding crops in many situations (Dean et al. 2006), but not always (Peoples et al. 2008). Furthermore, the populations of soil fauna dependent on the bacteria also increase (Köpke and Nemecek 2010).

This is not the only means by which legumes contribute to soil organic matter accumulation. Many legume crops by their nature leave large quantities of residue. The overall effect is that legumes contribute more to the soil carbon balance in cropping systems than most non-legume crops, with especially large effects from forage legumes. The organic matter contributes to the water-retention ability of the soil and helps to slow or reduce leaching.

Figure 14: Root systems of lucerne and maize



Source: Slightly modified from DAFA (2012)

Some legume species form a strong tap root. The tap root of lucerne (Fig. 14) can, in suitably deep soils, reach 6 m. Roots of annual legumes generally penetrate 50-100 cm. Deep-rooted species can bring up nutrients and water from depth (Jensen and Hauggaard-Nielsen 2003), while shallow-rooted species allow conservation of soil water for the next, deeper-rooted crop in a water-limited rainfed system (Köpke and Nemecek 2010). A strong tap root, such as that of lucerne or lupins, penetrates compacted soil layers and most legume roots are larger in diameter than roots of small-grained cereals such as wheat or barley, so they leave a continuous network of residual root channels and macropores ("biopores") in the subsoil (Peoples et al. 2009). The biopores ease the passage of water into the soil (increase its water-infiltration capacity), and are often followed by the roots of subsequent crops and by earthworms and other soil fauna.

Diversification of cropping, flora and fauna

Crop diversity supports wider biodiversity on many levels. Adding a different crop species and especially a crop species from a different plant family to an agricultural system obviously adds the species itself. In the case of legumes, rooting patterns and root exudates affect the growing environment of soil microbes and fauna. Different canopy structures and chemistry provide niches for different microbes, insects and other animals. The different physiology of the newly added crop requires different management procedures, including the use of different chemical and physical methods that affect below- and above-ground organisms.

Legumes enable temporal and spatial diversification of the agro-ecosystem, including the planned biodiversity of crops (crop rotation and mixed cropping) and the associated diversity of wild flora, fauna, and soil microbes (Peoples et al. 2009, Collette et al. 2011, Köpke and Nemecek 2010). This diversification results in ‘potentially more dynamic and sustainable systems’ (Peoples et al. 2009).

The contribution of legumes to wider biodiversity has a great deal to do with pollination. Legumes co-evolved with bees. Bumblebees with a long proboscis, such as *Bombus hortorum, B. pascuorum* and *B. ruderatus*, and other large-bodied wild bees such as *Eucera numida* in Spain, can reach the nectar at the base of the faba bean flower (Stoddard and Bond 1987; Palmer et al. 2009). Honeybees (*Apis mellifera*) cannot reach the nectar, and visit the flowers productively only when gathering pollen that is used for feeding the brood (Stoddard and Bond 1987). The cultivated lupins contain very little nectar, but are often visited by pollen-gathering bees, and the cross-pollination rate in white lupin is around 8% (Green et al. 1980).

Most protein crops are sown in spring rather than in autumn. Their inclusion in a crop rotation increases the opportunities to overwinter stubble in a system dominated by autumn sowing, such as is common in north-western Europe. Crop stubble provides winter forage and cover for small mammals, birds and insects that are not provided by winter cereal crops (Potts 2003, Evans et al. 2004). This effect thus has more to do with sowing time, and with having diversity in sowing time, than with the crop species concerned.

The nitrogen richness of legume residues and the structure of their root systems have been associated with increases in population size and diversity of decomposer invertebrates such as earthworms and Collembola (Eisenhauer et al. 2009, Sabais et al. 2011).

Suppression of pests, disease and weeds

Since legumes are generally not susceptible to the same pests and diseases as the main cereal crops, they break the life-cycle of these diseases and pests, reducing their incidence in the immediately following crop. This is particularly true of soil-borne root diseases such as take-all root rot (*Gaeumannomyces graminis*) of cereals (Kirkegaard et al. 2008). The process gives rise to the term 'break crop'. Root-lesion nematodes in the genus *Pratylenchus* are pests of a wide range of crops, and some cultivars of faba bean suppress the growth of *P. neglectus* (Yunusa and Rashid 2007). Through improving root health, legumes can also benefit the N nutrition of the subsequent crops (Kirkegaard et al. 2008).

However, legumes can also increase the incidence of some diseases (Skuodiene and Nekrosiene 2012). Broad-spectrum diseases such as *Sclerotinia sclerotiorum* and *Rhizoctonia solani* flourish on many legumes as well as on other broad-leaved crops, so a 3-4 year interval between successive legume crops is widely recommended.

ANNEX 3. FORAGE LEGUMES

This annex presents key basic information on forage legumes, as they are a vital source of protein for ruminants in EU agriculture and an important component of forage farming systems. Forage legumes add to the protein provision by domestic grain legumes, and especially in wet regions where N losses are a major limiting factor, they are more important than home-grown protein crops as an alternative to imported soya.

Forage is produced on permanent grasslands (pastures), on temporary grassland rotated with arable crops also known as leys, and by dedicated forage legume crops such as lucerne.

The area of permanent pasture (for grazing or conservation) has declined since the 1960s but still forms a high proportion of agricultural land and of forage production in several European countries. Grasslands can contain a high proportion of legumes, often around 30%, predominantly white clover, but the contributions of legumes to grassland are not well documented. Forage legumes are used in pasture in many extensive agricultural systems to replace the use of fertiliser nitrogen (e.g. in 15 M ha of Mediterranean grasslands with native legumes, Ledda et al. 2000). They are also used in some medium intensity systems to reduce the need for fertiliser nitrogen (e.g., organic grasslands covering 6.2% of permanent pastures in the EU[14], EUROSTAT 2013). The use of fertiliser reduces clover content of mixtures below 50% (Carlsson and Huss-Danell 2003) and the combination of high fertiliser use and stocking rates practically eliminates the legume component (clover) and its impact (O'Mara 2008).

Although forage legumes may be grown in pure stands, they are more generally grown in mixtures with grasses, other legumes and forbs. Pure stands were very important in the past. In France, for example, 17% of arable land was cropped with pure forage legumes in 1960 (Fig. 15, Cavaillès 2009). Since then, forage legumes in the EU have been increasingly replaced by N-fertilised pure grass and silage maize.

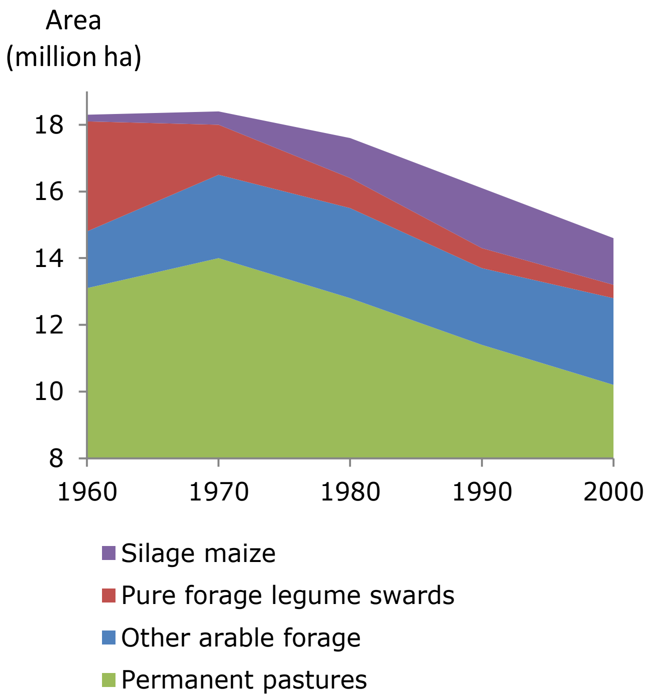
Areas of pure forage legumes declined by more than 80% in France (1960-2000, Cavaillès 2009), by 26-69% in Belgium (depending on the crop, 1990-2000, DGSEI in Peeters 2010), and by 40% in the EU-12 (1980-2001, Rochon et al. 2004). The current forage legume area in the EU is not well documented in EUROSTAT and different sources provide widely different estimates[15]. Of the documented pure forage legume area, 34% is dedicated to dehydrated fodder production, mainly the production of irrigated lucerne in Mediterranean countries (LMC International 2009). In intensive systems, fertilised grass and maize forage are more economic than forage legumes[16] (Peyraud et al. 2009, Knox et al. 2011).

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

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

[16] Pure grass and silage maize have high and relatively stable yields with a predictable yield response to N fertiliser

Figure 15: Forage production area in France (1960-2000)



Source: Cavaillès (2009)

Nevertheless, the area under pure stands of legumes underestimates their importance, as they play an important and increasing role in mixed pastures. These figures are hidden in agricultural statistics as they are categorised within other groups. Grass-legume mixtures remained stable in area between 1980 and 2001 in the EU-12 (Rochon et al. 2004). They made up 21% of arable forage areas in Belgium in 2000 (more than 11 times the area of pure legumes) and 35-40% in France in 2006 (Cavaillès 2009, Peeters 2010).

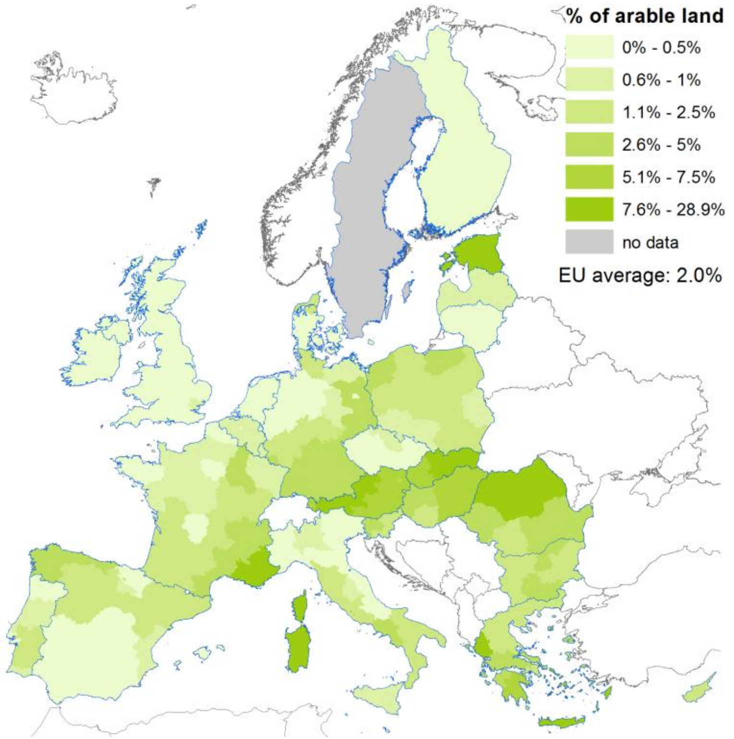
Data on changes in forage legume areas are available for only some member states (Figures 16 and 17). The rates of change and the regions of importance show different patterns from those for grain legumes. There are two belts where forage legumes represent a high proportion of arable land, one from Bavaria through Austria, Slovakia and Hungary to Northern Romania, and the other in Southeastern France, Corsica and Sardinia. Since these crops were little affected by policy changes, there have been no large changes in major production areas. Significant decline has mostly occurred in areas with a small proportion of forage legumes (Finland, Scotland, Ireland, Denmark, and New Castile in Spain), whereas there have been production increases in Belgium, Germany, Spain and northern Italy.

Reasons for the decline in forage legume production

As for grain legumes, forage legumes have become less widely grown with the availability of N fertilisers and soya feed at low costs and need for high per area productivity. These factors favoured fertilised forage crops (pure grasses, silage maize) and ruminant diets based on maize and grasses supplemented by soya. Forage legumes have never specifically benefitted from any specific EU-wide aid. Only the production of dehydrated fodder was subsidised. The inclusion of forage maize into subsidies under the past CAP further increased the competition between forage crops.

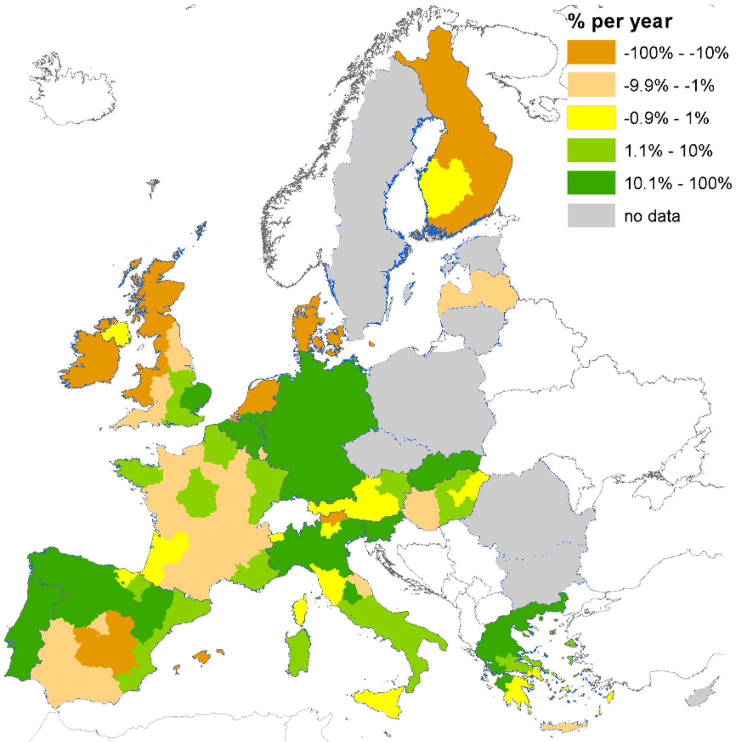
These challenges come on top of agronomic drawbacks. Clover often presents problems of lack of persistence and annually variable production (O'Mara 2008, Cavaillès 2009, Peeters 2010), although agronomic techniques are being developed for maintaining clover content (Humphreys et al. 2008). Red clover leys generally last 2-3 years, whereas white clover can last 15 or more (Humphreys et al. 2008, Stoddard et al. 2009). Excessive clover consumption in grazed swards can lead to bloat, the production of foam in the rumen, and this can be managed with appropriate mixtures of forage species (Peeters 2010). Grass-legume mixtures provide significant agronomic benefits in terms of yield, agronomic quality, low input costs, and feed quality as compared to pure grass and silage maize, but have the disadvantage of slow growth in spring (Peyraud et al. 2009).

Figure 16: Proportion of EU-27 arable land used for pure stands of forage legume crops in 2010 (%)



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

Figure 17: Rate of change in the proportion of EU-27 arable land used for pure stands of forage legumes (2000-2010) (%)



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

Drivers for a revival in forage legume production

Agricultural policies in the milk sector (limitations set by milk quotas, reduction in support prices in the 1980s) reduced the need for high productivity per unit area, and the Nitrate Directive limited stocking rates. These factors supported more extensive pasture management based on legumes rather than highly fertilised grasses (Rochon 2004).

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

Dehydrated fodder production, including non-legumes as well as legumes, represents a niche for support that was created in 1974 to protect the fuel-based dehydration industry in times of increasing fuel prices, and to contribute to the supply of plant protein for livestock (Marrugat 2001). A subsidy was paid to dehydration plants and later partly included in the single payment scheme for producers[17] (33 €/t for each party, phased out 2012) (Guerrero 2010). The EU produces around 4 M t of dehydrated fodder each year, and it is one of the largest hay exporters worldwide (LMC International 2009). Dehydrated fodder production is an especially important agricultural sector in southern European countries[18] and 92% of the Spanish dehydrated forage production area is occupied by lucerne, mostly grown under intensive irrigation (Guerrero 2010). According to Yuegao and Cash (2009), the EU contributes 25% of the world's lucerne production area, of which 1.3 M ha are in Italy, while Romania, France, Bulgaria, Spain and Hungary are other major producers.

Traditional systems using forage legumes

Forage legumes are an important source of protein for livestock feed, so play a key role in integrating livestock and crop production, increasing the recycling of nutrients on farms and thereby reducing nutrient losses (Granstedt, 2000). Traditional ley/arable rotations in cool temperate agriculture typically include 3–6 years of grass/clover leys to supply N fertility and livestock feed, and rotate them with other crops (Tivy, 1990). Within such systems, the length and management of the ley component has a critical effect on both the environmental impact and production. A well managed ley can reduce N leaching losses and GHG emissions (Ball et al. 2007; Watson et al. 2011) and longer duration leys lead to better weed control in the following crop (Watson et al. 1999). This type of rotation is still prevalent in organic farming, extensive production systems and regions where mixed farming is traditional. Mixed farming has a number of possible environmental advantages over specialised arable farming, including lower energy use for transport of home-produced feed and replacement of fertiliser by the effective use of manures.

Legumes play a role in agroforestry, such as Spanish silvopastoral systems. These farming systems combine grazing areas with forestry (predominantly oak trees), and cover about 4 M ha. Intensive and continuous livestock grazing (Olea and Miguel-Ayanz, 2006) creates and maintains a high representation of several legume species such as subterranean clover (*T. subterraneum*), and there are many self-sown legumes (e.g., 29 species in the Madrid region, González Bernáldez 1991). Forage legumes are often used in silvoarable systems

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

[18] The largest producers are France, Spain and Italy. The guaranteed national quantities have been repeatedly exceeded by Spain, Italy, Greece and the Czech Republic, demonstrating a high interest in this sector (PROLEA 2011).

where trees such as olive or carob are combined with mixed ley-arable rotations (Eichhorn et al. 2006).

Environmental and resource impacts

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

Soil biodiversity improves under legume-supported grasslands, with increases in populations of earthworms (Eisenhauer et al. 2009) and of Collembola, soil insects important in plant residue decomposition (Sabais et al. 2011). Clover-grass leys represent an important breeding habitat for farmland birds including skylark (*Alauda arvensis*), corn bunting (*Emberiza calandra*), yellow wagtail (*Motacilla flava*) and whinchat (*Saxicola rubreta*), but nesting can be disturbed by farming operations, particularly the timing and cutting height of harvesting (Stein-Bachinger and Fuchs 2012). Fuchs (2010) found that legume-grass leys were the most attractive habitat for the European hare (*Lepus europaeus*) on an arable organic farm in north-eastern Germany, but reproductive success was reduced due to harvesting operations, which could be altered by modifying cutting (Fuchs 2010). In addition, forage legumes are a critical component of extensive and traditional production systems such as the ones described above, which have a high value for biodiversity.

The effect of soil carbon sequestration is more clearly shown for forage legumes than for grain legumes, primarily because forages are in the ground 365 days per year, often for more than one year, and tend to have a high root biomass. Similarly, rotations that include forage legumes can improve soil organic matter levels compared with non-legume monocultures. Gregorich et al. (2001) showed that 35 years of a lucerne/maize rotation provided about 20 t/ha more soil carbon than continuous maize. Mixtures of grasses and legumes have been shown to sequester more carbon than the corresponding monocultures (Fornara and Tilman 2008).

Forage legumes take a larger proportion of their N from BNF than grain legumes (Carlsson and Huss-Danell 2003), and fix more N in total due to their high biomass production and longer growth period. Average annual BNF for clover-grass mixtures (>60% clover) and pure stands of red clover in Germany were 221 and 306 kg N/ha, respectively (KTBL 2009). In pure stands, forage legumes fix most nitrogen per hectare and derive a similar proportion of N in their shoot biomass from BNF as grain legumes (ca. 70%, Stein-Bachinger et al. 2004). In mixtures, total N fixation per hectare is somewhat lower but N efficiency is increased (80-95% of the N in shoot biomass is derived from BNF (*ibid*.)).

Forage legumes thereby save nitrogen fertilisers in three ways:

i) they require no nitrogen fertilisers compared to other forage crops (e.g. forage maize or grasses);

ii) they cover the nitrogen requirements of the other mixture components at least partially: A high legume content can save 136-400 kg N/ha in permanent pastures (Humphreys 2013) and 150-300 kg N/ha in leys (Peyraud et al. 2009), reducing the attendant problems of leaching and GHG release; and

iii) leys rotated with arable crops transfer fixed nitrogen to the soil (Carlsson and Huss-Danell 2003) and allow additional fertiliser savings of up to 34 kg N/ha (Legume Futures data, unpublished).

Perennial legume-grass mixtures lead to much lower N leaching compared to annual crops and pure grass systems (Crews and Peoples 2004), because the grass component of the mixture takes up reactive nitrogen as soon as it is released, and there is low input of fertiliser or manure nitrogen. However, N losses may occur in ley/arable rotations after the ley is ploughed, and these can be avoided when the forage crop is allowed to grow through the fallow season as a cover crop (Crews and Peoples 2004).

Conclusions

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

Some environmental benefits, such as soil carbon storage and biodiversity effects, are clearer for forage legumes than for grain legumes. Legume-grass mixtures are particularly beneficial in terms of biodiversity, carbon storage, and resource impacts. The resource impacts are related to BNF, eliminating the need for N fertilisation of the forage and reducing the need for fertilisation of the following crop. From an environmental perspective, it is unfortunate that forage legumes have never been considered in the CAP beyond some regional agri-environment schemes, but the CAP reform provides a opportunity to integrate measures relevant to forage legumes into measures used for protein crops.

ANNEX 4. ECONOMIC CONSIDERATIONS

'Public money for public goods' is a principle that underpins CAP reform. Implementing it requires assessment of both the economic and evironmental effect of including protein crops in farming systems.

Crop-level gross margins

To assess the economic implications of protein crop production, a number of indicators can be used. One is the crop gross margin which is the market value of crop outputs minus the direct variable costs. Although the (per hectare) costs of producing protein crop are usually lower than cereals, their gross margins were estimated to be between 55 and 586 €/ha less than that of cereals and oil crops in several case studies across Europe. In contrast, margin improvements were achieved in two case studies (Table 8). This shortfall compares with the protein premium paid in some EU member states of 57 €/ha.

Table 8: Gross margins of legumes, compared to cereals and rapeseed

Case study, year		Annual gross margin (€/ha)	Gross margin deficit of legume compared to other crop (€/ha)			
			Wheat	Maize	Barley	Rapeseed
Netherlands, 2008 [1]						
	Pea	631	-571			
	Faba bean	796	-406			
	Lupin	616	-586			
France Midi Pyrenées, 1999-2003 [2]						
Rainfed loam	Soya bean	245	206	68	29	-196
	Pea	-48	-87	-255	-264	-489
Rainfed clay	Soya bean	253			188	58
	Pea	-52			-117	-247
Irrigated loam	Soya bean	83		-410		
	Pea	153		-340		
Irrigated clay	Soya bean	189		-214		
	Pea	190		-213		
France Ariege, 2009 [3]						
	Pea	-181	-622			
Average		**240**	**-344**	**-227**	**-41**	**-219**

Sources: Calculations based on data from: [1]Kamp et al. (2010), [2]Mahmood (2011), [3]Chambre d'Agriculture de l'Ariege (2009) in Mahmood (2011).

Gross margins of legumes and legume-supported rotations can increase through improvements in yields and prices, but this will affect cropping decisions significantly only if they improve relative to other crops or rotations.

A survey of farmers who did not grow protein crops highlighted yield variability and low yields as the major constraint to production (in Belgium, Germany, Spain and Switzerland; von Richthofen et al. 2006a). High yield variability leads to high fluctuations in gross margins for pea, lupins and faba bean, as well as rapeseed in some regions (LMC International 2009, Kamp et al. 2010). The variability is caused by climatic factors and the high susceptibility of legumes to those, affecting growth and harvest losses due to lodging and fungal infections (Kamp et al. 2010). Consequently, the income that can be derived from grain legumes fluctuates more strongly between years than that from cereals (Table 9). Yield stabilisation and improvements can be achieved through investments in research and breeding, with the potential to increase yields by 1-2% annually (Kamp et al. 2010).

The relative gross margins of protein crops versus other crops is largely influenced by crop yields, and the disadvantage for protein crops is generally smaller in regions with lower overall yield levels (LMC International 2009).

Table 9: Volatility of crop gross margins in 2001-2007

	Volatility (Coefficient of variation[1] %)				
	Faba bean	**Pea**	**Wheat**	**Barley**	**Oilseeds (mostly rapeseed)**
Germany Niedersachsen	46	51	34	21	35
Spain Castilla-La Mancha		78	42	48	74
France Seine Maritime		25	16	18	33
France Eure et Loir		31	29	22	22
UK East Anglia	36	31	23	21	49

[1] The coefficient of variation is an indicator for volatility that is independent of the size of the actual effect and can thus be compared between different sets of data. It is the arithmetic mean divided by the variance.

Source: LMC International (2009)

Farm-level economic effects

When the gross margin of the whole cropping system is considered, the average gross margin across all crops has been reported to be reduced by about 40 €/ha each year, but extreme reductions of up to 228 € as well as slight increases up to 67 €/ha are reported (Table 10). The main competing crops are rapeseed (as a break crop), as well as cereals, potatoes, and sugar beet.

To adequately represent the profitability of legumes, the simple crop-level gross margins discussed above have to be complemented with the effect of legumes on subsequent crops. When the most important precrop effects are taken into account (von Richthofen et al. 2006b, LMC International 2009), gross margins of grain legume crops increase, but still remain considerably lower than those of cereals and oil crops. The gross margins of crop rotations including legumes are in many cases not significantly different from those of rotations not containing legumes (Table 10), but in six cases they are 20-47 €/ha/yr lower, in a Swiss case they were even 181 €/ha/yr lower.

Table 10: Gross margins of rotations with and without legumes

Case study, year	Annual gross margin incl. precrop effect (€/ha/yr)		
	Legume rotation	Rotation without legume	Deficit of legume rotation
Regional data, averaged 2000-2004 [1]			
Germany Saxony-Anhalt	278	281	-3
Germany lower Bavaria	142	167	-25
Denmark Fyn	193	213	-20
Switzerland Vaud	926	1107	-181
Spain Castilla y Leon	55	53	2
Spain Navarra light soil	331	330	1
Spain Navarra deep soil	354	347	7
France Barrois	243	243	0
France Picardie	425	428	-3
Regional data averaged 2001-2007 [2]			
France Eure et Loir	737	738	-1
France Seine Maritime	833	839	-6
Germany Niedersachsen	745	792	-47
Spain Castilla-La Mancha	136	137	-1
UK East Anglia	813	852	-39
Average	**477**		**-24**
Range	**53 to 1107**		**-181 to 7**

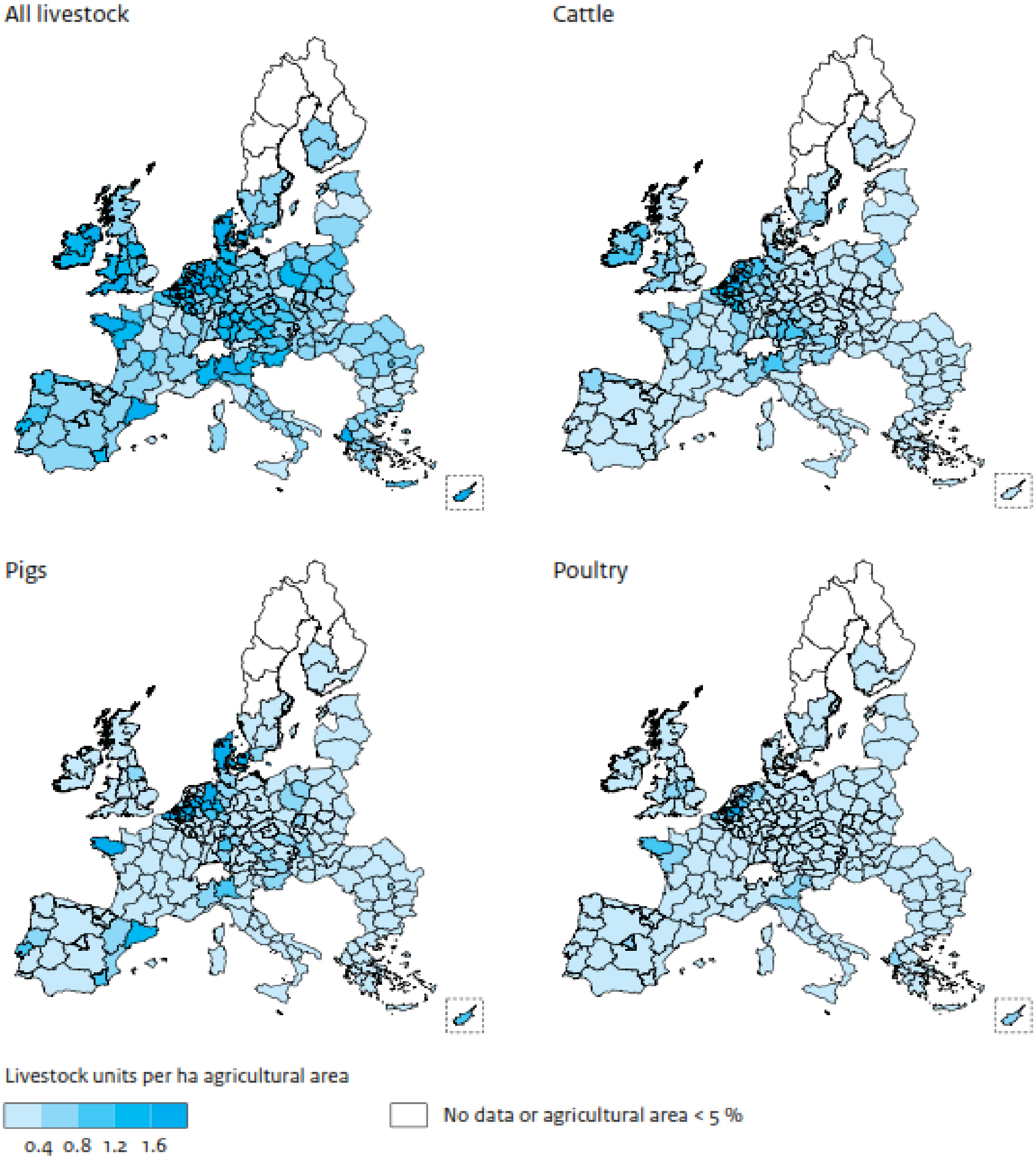
Sources: Calculations based on data from:
[1] von Richthofen et al. (2006b) (Considered precrop effects: yield effect on 1st subsequent crop, fertiliser saving, pesticide saving, reduced tillage).
[2] LMC International (2009) (Considered precrop effects: Yield effect on 1st subsequent crop, N fertiliser saving)

The most reliable and well-studied precrop effects of economic significance are yield increases and fertiliser savings in the first subsequent crop (von Richthofen et al. 2006b, LMC International 2009, Mahmood 2011). The value of fertiliser savings in subsequent crops can reach up to 38 €/ha but are not always realised by farmers (LMC International 2009, von Richthofen et al. 2006b, Legume Futures data unpublished).

Areas with a high concentration of pig and poultry production in particular lead to high organic nitrogen surpluses (Figure 18). There is little potential for fertiliser savings and economic benefits in these areas. In regions with high cattle densities, however, there is potential for forage legume production.

The yield of cereals is on average 15% higher after grain legume crops than that after cereal crops in temperate climate regions (Table 11). This difference amounts to 671 kg extra yield on average and is greater than the yield increase following other break crops (Kirkegaard et al. 2008). After forage legumes, yield benefits are even higher. The processes leading to yield increases in crops following legumes include the provision of nitrogen, phosphorus mobilisation, inducing growth of growth-promoting soil organisms, reducing disease, and improved soil structure (see Section 2.1 and Annex 2).

Figure 18: Livestock density in the EU-27 (2005)



Source: Calculations based on data from: Lesschen et al. (2011) in Westhoek et al. (2011).

The highest yield effects arise from introducing grain legumes in regions with high cereal proportions, such as above 75% (von Richthofen et al. 2006b). As shown in Figure 19, in central European regions, especially Poland, western Germany and northern Italy, increased legume cultivation may give high yield benefits for cereals, while in much of Scandinavia, Ireland and central Italy the benefits may be small.

Table 11: Yield effects in Europe of protein crops and rapeseed as precrops

Source	Precrop	Subsequent crop	Yield effect (%)	Yield effect (kg ha^{-1})
2	Pea	Barley	13-62	671-1500
10		Barley	15	799
10		Wheat	9	493
12		Wheat	-2	-147
14		Wheat		583
6		Rapeseed	10	580
10		Rapeseed	19	499
12		Rapeseed	54	1364
1	Faba bean	Wheat	3	
11		Wheat	62	2693
12		Wheat	3	221
14		Wheat		870
12		Rapeseed	13	328
2	Lupins	Barley	15-77	774-1301
1		Wheat	-12	
12		Wheat	-2	-147
12		Rapeseed	23	581
5	Lucerne, clovers	Wheat	24-36	488-733
9		Wheat	51	1994
11	Rapeseed	Wheat	8-31	434-1374
7		Wheat	2-13	130-694
13		Wheat	7	
14		Wheat		550
Average grain legumes			**15**	**671**
Range			**-12 to 77**	**-147 to 2693**

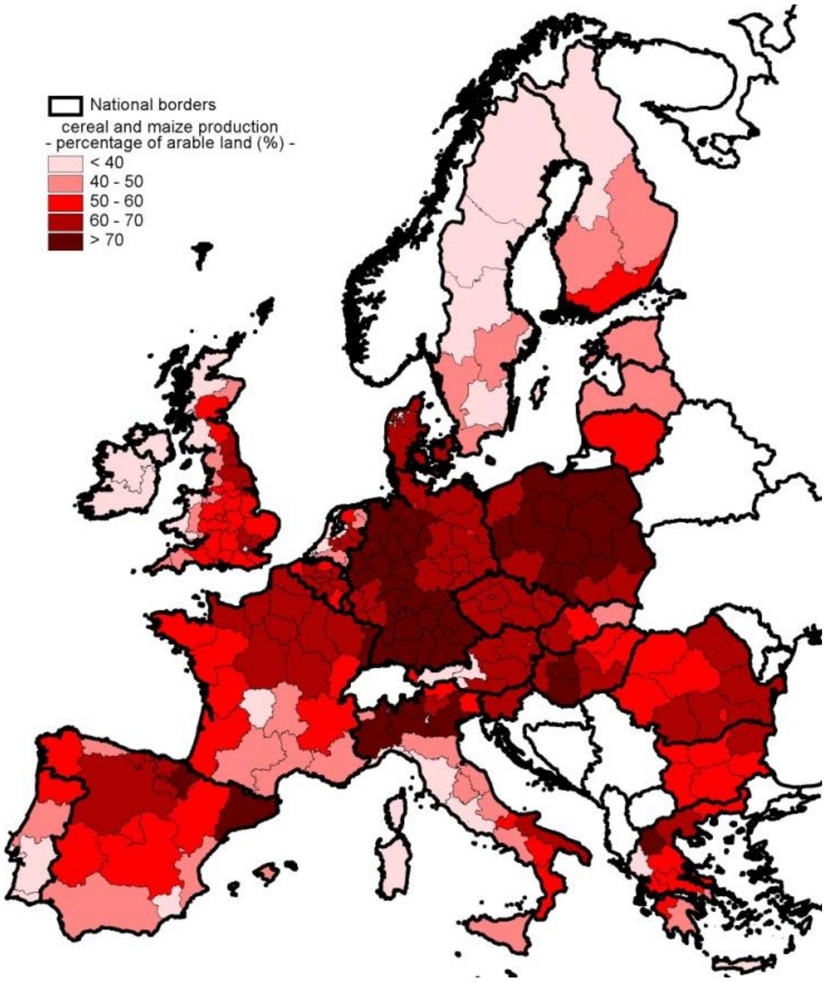
Sources: Calculations based on data from:
[1] Keskitalo et al. 2012, [2] Jensen et al. 2004, [3] Berzsenyi et al. 2000,
[4] Badaruddin and Meyer 1994, [5] Skuodiene and Nekrosiene 2012, [6] Charles and Vullioud 2001,
[7] Kraljević et al. 2007, [8] Papastylianou 2004, [9] Wivstad et al. 1996,
[10] Jensen and Haahr 1990, [11] Köpke 1997, [12] Kaul 2004,
[13] field research by UNIP France, Centres d'Economie Rurale, Unkovich and McNeill (1998), all cited in in LMC International (2009), [14] von Richthofen et al. 006b

There are further long-term economic effects that are not easily captured by gross-margin analysis. These arise from long-term yield increases, fertiliser savings, and reduced labour demand in peak periods in autumn due to replacing winter-sown with spring-sown crops. Most of these effects are not automatic but depend on farmers' management decisions as well as environmental and agronomic conditions, so they are difficult to quantify and to evaluate. Von Richthofen et al. (2006b) evaluated pesticide savings worth up to 31 €/ha and reduced cultivation costs of up to 10 €/ha, which are included in Table 10.

Economic aspects specific to forage legumes

As forage legumes are predominantly utilised on-farm, their economic value depends not on their market price but on their value within the farm: yield, feed value and savings of fertilisers and concentrate feeds are crucial for their economic effects. In the case of forage crops in rotations with other arable crops, the yield benefits and fertiliser savings in the subsequent arable crops also require consideration.

Figure 19 : Share of cereals and maize of EU-27 arable land (2011) (%)



Data on NUTS 2 level except for Germany (NUTS 1 level)
Source: Calculations based on EUROSTAT (2013)

In terms of feed value, legume-grass mixtures are superior to pure grasses: they are preferred by cattle leading to higher intake and have a high nutritive value, increasing both animal productivity and product quality[19] (Peyraud et al. 2009). The higher intake allows reducing feeding of concentrate (Rochon et al. 2004).

The yields of permanent pastures and temporary leys are affected differently by inclusion of forage legumes. In permanent pastures, the presence of clover depends on moderate fertilisation, because at high fertilisation levels it is gradually suppressed by grasses and

[19] Contents of unsaturated fatty acids in milk and milk protein content

forbs. Therefore, clover-containing pastures generally yield 15-20% less than highly fertilised grass pastures (Humphreys 2013). In contrast, the presence of legumes in leys depends less on fertilisation, and legume components improve the N nutrition of the sward, therefore increased yields of legume grass mixtures compared to pure grasses have been recorded (Peyraud et al. 2009; Le Gall 1999). In addition to the high nitrogen fixation (100-400 kg/ha), mixtures have additional agronomic benefits such as suppression of unsown species, benefitting from seasonal growth patterns[20], deep rooting systems, and higher yield stability (Peyraud et al. 2009). Nevertheless, mixed pastures sometimes do not provide yield benefits [21].

High fertiliser savings reduce the production costs of forages containing legumes. A high legume content can save 136-400 kg N/ha in permanent pastures (Humphreys 2013) and 150-300 kg N/ha in leys[22] (Peyraud et al. 2009). At current fertiliser prices this is worth 234-624 €/ha (urea price in 2011, 1.56 €/kg N). Rotated leys also enable additional fertiliser savings in the subsequent arable crop worth around 30 €/ha. Although the costs and skills required for pasture management, harvesting and conservation are higher with legumes, fertiliser savings lead in most cases to reduced overall costs (Doyle and Topp 2002).

Thus, increased production of leys and slightly reduced production of grazed pastures goes along with increased animal productivity and high fertiliser savings. Especially since fertiliser prices have sharply increased, forage legumes today have on average no substantial negative and often even positive economic impacts on a per hectare basis (review of 11 studies by Rochon et al. 2004, Humphreys et al. 2012, Doyle and Topp 2002). For legume swards and legume-grass mixtures, economic benefits of 136 €/ha on average were recorded in Germany, the UK and Sweden, whereas in Finland, some species of forage legumes led to negative economic impacts (Doyle and Topp 2002).

Conclusion

Grain legumes generally bring low economic returns compared to many cereals and oil crops. When precrop effects are considered and margins calculated over full crop rotations, legumes provide similar gross margins as non-legume rotations in about two thirds of the cases and lead to gross margin losses in one third. These deficits are much higher than the protein premium paid in the past. Besides direct support through subsidies, yield improvements and increased fertiliser costs are important to improve the profitability of grain legumes. Due to their high feed value and nitrogen fixation, forage legumes can be profitable as components of pastures and leys when fertiliser costs are high.

[20] Grasses are favoured in spring and legumes in summer.
[21] In cool soils, waterlogged conditions or dry summer periods, legume mixtures yield lower than grass-based pastures (Peyraud et al. 2009).
[22] Provided legume porportions are 30-80%.

ANNEX 5. AGRI-ENVIRONMENTAL SCHEMES IN DIFFERENT COUNTRIES

Country	Details	Source
Belgium - Flanders	Conditions and details for payments: at least 0.50 ha / farm cultivation: clover mixture (30 kg/ha, with a minimum 10% share of clover), lucerne (25 kg/ha) or red clover (10 kg/ha) grant amount: annual 275 €/ha.	Ministry website http://lv.vlaanderen.be/nlapps/docs/default.asp?id=232 (2013-04-12)
Belgium - Wallonia	Only support of organic farming: Support for conversion: 225 to 900 €/ha Support for maintenance: 75 to 750 €/ha	Programme wallon de Développement Rural 2007-2013
Estonia	Agri-environment scheme for legume crops: 15% of the eligible land must be covered by legume crops organic farming support: at least 20% of the area of crop rotation must be covered by legume crops	Resource person
France	Two agri-environment schemes that could indirectly support legumes: crop rotation : 32 €/ha integrated fodder polyculture-breeding system: 130 €/ha	Cavaillès 2009
Germany	North Rhine-Westphalia, Bavaria and Baden-Württemberg Program on crop diversification: cultivation of at least five different main crops; including the cultivation of legumes or legume mixtures on at least 7% of the arable land; the grant amounts to 40-85 €/ha per year depending on the federal state and farming system (organic/conventional). The minimum amount is 400 €/yr. Set aside or arable land taken out of production are not eligible. Organic farming support: subsidies for conversion and/or maintenance of organic production, regulated differently by each federal state	North Rhine-Westphalia: http://www.landwirtschaftskammer.de/foerderung/laendlicherraum/44.htm Bavaria: http://www.stmelf.bayern.de/agrarpolitik/foerderung/001007/ Baden-Württemberg: http://www.mlr.baden-wuerttemberg.de/mlr/bro/Broschuere%20MEKA%20III.pdf
Greece	600 €/ha/yr, where the farmer grows maize, cotton or lucerne under irrigation. To qualify, farmer must use crop rotation such that 20-35% of the land (depending on the crop) is in any year planted with legumes as a winter cover crop (without irrigation). Not necessary if the soil has already >3% organic matter, or if already three crops are grown in rotation. 936 €/ha/yr for a five-year period where the farmer grows tobacco under irrigation. Here, there must be a rotation or intercropping system where 20% of the land is growing legumes at any one time, as green manure (so he cannot harvest the legume crop). He must also have a buffer strip of fallow land amounting to 5% of his land, and he may not use herbicides to remove weeds. These conditions are not required if his soil has >3% organic matter. All this is part of measure 214.	http://www.agrotikianaptixi.gr/index.php?obj=4c1776c316a3cccb (2013-04-12)

Country	Details	Source
Hungary	Legume requirements are part of grassland and arable management in measures 214, 216 (non-productive investments) and 222 (agroforestry).	New Hungary Rural Development Programme, http://akg.umvp.eu/
Ireland	Rural Environment Protection Scheme (REPS), fourth and most recent version: REPS-4 (1994 to July 2009, then replaced by new programme called Agri-Environment Options Scheme) Incorporation of clover into grassland swards ("use a minimum of 5 kg/ha of white clover seed.") annual payment: 26 €/ha up to max of 40 ha	http://www.agriculture.gov.ie/farmerschemespayments/ruralenvironmentprotectionschemereps/overviewofreps/ (2013-04-12)
Italy	Emilia-Romagna has specifications for rotations and cover crops, but does not specify that any of them should be legumes.	http://www.ermesagricoltura.it/Programmazione-Regionale-dello-Sviluppo-Rurale/Programma-di-Sviluppo-rurale-2007-2013 (2013-04-12) (Emilia-Romagna)
Poland	Option 7: The programme for agri-environment schemes consists of nine packages and 49 measures. The cultivation of legumes is supported in Package 1: Sustainable Farming o Measure 1.1 Sustainable farming system Package 2: Organic farming o Measure 2.1 Agricultural cultivation with conformity certificate o Measure 2.2 Agricultural cultivation in transition period o Measure 2.5 Vegetable cultivation with conformity certificate o Measure 2.6 Vegetable cultivation in transition period Package 6: Preservation of endangered genetic plant resources in agriculture o Measure 6.1 Local crop varieties commercial production o Measure 6.2 Seed production of local crop varieties Option 8: As a rule, organic farming cannot be combined with a measure from the package "sustainable farming". Furthermore, in order to avoid double payments, no farmer may apply for both agri-environment schemes and Article 68 at the same time for the same area.	Communication with the Polish Ministry of Agriculture (2013)
Portugal	No requirement in M211/212 – only keep the land free of shrubs, maintain hedges, etc. In M214 – soil conservation: do not add nitrogen to 'extreme legume cultures'. There are integrated territorial interventions under M214	http://www.ifap.min-agricultura.pt/portal/page/portal/ifap_publico/GC_drural (2013-04-12)
Spain	**Castilla y León** has a scheme to expand protein crops (presumably forage legumes) at the expense of grain legumes (sic!). But the programme also mentions 'an adequate rotation of cultures through the introduction of legumes' (Vol. 1, p. 296). **Andalucía**: m211 and m212 speak about maintaining the land	http://www.jcyl.es/web/jcyl/AgriculturaGanaderia/es/Plantilla100/1175259682603/_/_/_ (Castilla y León)

Country	Details	Source
	in good condition as a requirement that beneficiaries must fulfil. For m214, erosion control is the main priority. For this and other objectives (less GHG emission, preserve soil fertility and structure, reduce pollution of dams, etc.), legumes are useful, but not mentioned specifically. But: sub-measure 13 is aimed at integrated production of lucerne. Described on pp. 290ff. farmers must maintain lucerne for 5 years, not use N fertiliser nor herbicides. Grant is 320 €/ha.	http://www.castillalamancha.es/gobierno/agricultura/actuaciones/programa-de-desarrollo-rural-2007-2013 (2013-04-12) (Castilla-La Mancha)

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