

Legume Futures Report 1.2

Agronomic case studies in Legume Futures

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www.legumehub.eu

Legume Futures

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

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FOREWORD

Legume Futures, "Legume-supported crop rotations for Europe", is an international research project funded under the European FP7 programme. It has 20 partners in 13 countries. The project aims to develop and assess legume-supported cropping systems that improve the economic and environmental performance of farming in Europe.

The project aims to make use of both data and professional expertise in various ways. Partners have contributed data on crop yields, biological nitrogen fixation and greenhouse gas releases for use in modelling of the biophysical and socioeconomic impacts of legumes in crop rotations.

This work reported here aimed to capture the *status quo ante* in terms of expertise at each of our partner institutions. It is constructed as a set of "case studies", in the sociological sense of the term, in which experts were asked about their knowledge and opinions on various legume-related issues.

In addition to the work presented here, five partner organisations have provided detailed data sets from which potential cropping systems are being developed and assessed. That additional case study research is the subject of further reports.

Each case presented here is set out largely as the correspondent sent it. Editing has been confined to grammar and clarifications of presentation. This is intended as a "living document" that can be updated as the correspondents have new insights.

Fred Stoddard,

Helsinki, Finland, June 2013

INTRODUCTION

The first objective of Legume Futures is to conduct 18 case studies across Europe on established field experiments. In addition to providing data for the environmental and economic assessments, these ‘case studies’ inform and validate new cropping system designs and provide a focal point for the local development of new cropping systems. This responds to the European Commission's request that, on the basis of case studies, the project should take full consideration of the variety of agro-economic and pedo-climatic situations in Europe.

A case study is a research approach commonly used in social science that seeks to identify underlying principles by investigating a single individual, group or event (the case) in-depth. It is based on empirical inquiry that investigates a phenomenon within its real-life context. Case study research can include quantitative evidence, rely on multiple sources of evidence, and can benefit from the prior development of theoretical propositions. This understanding of case studies is supportive of our approach generally. The European Commission's use of the term ‘case study’ highlights the role of local and regional expertise and associated qualitative evidence should provide in this research. In the context of Legume Futures, the underlying processes or questions might be:

1. the factors affecting uptake and utilisation of legumes in crop rotations and cropping systems, the willingness of farmers and processors to use legumes;
2. the contribution of legumes to public goods: environmental benefits, agricultural sustainability, ecological services and social benefits; and
3. both 1) and 2).

The consortium's 18 on-going experimental field sites are the primary source of quantitative information for site-based case studies in Legume Futures. This report provides an overview of the experiments used and reports in particular on insights the relevant partners have. The focus is the insights the relevant partners have gained from this experimentation and related activities. The results of the experiments conducted at these 5 sites and the associated regional data are the subject of separate reports, particularly the environmental assessments and the five regional case studies.

In addition to the data from on-going experiments, Legume Futures has access to knowledge and insights beyond our experiments. The starting point is the wider agricultural, economic and environmental context in which we work, not just our experiments. The case studies include knowledge from our experiments in the context of the regional agricultural systems where the experiment seeks to contribute.

Fifteen of the eighteen partners in Legume Futures have conducted field experiments across Europe. The sites provided by these partners and their links to these case studies are shown in Table 1 and the locations are shown in Figure 1.

In addition to providing data for the environmental and economic assessments, the team in each organization hosting these sites was asked to provide information on the following topics, from the viewpoint of one delegated correspondent:

1. History of legume cultivation in the country/region.
2. Current status of legumes in the country/region.
3. Role of current local public policy and commercial circumstances.
4. Current research.
5. Potential for legumes in the cropping systems.
6. Insight into how this potential may be realised.

Table 1. The sites provided by the Legume Futures partners and their relations to the case studies.

Case study	Institute	Experimental sites
Scotland	Scotland's Rural College (SRUC), James Hutton Institute (JHI)	Bush Estate, Edinburgh (SRUC), Tulloch, Aberdeen (SRUC), Balruddery, Dundee (JHI)
Ireland	Irish Agriculture and Food Development Authority (TEAGASC)	Solohead, Tipperary
Germany	Leibniz Centre for Agricultural Landscape Research (ZALF), von Thünen Institute (vTI)	Müncheberg (ZALF), Trenthorst (vTI)
Poland	Institute of Soil science and Plant Cultivation (IUNG-PIB)	Osiny
Romania	National Agricultural Research and Development Institute (NARDI)	Fundulea
Greece	Agricultural University of Athens (AUA)	Agrinio
Italy	Mediterranean University of Reggio Calabria (UDM)	San Marco Argentato
Spain	University of Cordoba (UCO)	Malagón
Finland	University of Helsinki (UH), Agrifood Research Finland (MTT)	Viiikki (UH), Jokioinen (MTT)
Sweden	Swedish Agricultural University (SLU)	Säby, Lanna, and Stenstugu
Denmark	University of Aarhus	Foulum

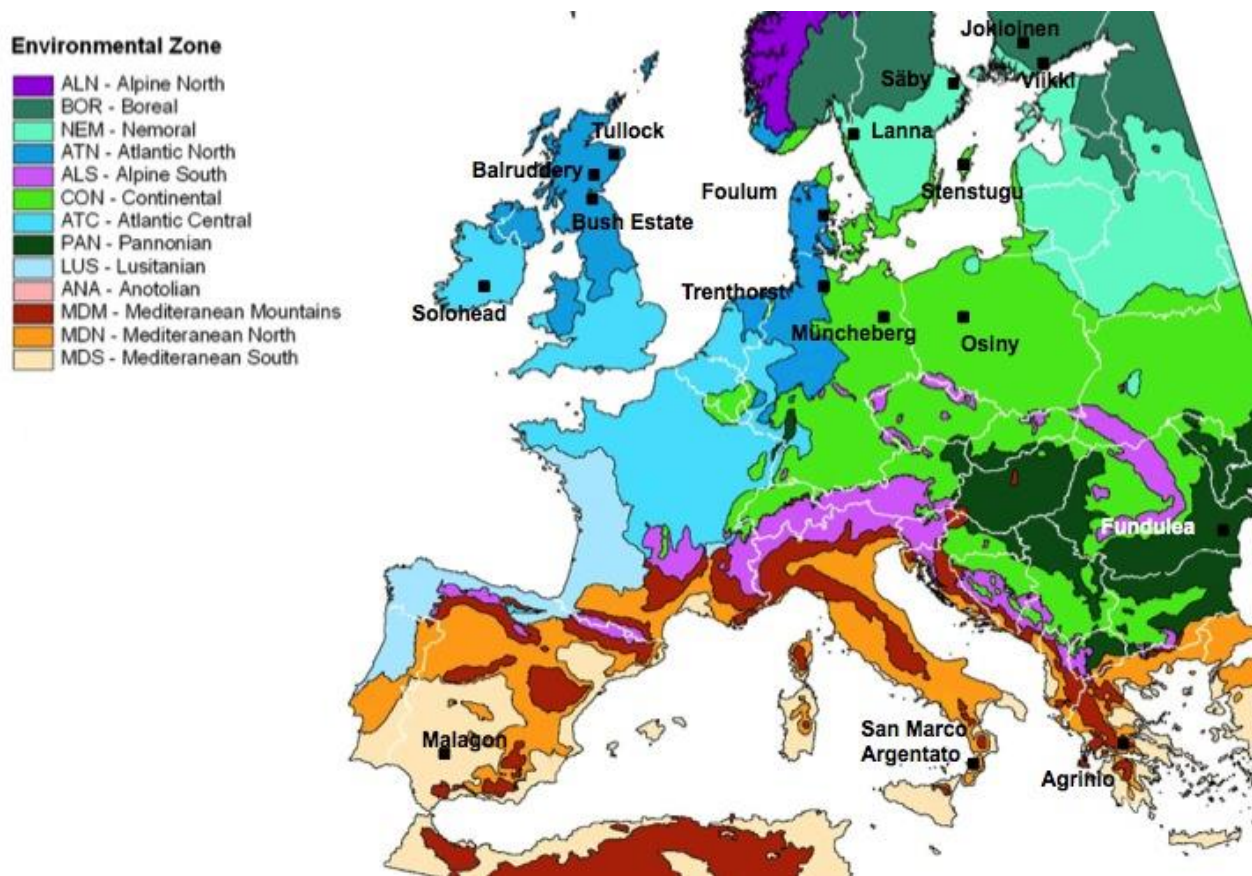


Figure 1. Locations of the Legume Futures field experiments. Map provided by courtesy of MJ Metzger and based on that in: Metzger M.J., et al. (2005). A climatic stratification of the environment of Europe. *Global Ecology and Biogeography* 14: 549-563.

These case studies should not be regarded as site reports. The SLU in Sweden has three field experiment sites. There are also three sites in Scotland. In these two countries, these sites are similar in relation to the case studies and so the insights from each of the three sets are merged. The insights from the two German sites were also merged. We thus have the basis of 11 case studies.

OVERVIEW OF THE CASE STUDIES

Grain legumes have been cultivated for thousands of years in Europe. Pasture legumes were taken into use throughout Europe rapidly from a central European start in the mid-17th century. Their main use in Europe is as livestock feed.

Grain legumes had an important role as a protein source for humans and, together with forage legumes, for draught animals until the mechanisation of agriculture in the 20th century reduced the need for draught animals and rising living standards. The associated economic growth shifted diets toward meat. The importance of grain legumes as food as resurged during crises, such as wartimes.

Increased availability and lower cost of nitrogen fertiliser reduced the need for biological nitrogen fixation in crop rotations. In addition, imported soy bean meal was found to be a uniform, reliable, and for a long time cheap protein supplement for meat and dairy production. Finally, the Blair House Agreement of 1993, that was intended to support trade in oilseeds from America to Europe, ended up doing significant damage to protein crop production in Europe. Many European legume breeding programmes shut down or were amalgamated after 1985.

Moves to reverse the decline have come due to a number of factors which include concerns about reliance on imported protein (soy), the impact of that soy production in exporting countries, the need to fill the gap in protein supplies arising from bovine spongiform encephalopathy (BSE) crisis, and due to Europe's rejection (for political rather than scientific reasons) of genetically manipulated organisms (GMOs) as the world soy crop has become increasingly GMO-based.

There is consensus in the Legume Futures consortium that increasing legume cultivation (by area or increasing legume share in rotations) would contribute to greater protein self-sufficiency and reduce independence on imported protein.

Through the geographic regions covered by Legume Futures, limitations to the usage of grain legumes are broadly similar. Climate constrains the choice of species and cultivars in all regions, with earliness of maturity being an important trait for the boreal and oceanic zones, and escape from terminal drought important in the Mediterranean zone. The lack of recent investment in breeding throughout Europe means that there have been few advances in breeding for disease resistance in grain or forage legumes. Some users of legumes grow them in rotations which are too short leading to the build-up of soil-borne pathogenic fungi (the best known case being *Aphanomyces* root rot of pea in France). This disease results in poor emergence and vigour.

Further limitations come from farmers' unfamiliarity (particularly younger farmers) as cereal monoculture has become more widespread in Europe. The small batches arising from the

relatively small scale of production limit markets (compared with soy bean meal which is uniform). Legume Futures partners also report considerable prejudice (legumes are "demanding" crops that give "unstable" yields and "low" profits so they are "for the organic sector only"). A Finnish farmer said "I don't have time to wait for legume nitrogen" and an Italian farmer said that "legumes are for old men", and these statements lodged in the memories of our correspondents. The environmental effects of legume crops have not been economically evaluated.

Markets are limited by several factors. First is the wide range of species that can be grown for stockfeed or animal feed ingredient use, thus by definition providing a wide range of qualities in contrast to the consistent uniformity of soya bean and its meal. Furthermore, anti-nutritional factors differ between species and this variation limits their use in feed compounding. Breeding is needed to improve feed quality (e.g., low vicine-convicine faba bean) and to improve stress tolerance (against drought, pathogens, and extreme temperatures). However, the market price of locally produced legume products is competitive compared with imported soya bean products.

Much of information from partners that was particularly relevant to specific regions relates to the range of crops adapted within the case region and the specific biotic and abiotic stresses that affect them in those regions. In the Continental region, where sowing is mainly in the spring. Lupins are important in Poland and soy is important in Romania. A wide range of grain legume species are used in Germany. In the Mediterranean region, broomrape and terminal drought are far more important stresses than elsewhere.

Every case study mentioned the potential of at least one grain or forage legume species that was even more underutilized than the mainstream species. Serradella could return to the rotations in Poland, while lentil could be used in many countries, as shown by its success in the sub-boreal climate of Saskatchewan in Canada.

Even though we as scientists feel that the message about the positive impacts of legumes on crop rotations and the environment is well known, most of the correspondents in the consortium felt that farmers in their regions did not adequately understand these effects, and management techniques are largely lost as the more experienced farmers retire. More novel methods such as intercropping have made little impact at the farm scale, because farmers do not know how to manage these crops, except in the narrow case of cereal-legume mixtures for on-farm livestock feeding in organic systems.

We may expect that increasing knowledge of the environmental benefits of legumes in rotations, and of their dietary benefits to the consumer, will increase their usage in cropping systems. Interest in legume production will also continue to follow increases in price of soya bean and N fertiliser. As novel food uses are developed, market demand may be expected to increase. The research knowledge on the potential of legumes has to

be transferred to farmers and show the best practices to manage/establish legume based agriculture, as well as to develop legume processing and fractionation facilities.

However, the economic output of grain legumes is usually lower than other crops. Growers need appropriate financial support and subsidies to justify the introduction of legumes into their systems. An example of an appropriate measure is The Rural Environmental Protection Scheme (REPS), introduced by the Irish Department of Agriculture, which financially rewarded farmers for farming under environmentally friendly practices. Several of our contributors were concerned about the draft revisions of the Common Agricultural Policy (CAP) and whether it would adequately promote crop rotations.

Policies should seek to support agronomic and environmental outcomes. Local and international policy makers need to be informed on the role of legume in sustainable agriculture and on their potential benefit to the environment. The social and environmental effects of soya bean production in South America should also take in account when decisions are made.

ATLANTIC REGION

This region is characterised by mild winters and plentiful rainfall distributed through the year. Autumn-sown crops take priority over spring-sown, and the yields of small-grained cereals are among the highest in the world, showing a substantial yield difference from those of the grain legumes. The main grain legumes are pea and faba bean, with much of the latter being autumn-sown, particularly in England. The primary forage legumes are white clover. Our participants are in Scotland and Ireland, and the region spreads well into France, the Netherlands, and north-western Iberia.

Scotland

Correspondents: Christine Watson, Scotland's Rural College, Aberdeen, and Pietro Iannetta, James Hutton Institute, Dundee

History of legume cultivation

Land use in Scotland is dominated by grasslands, which cover 81% of the land area or 4.6 M ha (Figure 2). They are used primarily for livestock production and vary in the intensity of production from high input beef and dairy systems (defined as grass in Figure 2) in the SW and NE of the country, to more extensive sheep and cattle based systems in the upland regions located on rough semi-natural grasslands. The grassland area is dominated by permanent grasslands although about 300 000 ha were classified as rotational grass in 2010 (Scottish Government 2011). Many of these grasslands contain clover, but this is not captured in government statistics. White clover is the most common forage legume used in grassland. Red clover also grows well and is used in short-term leys, particularly by organic farmers. Clover-supported pastures, both within rotational and permanent grasslands, are critically important to organic production systems in providing an input of N. However, such pastures are also widespread in the conventional sector, particularly in the more extensively managed systems. Grass/legume mixtures are often established as an understorey to cereal crops, particularly in organic systems. There is still a reasonably active breeding programme of forage legumes in the UK, notably for clover cultivars.

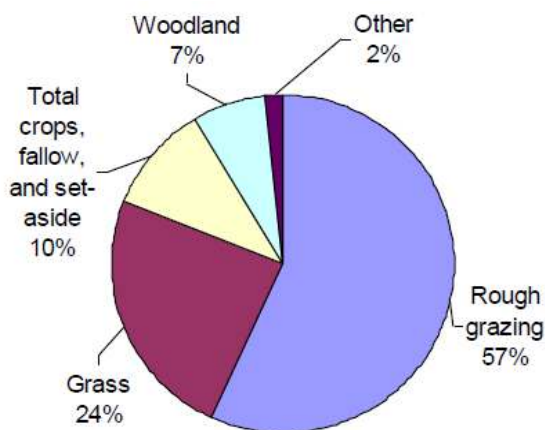


Figure 2. The distribution of different land use categories in Scotland in 2010 (Data from Scottish Government 2011).

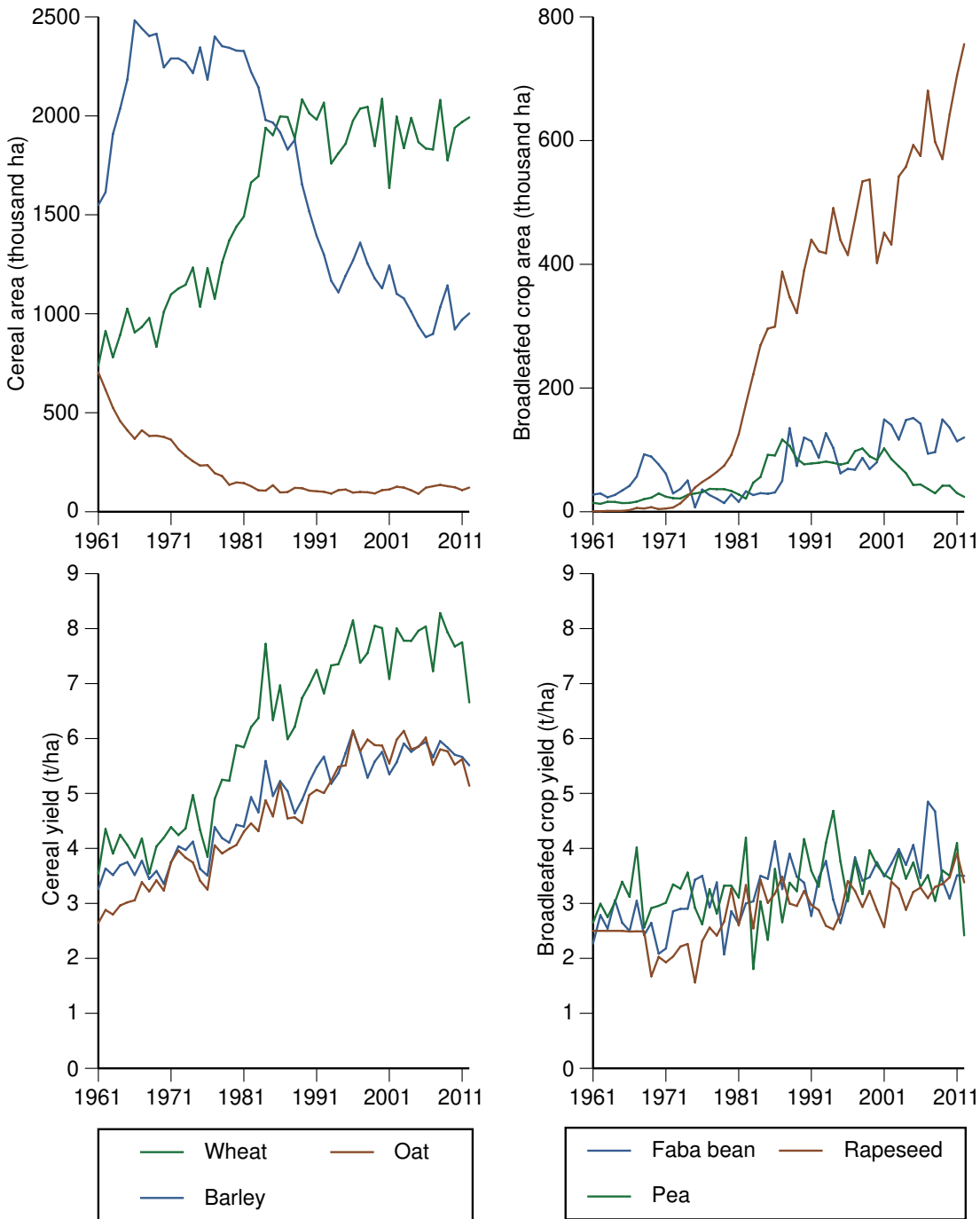


Figure 3. Harvested areas (thousand ha) and average yields (t/ha) of the main cereals, grain legumes and oilseeds in the UK, 1961-2012 (FAOstat data).

The main grain legume grown in the UK is faba bean (Figure 3) but grain legumes are less widely grown in Scotland than in England because of climatic constraints. In Scotland, the area of beans in 2010 was 5,264 ha and of combining peas 1668 ha. Approximately 30,000 tonnes of vining peas were produced in Scotland in 2010. Most Scottish faba bean crops are harvested as dry grain for animal feed and for export for human consumption.

Broad beans for human consumption, mostly as frozen fresh beans, are also produced in small quantities. Crops may be sown in autumn or spring, with the spring sowing being far more common.

Faba bean production declined during the 1960s and 70s as it was economically less attractive than wheat (Figure 3). However, rising prices of grain legumes have led to an increase in production with current output at an all time high. In Scotland, spring beans mature in mid-late September, so only early cultivars tend to be grown. There is a demand for the development of early maturing winter bean crops. The protein levels of winter bean grain are usually lower than that of spring beans.

Breeding programmes for grain legumes were in place in the UK, but have been largely closed down as a consequence of reduced government funding. NIAB now has a programme, linked to PGRO, and some seed companies also have breeding programmes.

Peas are grown for animal feed (combining and forage peas) and for human consumption as vining peas, dried processing peas and mange-tout or whole-pod peas. Some pea cultivars can be sown in the autumn, but this is rare in Scotland. Weed control is a major issue in all grain legume crops, and peas tend to fare worse as they are less competitive than beans. Weed control in lupins is also troublesome.

Current status of legumes in Scotland

Grain legumes are currently grown on a relatively small area in Scotland, and their main use is for livestock feed. There is increased interest in the production of grain legumes due to increased prices of soy bean meal and N fertiliser. There is also a growing interest in legume production from livestock producers – for feeding pigs, poultry, cattle and fish. The area of faba beans planted in Scotland increased from 1138 ha in 2000 to 5264 ha in 2010 (Figure 4).

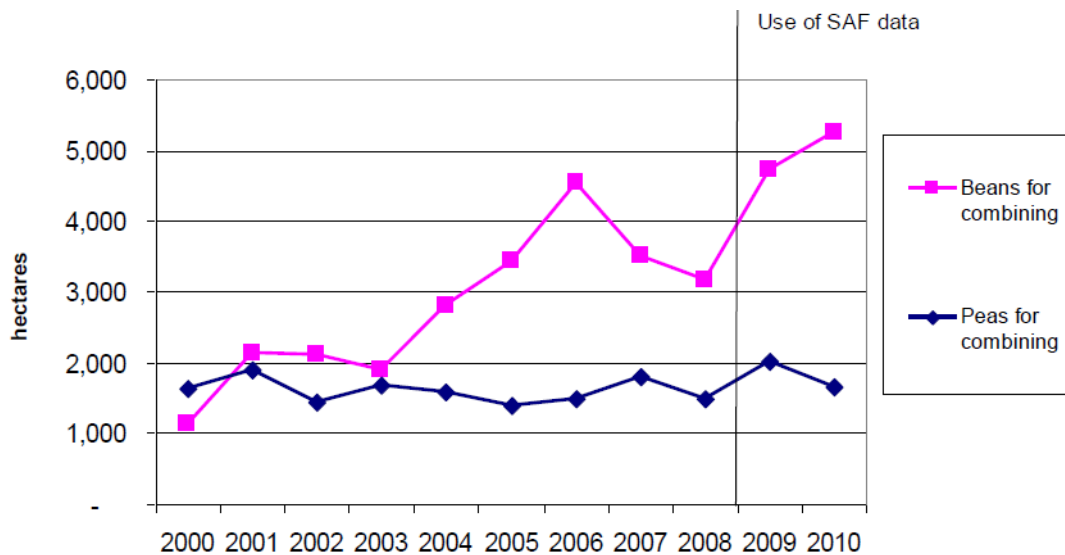


Figure 4. The areas of cultivation of combining (grain) faba beans and grain peas in Scotland 2000-2010.

Scottish faba bean crops produce about 1.25 t / ha of protein. There is considerable variation between crops as grain legumes in Scotland are particularly sensitive to soil conditions and are considered more susceptible than cereal crops to moderate soil compaction and imperfect drainage.

Producers of fresh and frozen peas and beans in Scotland struggle to find enough land to rent or contract for their crop. They need access to larger areas of high quality arable land to avoid growing these peas in rotations which are too short, which can contribute to the build up of soil-borne fungi leading to poor emergence and vigour.

A faba bean breeding programme has been initiated at the JHI. It is anticipated that there will be increased industry demand for high yielding and higher protein beans (>28% protein content) with low levels of anti-nutritional factors. Breeding programmes are particularly important in allowing the improvement of the essential amino acid complement of grain legumes necessary to support livestock production. Breeding for improved disease resistance can also be beneficial in all grain legumes suited to Scotland. The use of forage legumes to substitute for the use of synthetic nitrogen in grasslands has been identified as a potential option for mitigation of nitrous oxide emissions. Increasing fertiliser N costs are encouraging more farmers to use clover-based grasslands to replace those with synthetic fertiliser N inputs.

Less information is available on trends in the use and production of forage legumes. Over the period 2000-2010 there has been a reduction of approximately 10% in the land area planted with forage crops, as grasslands have been ploughed to allow the cultivation of

more profitable cereals. This is therefore likely to have been associated with a reduction in the area of forage legumes.

Lists of cultivars of clover and their suitability for cultivation in different areas of Scotland are maintained by SRUC, who also provide advice to farmers on agronomy of clover-based pastures.

Current local public policy and commercial factors affecting legumes in Scotland

- Growers are generally unfamiliar with grain legume crops, but have much greater experience and success with forage legumes.
- Disease risks – 6 years between grain legume crops is needed to reduce disease risks.
- New markets, new products, and education are needed to support legumes: food types, novel non-food uses, health foods (low glycaemic index (GI)).
- Cultivars need to be different across the UK: more planophile leaves in south to shade soils and help restrict water loss, and more open canopy in Scotland. Peas are sensitive to damage from drought. If root systems were more extensive some of the susceptibility to drought could be avoided, which would then probably lead to higher levels of biological nitrogen fixation (BNF).
- There is insufficient quantitative data on the economic performance of legume break-crop and cover crops (considering the value to the following crop in the rotation) and ecological services. These have most commonly been studied in organic systems.
- Lack of grain legume processing and fractionation facilities in the UK, for dehulling seeds and to enrich/fractionate starch and protein components.
- There is a lack of information on the role of legumes in contributing to greenhouse gas emissions and in particular the importance of legume crop residues (grain legumes) in contributing to nitrous oxide emissions.

Current experiments of Legume Futures partners in Scotland

- Faba beans to support environmentally sustainable crop rotations (field trial at JHI).
- Cultivar trials at SRUC, also included as a component of organic rotations trials.
- SRUC has been monitoring GHG emissions and leaching losses from field trials including both forage and grain legumes for a number of years.
- SRUC is undertaking experiments designed to characterise the loss of N₂O from grain legume residues within an arable rotation.
- Faba beans and peas - grain quality ~ biological and environmental drivers (JHI).
- Wild legumes - surveys, functional characterisation, diversity and phylogeny (JHI).

Potential for legumes in cropping systems in Scotland

- Could increase grain legume cropping area 10-fold to result in 15% of arable land.
- Earlier maturity is needed to increase the flexibility of legume-supported rotations, especially in faba bean, or/and development of winter beans.
- Better feed quality (low vicine-convicine faba bean).
- Development of less vigorous understory legumes for use in intercropping systems. There is an opportunity here for both breeding and improved management.
- Inclusion of legumes within perennial systems – such as grassland, orchards and biomass crops.
- Woody legumes in field margins.
- Horticultural production of specialist legumes for various bioactives.

Insight into how this potential may be realised

- Basic underpinning academic studies to be done using funding sources from public purse to assess full potential and proof of concepts.
- Commercial-public partnerships.
- Recognition and management of the costs and benefits (Table 2).

Table 2. Costs and benefits of increasing faba bean production in Scotland

Costs	Benefits
Displacement of winter barley and wheat.	N fixation and reduced reliance on synthetic N supply – improving long-term sustainability of all cropping systems (forage and arable).
Long-distance transport costs for processing, or establishment of new processing plants.	Reduced greenhouse gas emissions.
Loss of revenue to farmers if suitable cultivars are not available and markets are not well established.	Increased resource for pollinators (biodiversity benefits).
Increased risk to farmer due to late harvesting weather conditions etc.	Enhanced within-field biodiversity due to open canopy and development of a dicot weed understory.
	Potential supplement/replacement of imported protein with home-grown feed (economic benefits).
	Farm-scale diversification (economic benefit – spreading risk; biodiversity benefit – landscape diversity).

Ireland

James Humphreys, Teagasc, and William Burchill, Trinity College Dublin

History of legume cultivation

Permanent grassland occupies 90% of the agricultural area of Ireland. Historically, white clover is the most important legume grown in Ireland. Before 1980, white clover was a large contributor of N in Irish grassland. The availability of relatively cheap N fertiliser in the 1980s led to reduction in white clover in Irish grasslands due to the ability of grasses to shade out white clover under high N fertiliser inputs.

In recent decades, legume crops such as peas and beans have been grown but on a very limited scale. An area of 4,600 ha out of a total agricultural area of 4.4 M ha was sown to peas and beans in 2010. Average crop yield for both peas and beans was 5.5 t / ha in 2010. Peas and beans grown in Ireland are primarily used as a protein source in animal feedstuff production.

Teagasc Oak Park has a well established breeding programme for white clover cultivars in Ireland. Five cultivars have been released and are on Recommended List in Ireland and elsewhere (Table 3). Aran, first released in 1981, has shown good performance in UK trials, and is also widely grown in New Zealand, Australia and France as well as Ireland and UK. Avoca has shown very good yield and persistency under a range of managements and is widely used in Ireland and UK. Chieftain, the most recently released cultivar, has also shown strong performance in clover yield under lax defoliation (simulated grazing) management in UK Recommended List trials.

Table 3. Cultivars released from Teagasc Oak Park.

Name	Leaf size	Recommended listing
Aran	Large	Ireland, N. Ireland, England, Scotland, France, New Zealand, Victoria (Australia)
Avoca	Medium	Ireland, N. Ireland, England, Scotland
Susi	Medium	Ireland, France
Tara	Small	Ireland, N. Ireland, Scotland
Chieftain	Large	England, Scotland, N. Ireland

Current status of legumes

The area of grassland in Ireland which includes significant levels of white clover is low, but there is an increasing interest in white clover due to the increase in the N fertiliser price relative to beef and milk prices. The farm-gate cost of N fertiliser in Ireland has been increasing at an annual rate of around 9% over the last ten years, from €0.5 / kg N in 1996 to €1.0 / kg N in 2009. The fertiliser N:milk price ratio has increased from just under 2 to almost 4 in the same time period. Standard grass seed mixtures contain around 8-9% white clover, and high white clover mixtures, containing around 16% white clover, are now becoming more available and are popular.



A productive mixture of perennial ryegrass and white clover in Ireland

Current local public policy and commercial factors affecting legumes in Ireland

The Rural Environmental Protection Scheme (REPS), introduced by the Irish Department of Agriculture in 1994, provided payments to farmers for using environmentally friendly farming practices. Farmers sign up to the scheme for a 5-year time period and have the

option to reapply after the end of every five years. Over 52,000 Irish farmers participate in REPS. One of the options in the fourth and final version of the scheme (2009 – 2014) encourages the use of white clover. The REPS scheme has been an incentive for Irish grassland farmers to increase the white clover content of their pastures.

However, there remains a lack of interest by farmers generally in using white clover due to:

- the lack of awareness of the benefits that can be gained by the use of white clover;
- mistrust of the ability of white clover to consistently supply N for herbage production during the growing season and from year to year; and
- the lack of familiarity with the management practices required to grow white clover in pasture successfully.

Current experiments

Comparison of milk production from clover-based and fertiliser-N-based grassland

This study, conducted over four years (2003–2006), compared herbage production, nutritive value of herbage, the length of the grazing season and milk production per cow and per hectare from grassland systems based on:

- (i) inclusion of white clover (average 219 g / kg of herbage DM) (WC) receiving on average 90 kg N / ha (s.d. 6.4) in spring and 20% of the area successively over-seeded with white clover seed each year, and
- (ii) fertiliser N (FN) input of 226 kg / ha (s.d. 9.7). The stocking density of Holstein-Friesian dairy cows on both systems was 2.0 / ha 2003 and 2.2 / ha in each of the following three years.

Cows calved within a 12-week interval in spring with mean calving date in mid-February. Milk was produced until mid-December each year. Total annual herbage DM production was lower ($P < 0.01$) on WC than FN (0.92 of FN). There were no ($P > 0.05$) differences in the *in vitro* organic matter digestibilities of pre-grazing herbage. The crude protein concentration in pre-grazing herbage DM was higher ($P < 0.001$) on FN than WC: 219 and 209 (s.e. 8.4.) g / kg, respectively. There were no ($P > 0.05$) differences in annual production of milk per cow (mean 6,524 kg; s.e. 83.9 kg), live-weight or body condition score between the two systems. There were no significant differences ($P < 0.05$) in the lengths of the grazing season, which averaged 254 days (s.e. 0.9). The WC swards supported an annual stocking density of 2.15 / ha and a milk output of 14 t / ha.

Measured and simulated N₂O emissions from ryegrass- and ryegrass/white clover-based grasslands

There is uncertainty about the potential reduction of soil nitrous oxide (N₂O) emission when fertiliser nitrogen (FN) is partially or completely replaced by biological N fixation (BNF) in temperate grassland. The objectives of this study were to investigate the changes in N₂O emissions when BNF is used to replace FN in permanent grassland, and to evaluate the applicability of the process-based model DNDC to simulate N₂O emissions from Irish grasslands.

The three fertiliser treatments were:

1. ryegrass (*Lolium perenne*) grasslands receiving 226 kg FN / ha / yr (GG+FN),
2. ryegrass/white clover (*Trifolium repens*) grasslands receiving 58 kg FN / ha / yr (GWC+FN) applied in spring, and
3. ryegrass/white clover grasslands receiving no FN (GWC-FN).

Two background treatments, un-grazed swards with ryegrass only (G-B) or ryegrass/white clover (WC-B), did not receive slurry or FN and the herbage was harvested by mowing.

There was no significant difference in annual N₂O emissions between G-B (2.38 ± 0.12 kg N / ha / yr (mean ± SE)) and WC-B (2.45 ± 0.85 kg N / ha / yr), indicating that N₂O emission due to BNF itself and clover residual decomposition from permanent ryegrass/clover grassland was negligible.

N₂O emissions were 7.82 ± 1.67, 6.35 ± 1.14 and 6.54 ± 1.70 kg N / ha / yr from GG+FN, GWC+FN and GWC-FN, respectively. N₂O fluxes simulated by DNDC agreed well with the measured values with significant correlation between simulated and measured daily fluxes for the three grazing treatments, but the simulation did not agree very well for the background treatments. DNDC overestimated annual emission by 61% for GG+FN, and underestimated by 45% for GWC-FN, but simulated very well for GWC+FN. Both the measured and simulated results supported that there was a clear reduction of N₂O emissions when FN was replaced by BNF.

Measurement of biological N fixation of white clover at three different N fertiliser inputs

This study commenced in March 2011 and will continue until December 2012. The objectives of the study were to evaluate three methods of measuring biological N fixation (¹⁵N isotope dilution method, ¹⁵N natural abundance method and nitrogen difference method) under fertiliser N inputs of 0, 90 and 280 kg / ha. Results will provide recommendations on the level of fertiliser input best suited to optimise annual biological N fixation and herbage production. The evaluation of methods of measuring BNF will determine which method is best suited to quantification of biological N fixation in Irish grassland.

Determination of total farm nitrogen flows and balances on a white clover based system of milk production

This experiment commenced in 2010 and will continue until the end of 2012. The objective of this study will be to measure all the N flows on the white clover-based system of milk production on the Solohead Research Farm to create a total N budget for the system. Previous measurements of N flows on the farm such as emissions of N₂O, NH₃ volatilisation and N leaching have not been able to entirely account for the differences between inputs and outputs of N. This study will focus on accumulation of N in soil organic matter and in N₂ emissions to close the gap in knowledge on the N balance of the farm.

Potential for white clover in Ireland

Pastures with 20% white clover in the herbage dry matter are capable of supporting the same level of herbage and milk production as pastures receiving 200 kg N / ha. White clover swards in Ireland have the ability to support a stocking density of 2.15 livestock units / ha and an annual milk output of 14 t / ha. National farm survey data for Ireland have shown that the average annual stock density on dairy farms in Ireland is 1.9 livestock units / ha producing a milk output of 9 t / ha. Therefore, current milk production could be achieved and exceeded using white-clover based grasslands receiving lower N fertiliser inputs. Stocking densities and annual N fertiliser input on beef farms is just over one livestock unit / ha and 56 kg N / ha respectively. Therefore there is great potential to increase herbage production and stocking densities on Irish farms producing beef by incorporating white clover into Irish beef production systems. White clover also has the potential to be used to supply N for organic systems of milk and meat production in Ireland and to increase herbage production on low N fertiliser input systems.

In general, white clover-based systems are associated with lower stocking densities, higher N use efficiency, lower surplus N per hectare, lower losses of nitrate to ground water and of ammonia and nitrous oxide to the atmosphere than N-fertilised grass based systems. The use of white clover has the potential to contribute to a reduction in Ireland's green house gas emissions by reducing N fertiliser usage and in doing so help Ireland to meet its Kyoto protocol targets. White clover systems, compared to N fertiliser grass based systems, are found to reduce greenhouse gas emissions by 12% at same stocking density and 35% at the same farm income level for dairy farms.



A dairy cow grazing a grass-white clover pasture in Ireland. Such pastures require only about one quarter of the nitrogen fertiliser that grass-only pastures require to give optimum yield.

Realising the potential of white clover in Ireland

Much research has already been carried out on white clover systems and the management practices required to establish/maintain them in Ireland. The transfer of this research knowledge to farmers on the potential of white clover and the best practices to manage/establish white clover based grassland is central to realising the potential of white clover in Irish grassland. An action plan is required on how to transfer this knowledge into practice.

Further research into the quantification of biological N fixation of white clover could be used to provide farmers with hard evidence that white clover does supply N for herbage growth and can be used to reduce N fertiliser input. The factors affecting biological N fixation need to be quantified in an effort to draw up recommendations on how to maximise the supply of biological fixed N from white clover.

Local and international policy makers need to be informed on the potential benefit to the environment of using white clover to reduce N fertiliser input when drawing up environmental protection plans and legislation.

CONTINENTAL REGION

The range of crops is probably widest in the Continental region, where winters are shorter and less harsh than in the Boreal-Nemoral region, and rainfall is less limiting than in the Mediterranean region. Lupins are well adapted to these conditions. The margin between cereal yields and those of broad-leafed crops is less than in the Oceanic region, but is still large. Except in Poland where lupins are the main grain legume group, grain legume production is based on faba bean and peas. Soya bean, common bean and other warm-climate crops are also grown, particularly in the southern part of the region. Forage legumes include alfalfa along with the clovers, and many others such as serradella are grown on a small scale. Autumn-sown grain legumes succeed only on the margins of this region. Our case studies from this region are from Germany, Poland and Romania.

Germany

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History of legume cultivation

All pulses grown in Germany originate from southern Europe. They played an important role in the nation's food supply in the past, but now have a minor role in terms of acreage. In 1927 there were 0.27 M ha of legumes (peas, beans, vetch, lupin), 6.57 M ha of cereals, and 2.11 M ha of clover and alfalfa.

The cultivation of clover was introduced in Germany in 1780. The first large-scale seed production in Germany was in the Palatinate (Pfalz). In the 1950s, lentil cultivation in Germany stopped because of low yields and high labour costs for harvesting and cleaning. Today, only 150 ha on lentil is grown in Germany. Since the 1960s, due to the rising prosperity, the consumption of meat has increased enormously. Beans and peas are now eaten mostly as fresh vegetable rather than as a pulse. Faba bean, used previously in the human diet, now serves mainly as a feed for cattle.

Current status of legumes

Cultivation area

- Continuous decline in cultivation of domestic legumes.
- Most of the production is in eastern Germany.
- In 2008 the area grown was 80 000 ha, corresponding to only half of the average in 2002 – 2007. This stabilised at 83 000 ha in 2009.
- Comparison with the area in 1999 (212 200 ha) shows that cultivation of grain legumes decreased by approximately 71% in 10 years (Figure 5).
- Agricultural land in Germany in 2009 is about 17 M ha, of which about 12 M ha are arable land: 0.5% of agricultural land or 0.7% of the arable land area is cultivated with grain legumes.
- In 2010, legume areas recovered slightly. The main grain legumes in Germany are field pea (58 700 ha), lupin (24 100 ha) and faba bean (16 900 ha).

Legume-supported cropping systems for Europe

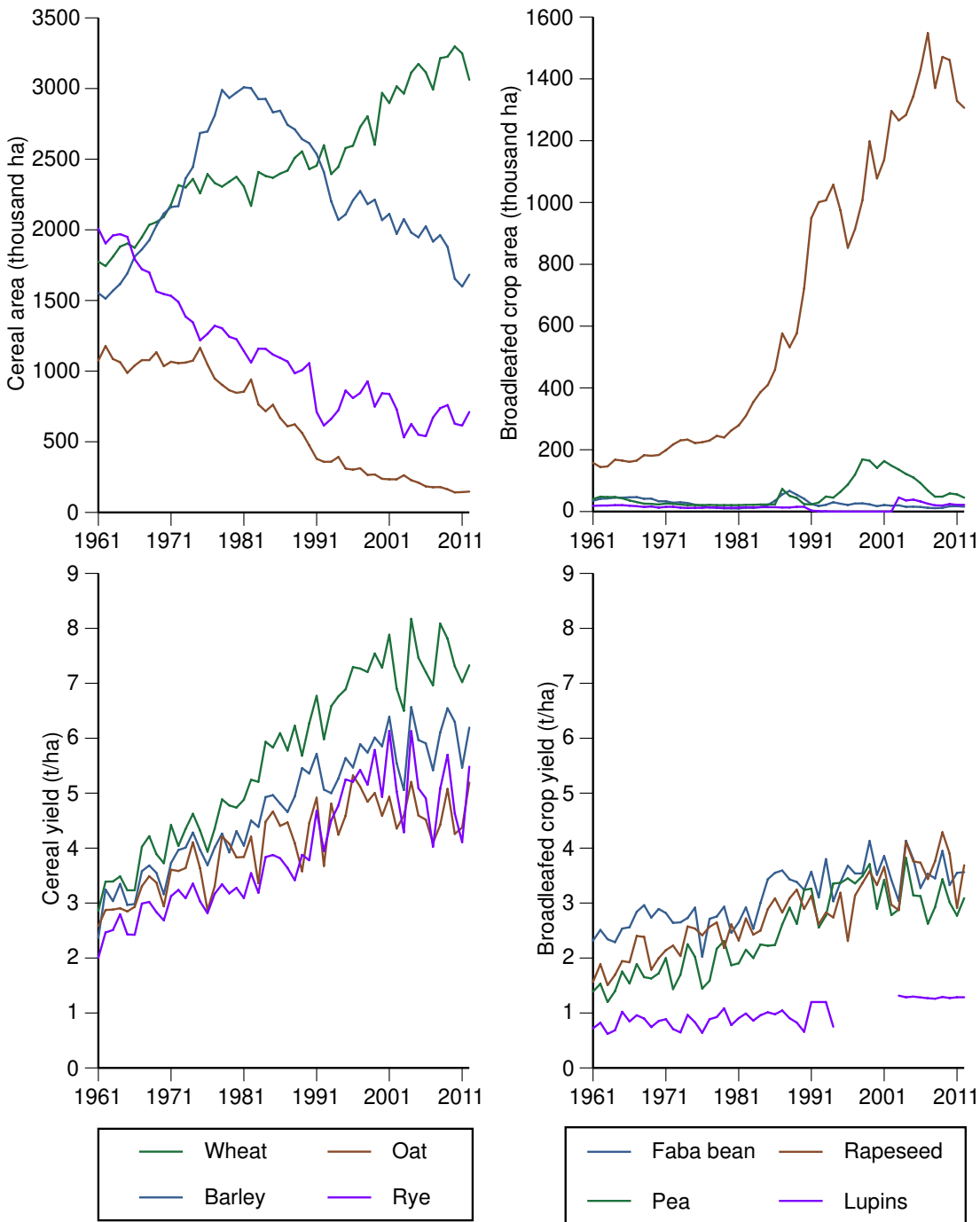


Figure 5. Harvested areas (thousand ha) and average yields (t/ha) of the main cereals, grain legumes and oilseeds in Germany, 1961-2012 (FAOstat data).

Breeding

There are few breeders of legumes, so the range of cultivars is narrow.

Subsidies

The changes in the production of grain legumes are related to the introduction (1993) and ceasing (2003) of EU funding premium for protein crops; specifically:

- With the MacSharry reform in 1992, inclusion of protein crops in the general support system for crops in the MacSharry reform of 1992.
- Since 1993/94, grant of compensatory payments per hectare for protein crops.
- With Agenda 2000, reducing the amount of area-based compensatory payments for cereals, oilseeds and set-aside;
- For protein crops, however, an increase in direct payments to ensure their profitability relative to other arable crops (EU).
- With the reform 2003, in the context of Agenda 2000, partly inclusion of paid subsidies in the single payment scheme (SPS) and introduction of a special subsidy of 55.57 € / ha which is granted subject to a maximum guaranteed area for payments.

Organic farming

- relatively high cultivation of domestic grain legumes as an important protein-rich feed component
- Play an important role in the rotation as producers of nitrogen and as a soil improvers
- Trend of the cultivation is continued increase
- About 38% of forage legume area is organic

Forage legumes

The agricultural policy framework has a great influence on the profitability of forage legumes. Price support (Pillar 1 of CAP) supports maize and grain legumes rather than forages, with the exception of the use of set-aside for forage legumes and the premiums for organic farms and dry fodder support. The fodder legume area is encouraged in organic farming, by promotion of extensive (low-input) farming, and by non-cultivation of maize in the context of agri-environmental measures. In Brandenburg, a quarter of the area receiving dry fodder support and special agri-environment measures is on sloping land and related to erosion control. The area sown to forage legumes is about 213 000 ha. The KULAP support schemes (2000-2006 and 2007-2012) supported "Environmentally sound agriculture and horticulture" and in section B4 paid particular attention to the prevention of erosion and protection of soil through the planting of cover crops, catch crops and forage legumes, with acknowledgement of their benefits to pollinators, biodiversity, and high ground cover through the winter. In the later scheme, at least 40% legume content was required in a grass-legume mixture to qualify for the 70 € / ha/year grant.

Current local public policy and commercial factors affecting legumes in Germany

Especially the Health Check 2008 has impacted on the agricultural policy framework for field beans, peas and lupins, because the coupled protein crop aid of 55.57 € / ha should be dropped at least in 2012.

The funding of domestic grain legumes in the context of agri-environmental measures did provide sufficient incentives to stop the decline in legume cultivation.

The situation of grain legumes is determined by several limiting factors: They are economically less attractive in cultivation, because of unattractive producer prices; planting decisions are mostly based on simple gross margin comparisons, and do not account for the services provided by legumes within a crop rotation system (N provision, reduction of pests and diseases); processing value exceeds market price, because the market price is significantly below the price of forage; insufficient yield level with poor yield stability; the huge import of soya beans from overseas in the EU leads to extensive coverage of the dietary protein requirements from imported soya bean meal; and relatively low mineral nitrogen prices.

Grain legumes in organic farming gain in importance because of the expansion in organic livestock farming.

Current experiments of the Legume Futures partners in Germany

- Analysis and evaluation of organically produced legume feed compounds and their feeding values.
- Quality assessment of soy beans and soy meals.
- Feeding experiments to evaluate the potential of faba beans for broiler breeders.
- Silage characteristics and quality of alfalfa and red clover in different grass-mixtures.
- Technical treatments (e.g.: heat) of grain legumes to improve the protein digestibility.
- Research projects to improve the knowledge transfer from science to farmers.
- Extension projects to improve the farmer's knowledge about legume cropping systems, novel cultivars, better pest & disease management, e.g: development of a manual for the organic production, utilization and on-farm management of lentils.
- Developing novel cropping methods to enhance the output per unit area, increase the N-efficiency and reduce weed and pest problems.
- Evaluation of legume intercropping systems: Intercropping of different legumes with cereals and oil crops.
- Effects of legume-cereal-intercropping on grain yield and quality. Potential of legume undersowing in grain peas; testing the suitability of different legume species and cultivars in mixed cropping systems.
- Species specific competition and how it is influenced.

- Efficiency of legumes grown as winter catch crop.
- Comparison of yield, forage quality, N₂ fixation, residuals and pre-crop effect of different grain legumes species in pure stands and in intercrops with cereals.
- Image analysis to evaluate characteristics of clover/grass mixtures.
- Yield and forage quality of red clover and alfalfa in pure stand and grass mixtures.
- New strategies to optimize and enhance soil fertility, improve BNF and reduce N-losses
- Suitability of grain legumes for direct sowing and preserving soil tillage systems. influence of the soil cultivation intensity on N-mineralization.
- Nutrient-availability and nutrient uptake of clover- and herb-rich grasslands.
- Evaluation of different legume living mulches.
- Non-legume catch crop cultivation and reduced soil tillage to enhance BNF of faba beans.
- Nitrogen leaching and beneficial effects of forage and green manure legumes on subsequent crops.
- Effective use of legume nitrogen in the crop rotation.
- Nitrogen budget types for use in organic farming practice; calculation of the symbiotic N₂ fixation and N balance.
- Development of calibrated rapid methods for symbiotic N fixation of fodder legumes.
- Rhizodeposition effects of grain legumes on the turnover of its crop residue.
- Climate gas emissions in legume-based fodder production systems.
- Cultivar trials for faba beans and fodder peas: yield potential, sensitivity for pests and diseases, feed quality.
- Screening of different legume species and cultivars to evaluate their suitability in mixed cropping systems and for green manuring.
- Development and selection of locally adapted legume cultivars: Improved winter hardiness of faba beans and peas.
- Breeding of soya bean cultivars that are adapted to the local climate conditions.
- Breeding of legumes with lower contents of antinutritive feed compounds, e.g., faba beans with low vicine/convicine content.
- Improved resistance for pests and diseases, e.g., improved resistance of lupins to anthracnosis.
- Improved management of legume-specific pests and diseases, e.g., risk assessment concept for pea moth infestation, including preventive measures and direct control options, and application of Trichogramma-wasps to solve Lepidopteran pest problems such as pea moth.

Potential for legumes in cropping systems in Germany

- Increased market demand due to increasing demand for GMO-free food and feed components, locally produced protein-rich food and fodder components, and reduction of anti-nutritive compounds (e.g. faba beans with low vicine/covicine contents).
- Enlarged cropping area from 4 to 20% legumes would lead to reduced greenhouse gas emissions by savings of mineral fertilisers produced with fossil resources (savings of one-fifth of mineral N-fertilisers are possible).
- Legume-fodder imports could be reduced by 10%.
- Expectations of increased yields (up to 10%) and higher grain quality (crude protein content) due to N-transfer from legumes to the following crops, positive effects on soil organism and reduced cereal rotation pests and diseases by broader rotations and improved soil structure by high rooting intensity and soil coverage of legumes.
- Advantages of legume intercropping systems include reduced risk of soil erosion, better utilisation of growth factors, reduced susceptibility to pests and diseases, reduced lodging (e.g. leaf tendrils of peas can fix/be fixed by cereal stems), and better feed value by higher protein contents.
- Low susceptibility of soya beans to legume specific pests and diseases might improve the yield stability.
- Locally adapted cultivars with sufficient winter hardiness and disease resistance are needed (especially for faba bean).
- Varying prices and qualities of legume fodder compounds results in low market demands.

Insight into how this potential may be realised:

- Funding/support for legume breeding programmes needed for admission of new locally adapted cultivars.
- Improved knowledge transfer from researchers to farmers, e.g. sparse knowledge about water use and productivity of different alfalfa cultivars in organic farming
- Insufficient knowledge about legume free cropping periods to reduce soil-borne diseases.
- Breeding of legumes with low contents of anti-nutritional compounds would improve the feed quality.
- Locally adapted legumes with sufficient winter hardiness and higher tolerance to pests, weeds and diseases would result in more stable yields and quality.
- Economic assessments of legumes should include the indirect benefits such as fertiliser savings, improved soil structure, better yield and quality of the following crops.

Poland

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History of legume cultivation

The presence of legumes in Poland can be traced back about 2,500 years (excavations in Ćmielów and Biskupin).

Pea: The first record of the pea crop in Poland comes from the mid-nineteenth century, but it spread to a larger scale after World War I. In the 1930s, about 25% of the pea cultivation area was field pea.

Faba bean: Data from the interwar period (1920-1939) show that faba bean covered 84 000 – 146 000 ha. After World War II, about 90 000 ha of this plant was grown.

Lupin: The beginning of cultivation of lupin on Polish territory was recorded in the second half of the nineteenth century. It was initially grown as an ornamental plant and green manure, and later as feed. In about 1930, the first two Polish cultivars of lupin were developed: Early Puławy and High Puławy. Unlike in Germany, lupin yields have kept pace with those of faba bean, pea and rapeseed (Figure 6).

Vetch: The first information about cultivation of vetches in Poland comes from the eleventh century. The oldest seeds were found in Gniezno, Gdańsk and Kraków. The first records of cultivation of this species come from the sixteenth century. During the years of 1883-1885, about 28 000 ha of vetch were grown in Poland, between 1931-1934 about 8 000 ha, and after World War II (1951) 94 000 ha.

Clover: In Poland, the cultivation of this species began in the seventeenth century. It was more widespread in the mid-eighteenth century, mainly in Silesia. With the introduction of crop rotation, clover eliminated fallow, and became an economically important fodder plant.

Alfalfa: Alfalfa appeared in Poland in the late fifteenth century, but it started to be grown on a larger scale in the 1960s. Interest in the cultivation of this species was variable. A strong decline in cultivation area was recorded in the late 1990s.

Breeding programs in Poland in the first half of the twentieth century were sporadic. It was not until after 1950 that breeding programs for individual species were established.

Introduction of low-cost nitrogen fertilisers in the cultivation of cereals has reduced farmers' interest in legume plants. Cultivation of serradella as a catch crop was almost completely abandoned. As a result of systemic changes in Polish agriculture in the early

1990s, the area of legume crops cultivation declined greatly (from 1.5 M ha in 1989 to 220 000 ha in 2010).

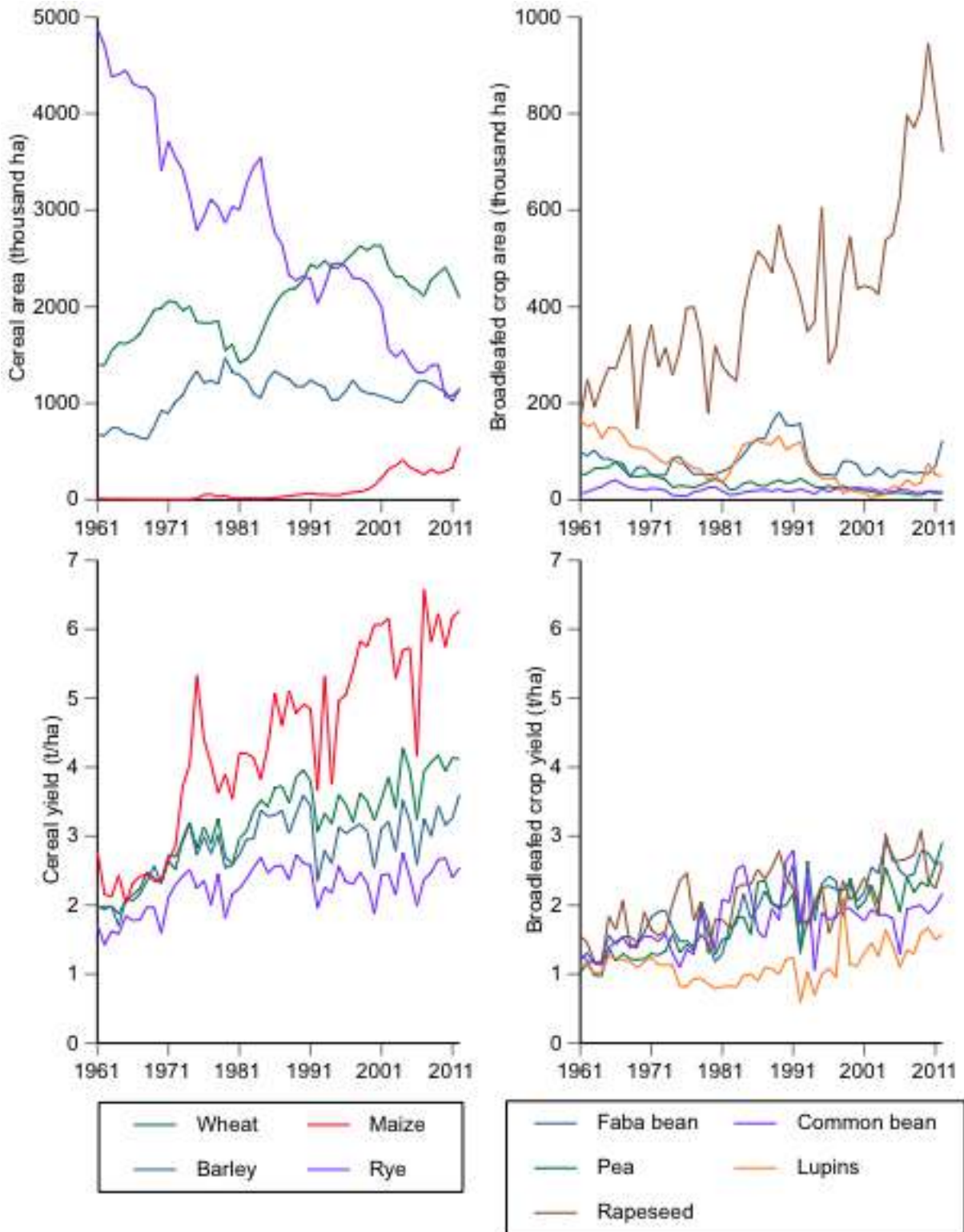
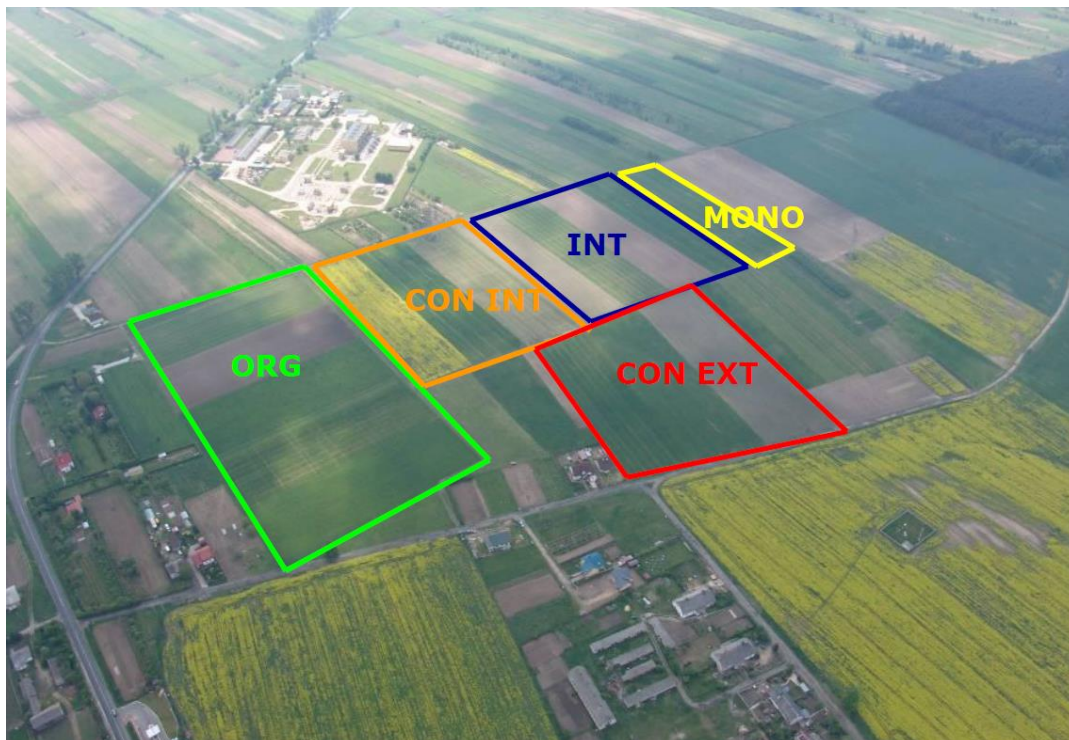


Figure 6. Harvested areas (thousand ha) and average yields (t ha⁻¹) of the main cereals, grain legumes and oilseeds in Poland, 1961-2012 (FAOSTAT data).

Crop performance at the case study site in Osiny IUNG-PIB, Poland

The Legume Futures partner in Poland runs a long-term experiment established in 1994 in Osiny (Lubelskie region, [51°28'N, 22°04'E]) comparing organic, integrated and conventional crop production systems with different share of legumes. Legume crops are cultivated both in the organic and in the integrated systems. In the organic fodder legume based system (potato - spring wheat - red clover with grass grown two years - winter wheat + catch crop) neither synthetic mineral fertilisation nor chemical pesticides are applied. Organic fertilisation includes only compost application (30 t ha⁻¹) to land then used for potatoes. The conventional non-legume system (winter rape – winter wheat – spring wheat) is managed as an intensive crop production technology, whereas the integrated grain legume based system (potato - spring wheat – horse bean - winter wheat + catch crop) uses more extensive conventional techniques. In addition, a monoculture of winter wheat is cultivated. The area of each field in all systems is about 1 ha.



Layout of a field experiment on comparing different farming systems (ORG –fodder legume organic, CON INT – non-legume conventional, CON EXT – grain legume conventional, INT – grain legumes integrated, MONO – monoculture of winter wheat) at the Experimental Station in Osiny near Pulawy, Poland.

Yield responses

The biggest yields of cereals (winter and spring wheat) and potato were noted in the grain legume integrated system (Table. 4). Average for 4 years winter wheat in this system yielded on the level of 6.5 t ha⁻¹. In the conventional non-legumes system yield of winter wheat amounted to 6.3 t ha⁻¹ and was smaller about 3% than in the integrated system. Winter wheat cultivated in the monoculture yielded on the level of 6 t ha⁻¹ (decrease of about 7% in comparison to the integrated system). In the fodder legume organic system average yield of winter wheat was the smallest and amounted to 3.7 t ha⁻¹ (43 % smaller than in the integrated system). The biggest variability of yields in particular years was noted in the organic system and in monoculture of winter wheat.

In the organic system crop canopy was not enough dense because of weaker tillering of wheat, probably due to scarce pool of nitrogen in the soil. In this system higher intensity of leaf and ear diseases infestation (mainly leaf septoria and brown rust) accelerated the process of leaf withering. As a consequence the wheat matured earlier, and the grain was not enough developed.

Productivity expressed in cereal units

Averaged for 4 years the highest productivity on the level of 63 cereal units were noted in the integrated system (Table 5). In monoculture productivity, was on similar level, mainly thanks to high yields of winter wheat in recent years of the study (2012 and 2013). In the organic system the average productivity of the entire five field's crop rotation was comparable with a simplified three field's crop rotation in the conventional system. High productivity of organic crop rotation was an effect of big yields of grass/clover mixture expressed both in cereal units and in t ha⁻¹.

Impact on the environment

Analysis of the chemical properties of the soil indicated that in the longer perspective (16 years) there were no negative effects on the environment of the compared systems (Table 6). After the first rotation there was a significant decrease in potassium concentration in soil in the organic system and its deficiency symptoms were evident on potato and clover, and the nutritional status of cereals in potassium was clearly deficient. This was a consequence of large export of potassium with yields of clover/grass mixture - about 600 kg/ha of K₂O during 2 years. Systematic application since 2002 of mineral potassium fertilizers and lower yields of clover/grass mixture in the last few dry years slowed the process of impoverishment of the soil in the potassium content. Additionally during last years a trend in decrease of the soil phosphorus concentration in soil has been observed. In order to counteract this decrease, phosphorite meal has been applied since 2007. Organic carbon concentration in the soil has been systematically increasing in the organic system during last years, while in monoculture of winter wheat the decline was noted. In other systems no significant changes were observed in this area (Table 7).

Analysis of the environmental effects of different farming systems indicated a beneficial effect of organic fodder legume-based method of farming on soil biological activity. Analyses of soil under cereals made several times since the beginning of the experiment have shown that in the organic system the indicators of biological and enzymatic activity of soil more often reached maximum values than in other systems. It is assumed that the quantity and quality of crop residues, use of organic fertilizers and the impact of chemical pesticides are the main factors influencing the biological activity of soil. The beneficial effects of organic farming method has been also manifested by numerous population of Carabidae beetles, which are often regarded as an important indicator of biodiversity.

Content of mineral nitrogen in the soil

The compared systems showed high variability in mineral soil N due to the differences in agricultural practice and the course of weather. These factors significantly influenced the rate of mineralization of organic matter and movement of mineral nitrogen in a soil profile. In late autumn the smallest amount (88 kg ha⁻¹) of mineral nitrogen (N-NO₃ + N-NH₄) in the 0-90 cm soil layer was found in the organic system. In conventional and integrated systems this amount increased by 23-29 kg ha⁻¹, while in the monoculture by 44 kg/ha. In the organic system the largest amount of nitrogen was found in the position after clover/grass mixtures and after potato, in a conventional system after winter oilseed rape, while the integrated system after grain legumes. Comparison of N_{min} concentrations from autumn and spring terms indicates that potentially the greatest leaching potential has been observed in monoculture -32 kg N_{min}/ha and in the conventional non-legumes system -25 kg N_{min}/ha, whereas the smallest in the organic system +6 kg N_{min}/ha (tab. 8-11). The highest concentrations of mineral nitrogen in soil percolates were also noted in monoculture of winter wheat and in the conventional system (Fig. 1). In contrast, the lowest values of this index were recorded in the organic fodder legume based system.

Table 4. Yielding of winter wheat (t ha⁻¹) in crop production systems with different shares of legumes

	Fodder legume/organic	Conventional without legumes	Integrated with grain legumes	Continuous wheat	Mean
2010	2,15	4,45	4,36	4,21	3,79
2011	4,63	4,86	6,56	5,08	5,28
2012	4,31	6,80	6,06	6,60	5,94
2013	3,74	9,22	9,07	8,31	7,59
Mean	3,71	6,33	6,51	6,05	5,65

Table 5. Productivity of particular crops and crop rotations expressed in cereal units

System	Crop	2010	2011	2012	2013	Mean
Organic	Potato	66	34	85	74	65
	Spring wheat	33	37	23	23	29
	Grass/clover 1st year	103	131	69	109	103
	Grass/clover 2nd year	74	58	26	73	58
	Winter wheat	22	46	43	37	37
	<i>Mean</i>	60	61	49	63	58
Integrated	Potato	78	100	125	85	97
	Spring wheat	48	45	63	50	52
	Grain legumes (faba bean, lupin)	26	38	49	44	39
	Winter wheat	44	66	61	91	66
	<i>Mean</i>	49	62	75	68	63
Conventional	Winter rape	61	53	44	66	56
	Winter wheat	45	49	68	92	64
	Spring wheat	28	38	59	60	46
	<i>Mean</i>	45	47	57	73	55
Mono-culture	Winter wheat	42	51	66	83	61

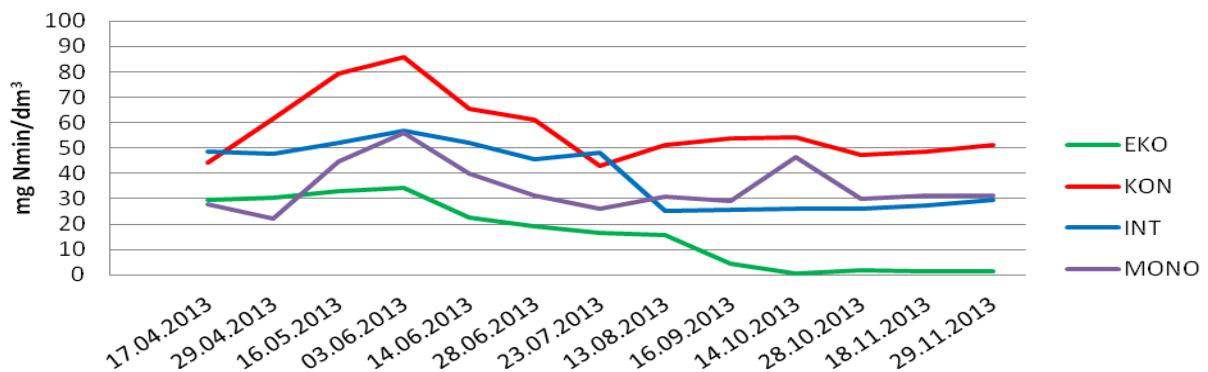
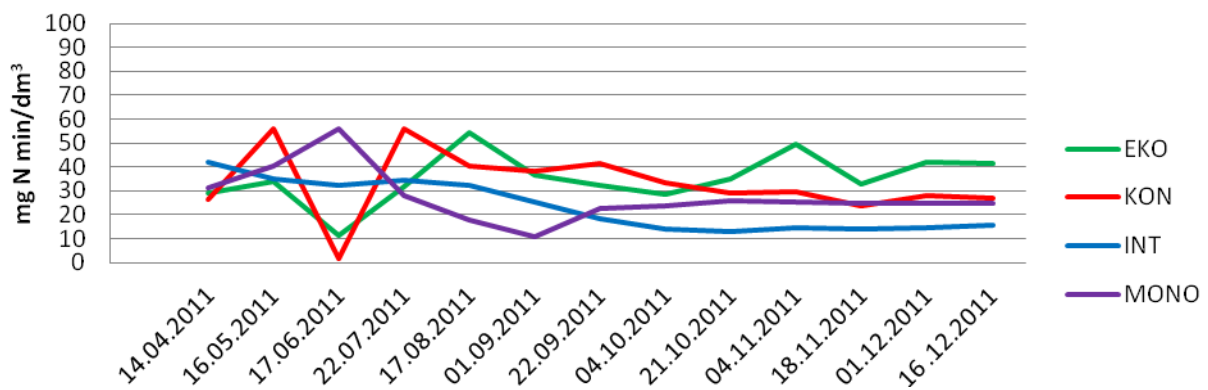
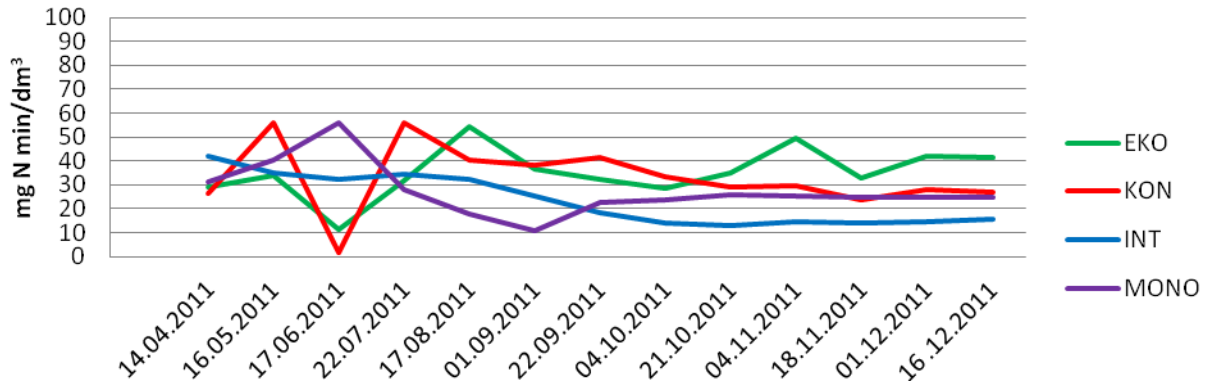
Table 6. Yielding of legumes (t ha⁻¹)

Crop production system	Crop rotation	2010	2011	2012	2013	Mean
Organic	Grass/clover 1st year (green mass)	73,57	93,57	49,29	77,86	77,14
	Grass/clover 2nd year (green mass)	52,86	41,43	18,57	52,14	42,14
Integrated	Faba bean (grain)	2,17	3,17	4,08	3,67	3,75

Table 7. The chemical properties of soils in crop production systems with different share of legumes - the average for three independent periods from 1996 to 2011

Crop production system	Period	Humus in %	pH in H ₂ O	Concentration in mg/100g of soil		
				P	K	Mg
Organic	1996-2000	1,54	6,41	4,75	6,25	6,58
	2001-2005	1,48	6,51	4,11	5,60	8,0
	2006-2011	1,55	6,58	4,59	5,76	9,51
Conventional	1996-2000	1,38	6,81	6,56	8,59	5,07
	2001-2005	1,32	6,63	7,20	11,07	5,55
	2006-2011	1,36	6,70	8,01	12,74	7,27
Integrated	1996-2000	1,36	6,33	4,85	7,55	5,50
	2001-2005	1,25	6,36	5,85	9,46	6,48
	2006-2011	1,34	6,48	7,05	10,79	8,22
Monoculture	1996-2000	1,27	6,23	3,72	7,12	4,80
	2001-2005	1,17	6,05	4,03	8,60	7,58
	2006-2011	1,14	6,16	4,28	9,09	9,07

Legume-supported cropping systems for Europe



Concentration of N_{min} in soil water solution (2011 - 2013)

Current status of legumes

The share of the cropped area used for legumes decreased from 3.6 to 0.86% in recent years. Grain legumes are grown on 95 500 ha (mostly in Mazowieckie, Lubelskie and

Wielkopolska regions). Lupins have the largest share (40%), followed by edible and fodder peas. The smallest area is covered by faba beans.

There was a significant reduction of cultivation area of forage legumes. Currently, red clover for forage is grown on about 37 000 ha (the largest in the provinces of Malopolskie, Lublin, Warmia-Mazury, and Mazowsze), alfalfa is grown on about 25,500 ha (the largest in the region of Wielkopolskie), and other legumes and serradella on the area of approximately 25,500 ha (the largest in Mazowieckie and Wielkopolskie voievodships).

The main source of protein feed is imported soy bean meal (over 2 M t).

Typical protein yields in Poland are: rape (0.6 t / ha), faba beans (1.1 t /ha), narrow-leaved lupin (1.3 t/ha), yellow lupin (0.5 t/ha), pea (0.7 t/ha), red clover (2 t/ha) and alfalfa (2 t/ha).

Current local public policy and commercial factors affecting legumes in Poland

Crop yield and profitability are variable and this has reduced farmers' interest in legume crops. Reducing cattle numbers in the country resulted in a lower demand for cultivated legumes.

Regionalisation of legume crops is a result of their habitat and soil requirements.

There is a need to increase the yield of tannin-free faba bean cultivars.

There is a need for breeding work towards reducing the susceptibility of pea to lodging (cultivars with stiffer stems).

Conventional commercial farmers are not interested in cultivation of legumes. They are profit oriented, and therefore apply mineral nitrogen.

The beneficial impact of legumes on soil environment and quality of feed are not fully appreciated.

Current experiments of the partners

Research to increase the yield and quality of grain legumes.

New trends in agrotechnology for leguminous crops and ways of increasing profitability of crops.

Leguminous crops as a source of protein for monogastric animals.

Determination of the content of antinutritional substances in seeds and their dependence on growing conditions.

Production of high-quality bulk feed with permanent and ley pasture with legumes.

Development of improved methods for bacterial inoculant for leguminous crops.

Assessment of the impact of legumes on soil fertility and other crops in rotation.

Evaluation of economic efficiency of production and utilization of legumes in concentrate feed.

Identification of factors that reduce sensitivity of legumes to drought during climate change

Potential for legume production

An increase in legume cultivation area to 500 000 ha and an increase in yields by 0.2 t / ha will increase domestic seed production by about 1 M t, and reduce imports of soya bean meal by about 50%.

Different soil and moisture requirements of different species of legumes make it possible to cultivate them in different habitat conditions.

Improving the quality of grain legumes will increase their use for feeding monogastric animals.

Preparation of silage from grass/legume mixtures limits quantitative and qualitative losses of feed.

Cultivation of legumes for green matter and making silage from whole plant is economically viable.

Respecting the optimal time harvest of forage legumes and their mixtures with grasses improves their productivity and quality of feed.

Competent deadline of the last cut of forage legumes improves their winter hardiness.

Insight into how this potential may be realised

The state, through subsidies, can contribute to an increased farmer interest in legumes.

Romania

Ion Toncea, National Agricultural Research and Development Institute

History of legume cultivation

Archaeological evidence shows that legumes have been grown for 4000 years in Romania. In the distant past, lentil, vetches, pea and faba bean, and in 20th century common bean, soya bean, alfalfa and clover were common on Romanian farms. Unfortunately, some of these legumes are now completely (bitter vetch) or generally (lentil and faba bean) unknown as crop. Legumes often occupied in excess of 5% of arable land (Figure 7).

In 1989, 500 000 ha of soya bean were grown, but this declined to about 50 000 ha by 2009. Common beans, which extended over 200,000 ha in 1988, have practically disappeared. Common beans used in mixed intercropping declined in the 1980s due to more widespread use of herbicides.

Alfalfa and red clover are still widely grown accounting for more than 3% of arable land.

Breeding programmes had a significant impact in 20th century.

Current status of legumes

The legumes are grown mainly for the proteins rich in essential amino acids and in fats.

Possible increased interest following peak in prices of N fertiliser.

The land area under grain legumes is increasing, primarily for the organic sector.

No change detected in clover and alfalfa.

Main “protein” crop is soya bean, average yield 2.0 t / ha of oilseed so about 0.7 t / ha of protein and 0.46 t / ha fats.

Breeding programmes sporadic in 20th century, all shut down.

Current local public policy and commercial factors affecting legumes in Romania

Growers are generally unfamiliar with legume crops

The natural potential to grow legumes is 2 – 5 times higher

Markets are needed that better link growers to the specific markets (humans and animal).

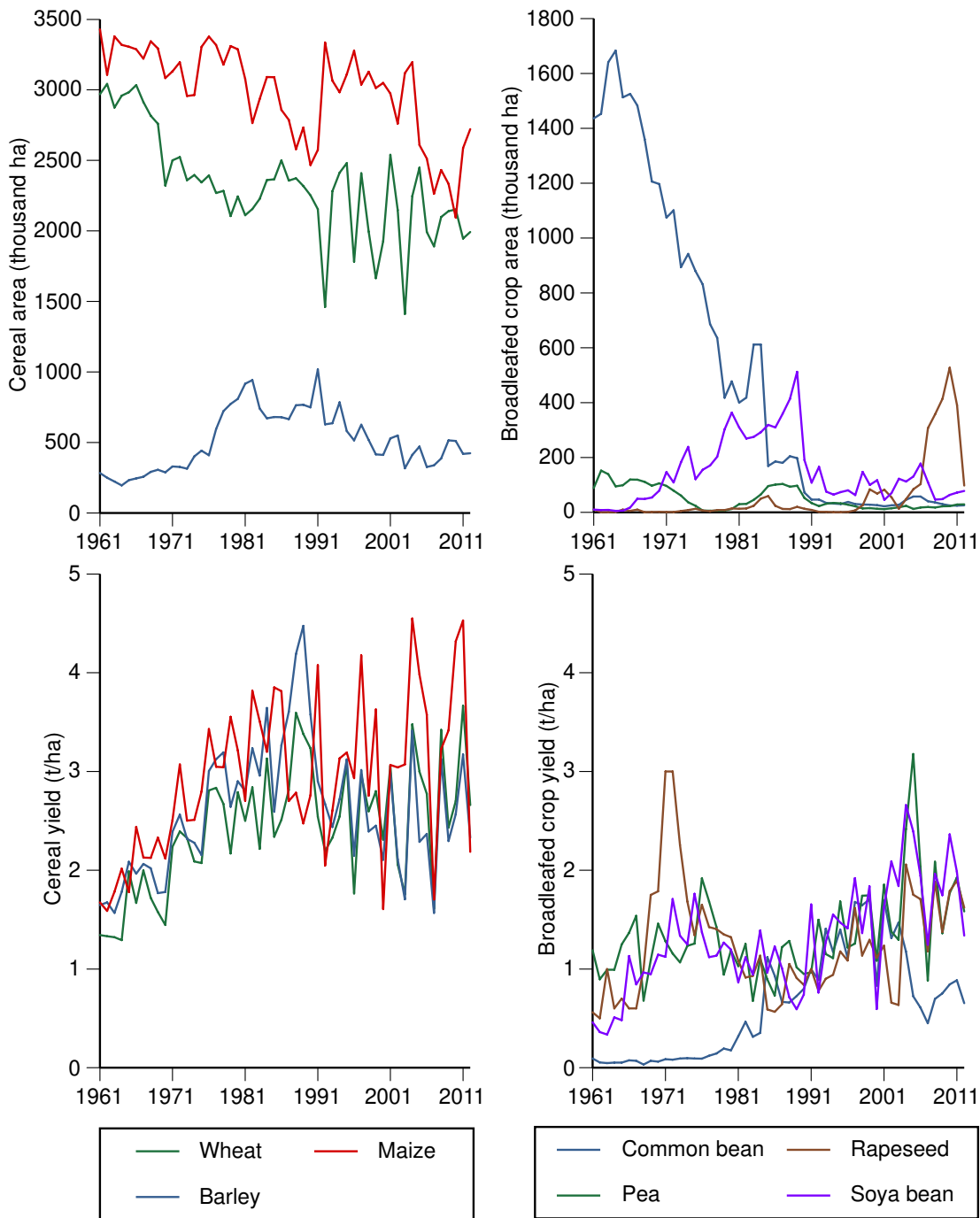


Figure 7. Harvested areas (thousand ha) and average yields (t/ha) of the main cereals, grain legumes and oilseeds in Romania, 1961-2012 (FAOstat data).

Peas, bean and soya bean cultivars are adapted to the local natural conditions.

Feed pea and lentil cultivars for autumn sowing needed.

Weeds infestation and drought are the most important factors of decreasing legume yields.

The pests and parasite plants are other limited yields factors.

Farmers don't have time to wait for legumes, they need N now.

Lack of localized information on break-crop value & value of ecological services.

Policy makers and large farmers are looking for GM soya bean.

Current experiments of the partners

Two cropping experiments have been established:

An organic farming system experiment with alfalfa in rotation with an annual crop rotation including winter wheat, sunflower, maize and soy bean;

An organic annual crops cultivars trial which includes winter cereals (barley, triticale, wheat) – industrial crops (camelina, linseed, coriander, sunflower) - maize – legumes (peas, vetch, lentils, lupin, and soya bean + bean).

In addition, legume field experiments examine the dynamics of NO_3 and NH_4 in soil, biomass dynamics and grain yield of legumes, as well as the fluxes of CO_2 and N_2O to the atmosphere. The legumes' effect on soil pH, $\text{NH}_4\text{-N}$ and $\text{NO}_3\text{-N}$ content seems to be significant too, but it needs additional studies.

Potential for legumes

Soy bean has the highest grain potential. Alfalfa has potential for biomass (silage and hay). Lentil is also a viable crop. Our research showed that autumn-sown peas can survive the Romanian winter.

The grain yield is reduced by the soil drought, pests, parasite plants and lack of suitable rhizobium strains in the soil.

The N_2O emission in legume crops is low.

An increase to 10% of arable land sown to food and feed-quality grain legumes would reduce soya bean imports by 100%. Increase to 60 % of legumes area would reduce nitrogen supply by 100%.

Different species and cultivars suit different climate and soil types.

Insight into how this potential may be realised:

Share knowledge and legumes species and cultivars between project partners.

Autumn grain legume cultivars would improve farm performance.

Better feed and food commercial quality will increase market demand.

Raise awareness of effects on soil fertility.

Investigations on functional food and feed uses will lead to increased demand for legumes for ingredient purposes.

MEDITERRANEAN REGION

This region is characterized by winter rainfall and summer drought. Grain legumes are primarily autumn-sown and mature in the spring. Where irrigation is possible, warm-season legumes can be grown, as is the case at our Greek site. Irrigated maize leads the yield of all grain crops and the margin between wheat yields and legume yields is relatively small. Traditional food uses of grain legumes in this region maintain the economic viability of these crops much more than in the other three regions. This is the only region with a significant area of chickpea, which is primarily a food crop.

Forage legumes, in contrast, are relatively little used, again with the exception that irrigated alfalfa can produce remarkably high yields and maintain its productivity through several harvests per year. Our correspondents cover the breadth of the region from Spain through southern Italy to Greece.

Greece

Dimitrios Savvas, Agricultural University of Athens

Agronomic background

Our agricultural region is a typical Mediterranean area. It presents many common characteristics with most Mediterranean countries and especially with Italy and Spain. In all these countries we can notice similar cropping systems not only in the field crops but also in the cultivation of trees (olive and citrus).

The prefecture of Aitolokarnania, which is the part of Greece where the Legume Futures experiments are conducted (at Agrinio), is the largest in Greece, has the highest crop production in Greece and the second highest animal production. Moreover, Aitolokarnania is the biggest prefecture in agricultural regions, with a total area of 5,661 km². The agricultural population runs into 114,000, from which 4,000 are organic farmers. This region is characterised by good supply of surface water from rivers and reservoirs. The dam of Kremasta, completed in 1969, holds water from four rivers: Acheloos (the longest and main river), Agrafiotis, Tavropos and Trikeriotis. The power station at the dam is the biggest hydroelectric plant in Greece.

The climate is characterised by hot summers and mild winters in the low lying areas, with cool winters dominating in the mountain areas. The annual precipitation varies between 800-1,000 mm. However, the allocation of the rainfall is unequal during the year; most rain fall in the period from October till April, while the summer is relatively dry.

The soil is typical Mediterranean, characterised by low organic matter content, a high percentage in sand and limestone and a relatively high electrical conductivity (EC) level. Legume crop productivity is constrained by drought, heat stress, salination and high soil pH (lupins).

Until 2004, the main crop cultivated in the region was tobacco and especially the Virginia variety. Agrinio was considered as an important tobacco-producing centre. Due to changes in EU policy in agriculture and concomitant changes in EU subsidies, the cultivation of tobacco was abandoned in the last decade and nowadays Agrinio is agriculturally used mainly for the production of alfalfa, corn, and asparagus, as well as olives and citrus fruits.

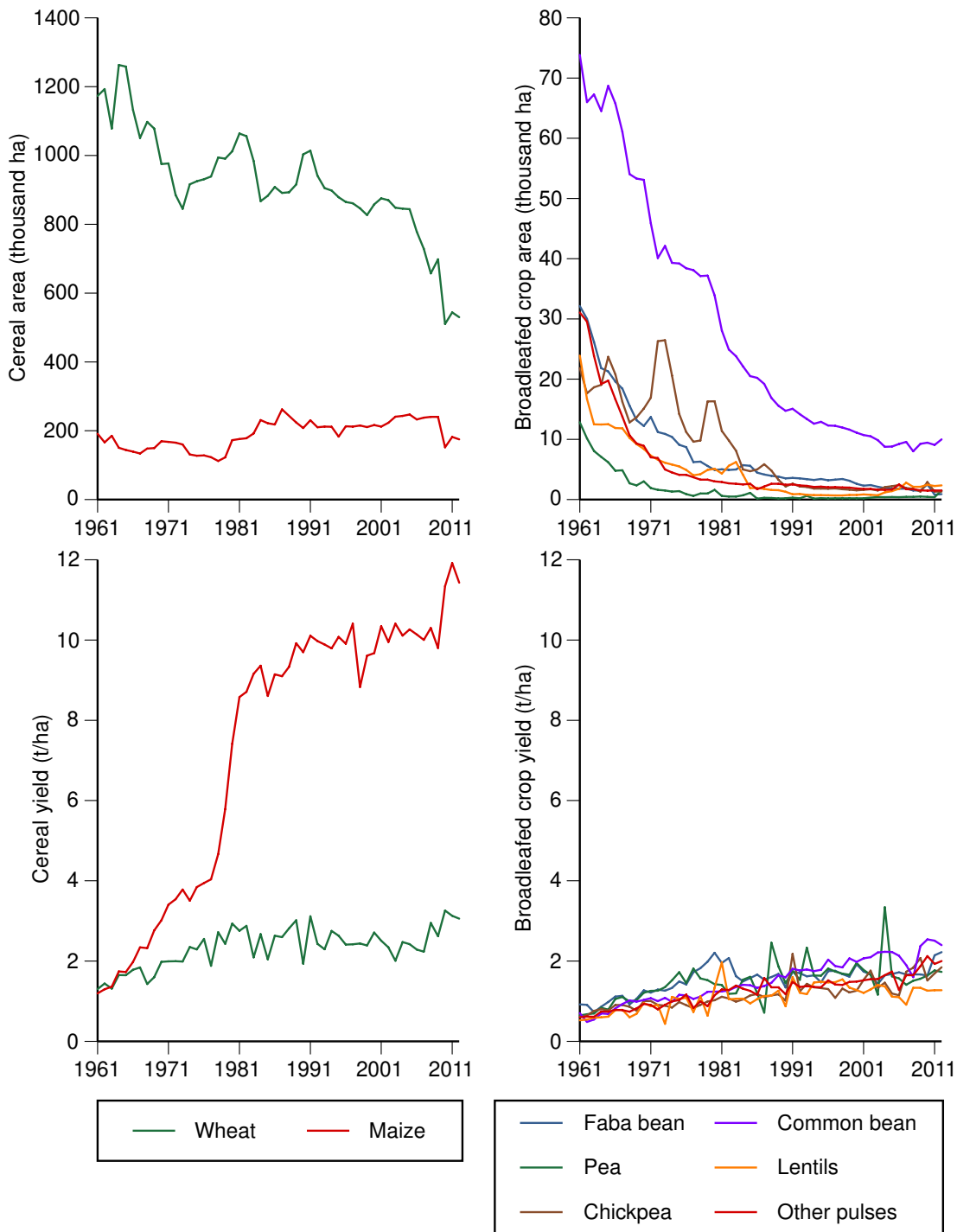


Figure 8. Harvested areas (thousand ha) and average yields (t/ha) of the main cereals, grain legumes and oilseeds in Greece, 1961-2012 (FAOstat data).

Local public policy and commercial factors affecting legume production

Around 40% of the agricultural area in Aitolokarnania is under protection of NATURA. Thus, the growers in this area are obliged to follow GAP practices (Good Agricultural

Practices) to comply with the restrictions imposed by the competent authorities in line with the prescriptions of NATURA. However, over-fertilisation and over-exploitation of the soil are serious problems in areas not under the status of NATURA. As a result, nutrient enrichment of surface waters caused by excessive phosphate fertilisation has been reported.

The strengths and weaknesses listed below apply only to Aitolocarnania Prefecture and not to whole Greece, because some environmental conditions (e.g. rainfall, water resources) are completely different in other parts of the country.

Strengths

- Climate suitable for crop production
- Sufficient water resources
- Soil fertility not a limiting factor

Weaknesses

- Farm structure (low acreage per grower)
- Distance from main markets and consumption centres
- Salinity in some soils

Potential for legumes in Greece

Inclusion of legumes which are used for human nutrition including fresh consumption as vegetables, such as beans, pea, and cowpea in the rotation might contribute to a decrease in use of inorganic-N fertilisers and improve soil fertility.

In our agricultural region, the cultivation of legumes such as fenugreek (*Trigonella*) could improve soil quality and reduce the soil electrical conductivity level that was increased through the continuous use of inorganic fertilisers during the tobacco cultivation. Moreover, the use of legumes as green manure will increase the soil organic matter, soil fertility and soil physical properties, like total porosity, air and water availability, and hydraulic conductivity. Currently, only a limited number of legume species are used for green manure. Most growers use vetch and, exceptionally, common pea as green manure crops but, due to their continuous use, their ability to biologically fix nitrogen may be compromised. Moreover, growers are not familiar with modern intercropping systems and, therefore, they do not use them, although research has indicated that they result in higher LER (Land Equivalent Ratio).

Greece is confronted with social-economic constraints that slow down agricultural development. The main limitation, which is similar in all Greek agricultural regions, is the farm size, with an average area of 3 ha per grower. Moreover, many problems limit access

to technology and information. Another key point is the lack of a well-organized and developed supply-chain that would be capable to maximize the profit. All these combined with the elderly population working in agriculture restrict growth. Finally, it is very important to mention there are a large number of low-paid employees working in agriculture without the appropriate education and training.

Insight into how the potential of legumes may be realised

There are some key factors that could promote the cultivation of legumes in this specific region. Intercropping with legumes, for example, can be used for fodder production with an important economical benefit for growers. The inclusion of edible legumes in rotations is considered an economically viable option especially in organic cropping systems due to the higher prices of the organic products. The low carbon footprint of legumes used for human nutrition may be quantified by competent organisations or companies and used to add marketing value and improve their competitiveness. Furthermore, leading farmers could be trained and informed about the benefits of legumes, and the possibilities to apply legume-supported cropping systems. Finally, financial support to the growers would be an important motive for the introduction of legumes into their systems.

Spain

Rafael Lopez-Bellido, University of Cordoba

History and current status of legume cultivation

Grain legumes are the oldest crops in the Mediterranean basin together with wheat. From the beginning, the role of legume to improve the soil fertility was well recognised. In recent history, the importance of grain legumes has decreased in Andalusia as consequence of European and Spanish agricultural policies. These policies have been rooted in global trade considerations rather than on supporting good local agronomic practice. Soy bean dominates the world plant protein market reducing the local contribution of other legumes. This discourages investment in crop improvement.

In Andalusia the main grain legume crops are faba bean and chickpea. Other legumes (bean, vetch, lentil, etc) occupy insignificant areas. Since 1970, the area of chickpea and faba bean has reduced dramatically (Figure 9). The pea area was significant for a short period in the last decade. The winter cereal area has been stable during the last years at about 700 000 ha (durum and bread wheat, barley, oat, etc). Durum wheat is the cereal with greatest area (320 000 ha) followed by bread wheat 150 000 ha. Sunflower covers about 260,000 ha. The ratio of the area of cereals to grain legumes is 14:1, demonstrating the low contribution of legumes to the agricultural system.

This situation is the legacy left by CAP. This situation persists even though it has been demonstrated that N fertiliser rate applied to wheat can be reduced substantially even to the point where no N fertiliser is necessary under Mediterranean conditions due to the water-related constraints on yields. In an environmental framework, in the light of agronomical knowledge, the area proportion between winter cereals and grain legumes must be close to one. This would maintain production and improve the eco-efficiency of the whole cropping system as estimated by product life-cycle assessments.

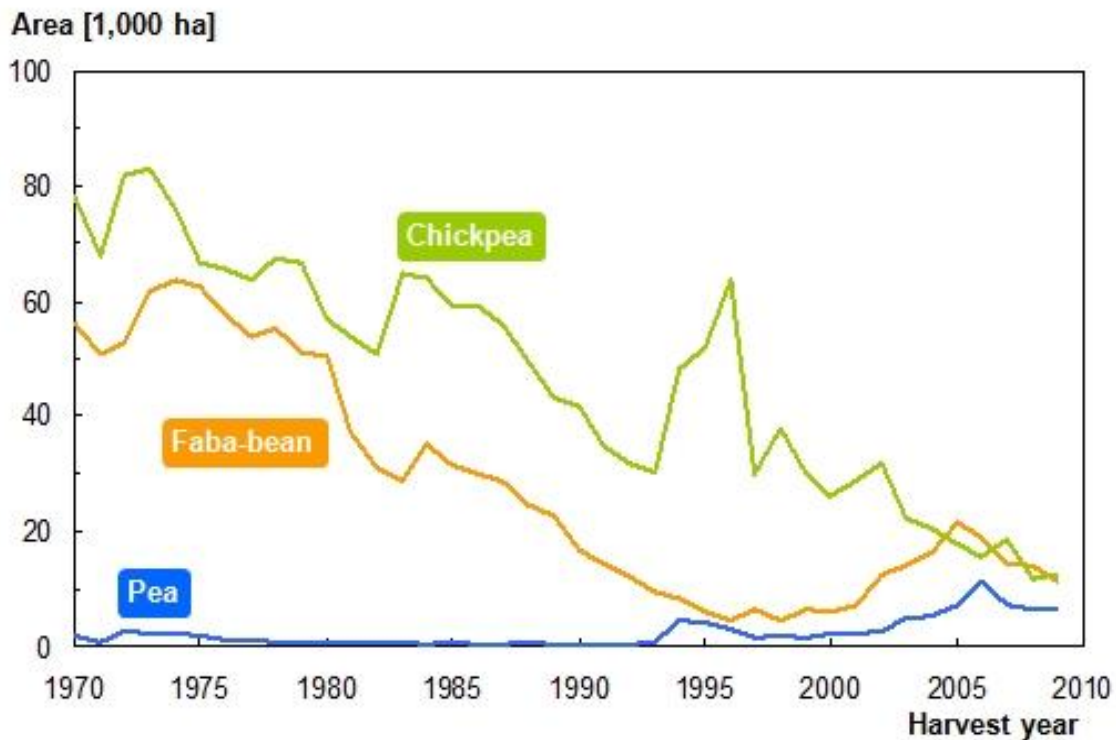


Figure 9. Changes in areas of chickpea, faba bean, and pea in Andalusia 1970 - 2010

This scenario of abandonment of grain legumes has had a negative effect on private investment on improve genetic programmes. A few small breeding programmes remain underfunded.

Current local public policy and commercial circumstances affecting legumes

The main factors that determine the extent of the use of legumes are:

- Absence of farm support payments targeted at legumes.
- “Apparent” low profitability. Farmers are not fully aware of the on-farm economic benefits. This has been demonstrated, but farmer do not trust in research. There is a mind-set in the farming sector that hinders the optimum use of legumes. The absence good extension service has contributed to increase the gap between agricultural research and practice.
- The positive environmental role has not been to take into account.
- Poor genetic material available.

Legume-supported cropping systems for Europe

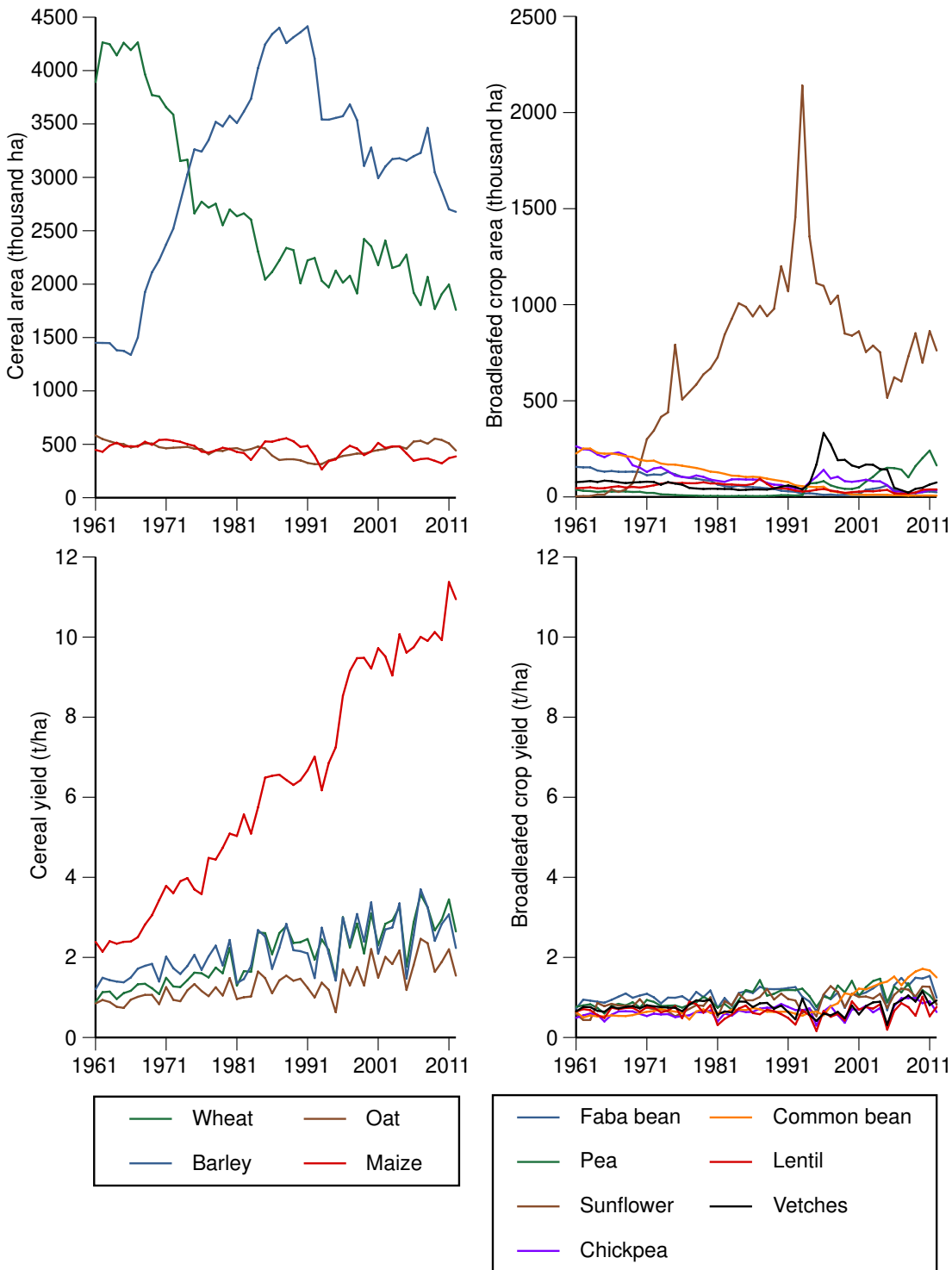


Figure 10. Harvested areas (thousand ha) and average yields (t/ha) of the main cereals, grain legumes and oilseeds in Spain, 1961-2012 (FAOstat data).

Current experiments of the partners

In the region, there are few experiments focused on the legumes. The long-term experiment at Malagon is the most relevant. This experiment tests the effects of legumes in the agroecosystem in terms of productivity, reduction N fertiliser rates, global warming mitigation by C sequestration, eco-efficiency, practices to fulfil the problems of low improved cultivars, etc.

Potential for legumes in the cropping system

In the framework of new CAP, the future of grain legumes seems uncertain because of a lack of effective policies. The CAP aims to improve environmental performance, but it is great contradiction that legumes are not the focus of measures. The potential benefits of grain legumes in Andalusia are well documented by many scientific publications from different authors. The only thing that the region needs is the application of this knowledge.

Insight into how this potential may be realised

- Policies are needed to promote legumes as valuable beneficial “environmental agents”.
- Effective public policies will attract private investment in crop improvement.
- A strong and effective extension system is needed.

Italy

Michele Monti, Mediterranean University of Reggio Calabria

History of legume cultivation

Except for some species of *Phaseolus* and *Lupinus*, legumes have been cultivated since ancient times. Usage has declined since the end of horse-powered farming, and especially since the 1970s with the increase in use of synthetic nitrogen fertiliser and the increase in the consumption of meat. Faba bean was the most cultivated, along with white and narrow-leafed lupin, lentil, chickpea, grasspea for human consumption, vetch and faba bean for animal feeding. In the country as a whole, yields of soya bean (largely spring-sown) have nearly kept track with those of wheat (largely autumn-sown) (Figure 11).

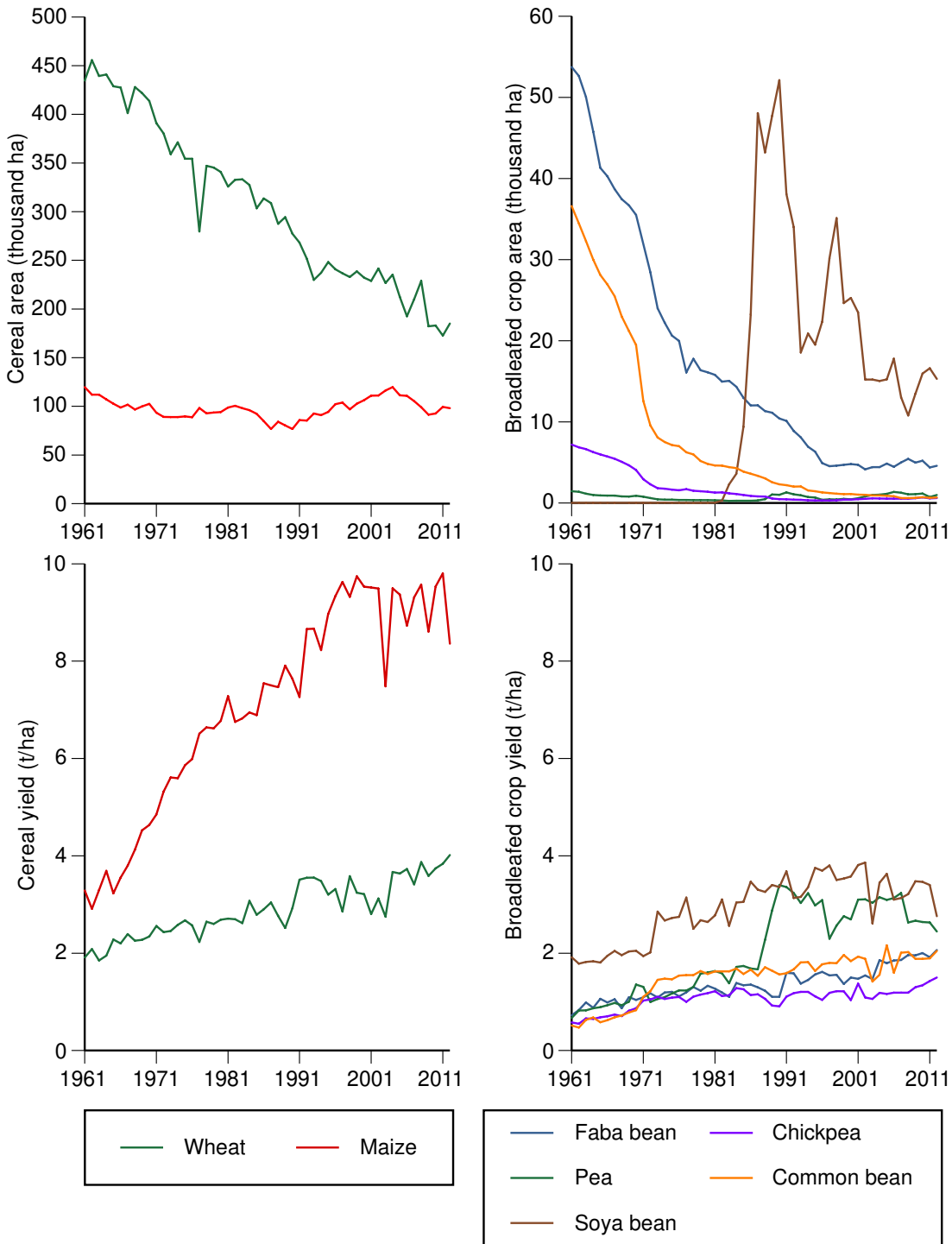


Figure 11. Harvested areas (thousand ha) and average yields (t/ha) of the main cereals, grain legumes and oilseeds in Italy, 1961-2012 (FAOstat data).

In Italy, the arable land (6.8 M ha in 2012) account for just over 50% of the utilized agricultural area and this incidence is not much changed during the last 30 years. The cereal crops (autumn-winter sowing) represent a large part of this category of land use with the incidence has varied over time and now stands at 52%. The legumes in Italy also including forage crops have reduced their surfaces in the last decade and currently (2012) occupy about 0.81 M ha (14% of arable land) and, along with the soy (0.15 M ha) are classified by statistics as protein crops (Fig. 12).

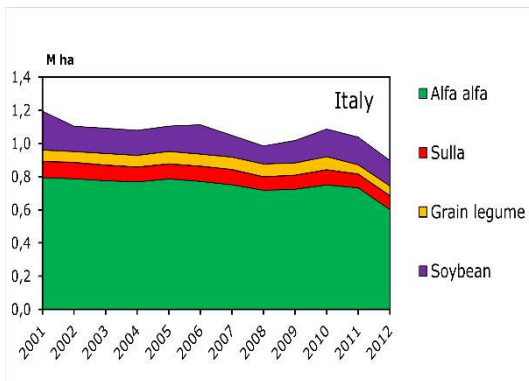


Figure 12. Changes in area of main legume crops (forage and grain) in Italy 2001-2012. (Data from Italian Institute of Statistics 2013)

Almost all of the protein crops (99.8%) and that is lucerne, soybean, faba bean and sulla are used for feeding (forage and fodder), along with clovers and lupin. These are not widespread. Bean, chickpea, pea and lentil have a limited spread and they are destined for food as pulses.

In Southern Italy (SI), arable lands are less than 50% of the utilized agricultural area (Fig. 2) where the Durum wheat (0.88 M ha) is the most widespread crop.

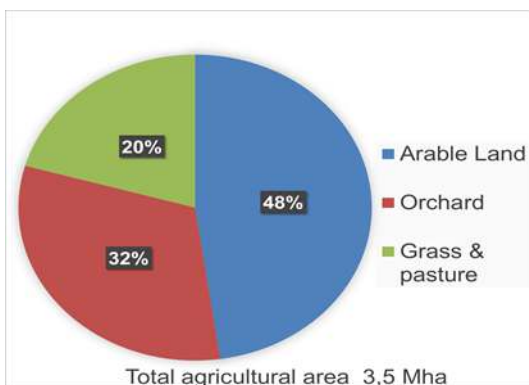


Figure 13. Distribution of total agricultural area in Southern Italy in 2010 (Data from Italian Institute of Statistics 2012)

Sulla (*Hedysarum coronarium*) continues to be the most widespread forage legume for hay production in S.I. due to its good productive performances under rainfed condition. By contrast, the irrigated areas planted with lucerne gradually decreased due to the greater profitability of irrigation of food crops (e.g. vegetables) (Fig. 14).

Vetch (*Vicia sativa*) and berseem clover (*Trifolium alexandrinum*) are recently less widely spread. They are grown in mixture with cereal for the hay production and their cultivated areas are not regularly detectable by the statistics because generally categorized as annual forage crop.

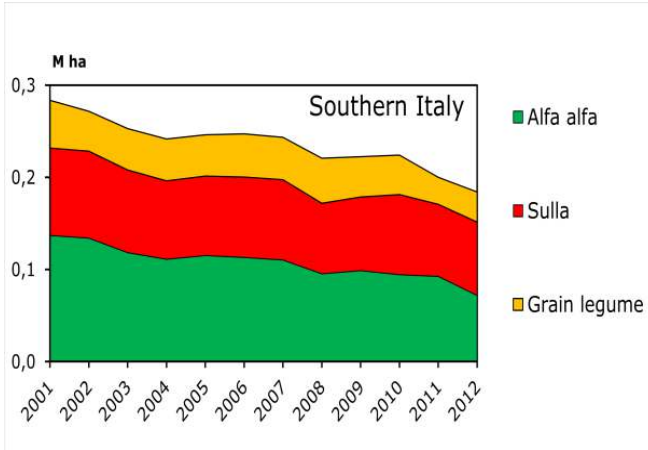


Figure 14. Changes in area of main legume crops (forage and grain) in Southern Italy. (Data from Italian Institute of Statistics 2013)

The total area of grain legume has declined since 2001, and this decrease was high in Faba Bean and Bean. In contrast, acreage of Lentil showed a strong expansion due to the demand for organic food arising from local production (Fig. 15).

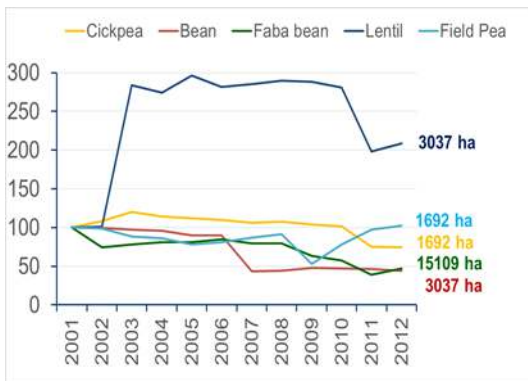


Figure 15. Changes in area of main grain legume crops during 2001-2012 period. Indexes: 2001=100 (Elaboration of data from Italian Institute of Statistics 2013)

Current status of legumes in Southern Italy

Actual yield of grain legume crops in S.I (Fig. 16) are less than 2 t ha⁻¹ as a result of genetic material and agronomic techniques (particularly weed control) that are used by farmers. Faba bean and field pea show the highest values associated with wide variability which is also caused by using genotypes at low adaptability (improved commercial varieties). By growing local populations of Lentil adapted to specific environments, farmers do not get high yields but have ensured both the stability and the quality of the production.

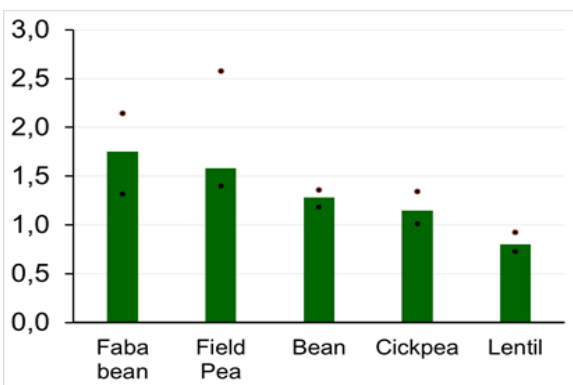


Figure 16. Actual yield (t ha⁻¹) of grain legume in Southern Italy. Mean values, maximum and minimum of 2001-2012 period. (Data from Italian Institute of Statistics 2013).

Some landraces are the protected brands of local lentil organic productions (*Castelluccio di Norcia, Ustica, Pantelleria*).

Sulla plays a key role in cereal-based cropping systems of SI, particularly in organic and low-input agriculture under drought. It is grown as a two-year crop, and this enhances its efficiency in the Mediterranean hilly areas in terms of forage sources and soil protection. This is due to its good level of productivity of aboveground biomass both the first and the second year, when a strong vegetative recovery occurs. (Figure 17).

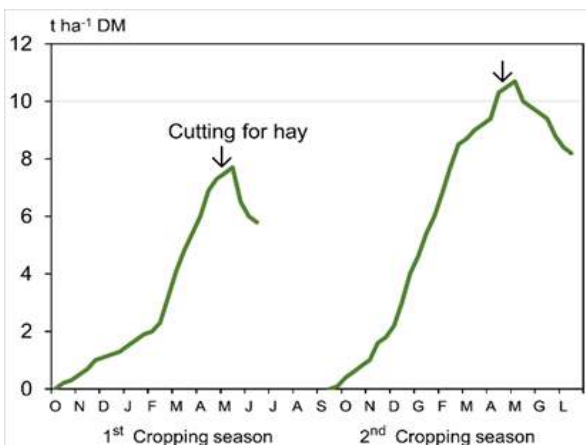


Figure 17. Dry matter production of Sulla in the two cropping seasons (Unpublished data from Regional experimental trials carried out in Sicily, 2010)

Current local public policy and commercial circumstances regarding legumes

Almost every farmer grows legume crops. Fresh and dry legumes are sold in indoor and outdoor markets, and also by individual street vendors. The greatest consumers of legumes are adults. Young men in particular are not familiar with legumes.

For faba bean, farmers use imported cultivars but also many local populations are still used. Other grain legume crops are frequently represented by landraces. Agricultural techniques adopted in field depend more on local practices passed on from generation to generation rather than new external scientific knowledge.

There is a lack of information on soil benefit of legumes in crop rotation.

Potential for legumes in Southern Italy

Profitable alternative to the traditional crop rotation: Legume-cereal intercrops (IC) for more stable feed production in Mediterranean area. Results by UDM's Case study showed that IC for grain production could be considered a suitable tool of ecological intensification of cereal cropping systems in Mediterranean area also providing an improve of the net farmers' income.

Intercropping barley with pea and faba bean for grain production showed a positive yield response and reaching an advantage compared to relative sole crop allowing a more efficient use of land not only in terms of grain production. The global advantage in complementary use of resources of additive and substitutive series of IC was confirmed by LER based on grain yield that was higher than 1 in all IC treatments demonstrating profitable land use of 16% and 17% more than sole crop (SC) for pea/barley and faba bean/barley IC respectively (Table 8).

The higher response of pea/barley could be explained by the better control of weeds than faba bean/barley. (tab.3),

High level of facilitation under low N-input, more in pea than faba bean intercropping were also showed by a higher N fixation of legumes and a higher protein content in the grain of barley avoiding external inputs and reducing the impacts on the agroecosystem. (Table 9)

Sustainability of intercropping in two-year rotation with cereal was also demonstrated by its great ability to weed control that also has positive effects on the subsequent crop. Intercropping left in the soil a good mineral nitrogen availability for the subsequent durum

wheat (Fig. 5) which allowed a productive performance comparable to that of wheat after legume crops as well (Table 8).

In addition to the production of grain mixture for human/animal feed Cereals-legumes intercrops can be considered as a source of crop residues as secondary product for biofuels production. Mixed crop residues from cereal-legume intercrops are supposed to have a higher N content than sole cereal straw. Such a bi-functional cropping system can make optimal use of available farm land and secures the best possible resource use efficiency throughout the full bioenergy manufacturing chain. UDM findings indicated a few main aspects that need to be taken into account when tall varieties of different cereals are intercropped with legume (Table 9). First of all, the legume component performance is crucial for the intercrop performance and therefore the right choice of the legume species and cultivars need to be taken in high consideration. The tall, indeterminate growth pea suffers the aggressivity of the cereal cultivars in intercrops. Appropriate genetic material to be intercropped with tall cereal cultivars has therefore to be identified and be commercially available. Secondly, the evaluated tall cereal cultivars provided high straw yields when supported by appropriate rainfall while they produced less when, in the second growing season, the rainfall is low. The potential of tall cereal cultivars needs therefore to be further investigated in semiarid and rain-fed areas like the South of Italy where the water availability to the crop is a limiting factor of yields.

'New' legume crops: White lupin seems to be the most interesting for S.I. arable cropping system. Narrow-leafed lupin may have a potential as grain legume. Other minor grain legume crops (lentil, chickpea, pea) are still cultivated in the region but are becoming unprofitable for farmers. However, these grain legumes could become cost-effective if it were used genetic material adapted to specific environments. For some years, interesting information on the productivity of adapted genetic material (varieties selected for the SI and landraces) and appropriate agronomic techniques (especially weed control) are available to farmers (Figure 10). Cultivars more adapted to winter sown with early growth vigour are needed for to control weed .

Information is needed to make legumes more attractive for farmers.

Annual forage legume, as vetch and clover are able to give good level of dry matter production also in mixture with cereals (Table 10) in short rotation and could therefore be better exploited to sustainably intensify forage systems under dry conditions.

Table 8. Yield performance and advantage (LER) of Grain legumes/ Barley intercropping (IC) in additive (100/50) and substitutive (50/50) series compared with respective sole crops. Three-years mean values ($n=3 \pm S.E.$) (Data by LF experiments at S. Marco Argentano 2011-2013).

Cropping systems	Absolute grain yield ($t\ ha^{-1}$)		Land Equivalent Ratio		
	Barley	Legume	Barley	Legume	IC
Barley sole crop (100)	4.11 \pm 1.2				
Faba sole crop (100)		3.85 \pm 0.36			
Faba100/Barley50	2.11 \pm 0.39	2.30 \pm 1.2	0,51	0,60	1.11
Faba50/Barley50	2.72 \pm 0.53	1.91 \pm 0.42	0.66	0.50	1.16
Pea sole crop (100)		2.65 \pm 1.13			
Pea100/Barley50	2.87 \pm 1.19	1.24 \pm 0,29	0.70	0.47	1.17

Table 9. Nitrogen uptake (soil and atmosphere) by intercropping and sole crop, and partitioning. (Data from LF experiment at S. Marco Argentano 2010-2011)

Cropping systems	Total N uptake ($kg\ ha^{-1}$)	NdfS (%)	NdfA (%)	N grain ($kg\ ha^{-1}$)	N straw ($kg\ ha^{-1}$)
Barley sole crop (100)	99.1	100.0	0.0	74.3	24.8
Faba sole crop (100)	224.0	24.0	76.0	158.5	65.5
Faba100/Barley50	175.8	23.2	76.8	136.4	39.4
Faba50/Barley50	165.9	20.9	79.1	128.0	37.9
Pea sole crop (100)	157.1	18.7	81.3	69.7	87.4
Pea100/Barley50	183.7	16.7	83.3	116.6	67.1
Pea50/Barley50	191.8	14.1	85.9	118.0	73.8

NdfS Nitrogen derived from soil; NdfA nitrogen derived from atmosphere

Table 10. Weed biomass and weed nitrogen uptake in Grain legumes/Barley intercropping in additive (100/50) and substitutive (50/50) series and respective sole crop. Two-years mean values 2011-2013. Data by LF experiments at S. Marco Argentano (CS)

Cropping systems	Weed biomass (g m ⁻² D.M.)		Weed N uptake (g m ⁻²)	
	Flowering	Harvest	Flowering	Harvest
Barley sole crop (100)	6.91 B	82.56 C	0.14 B	1.16 BC
Faba sole crop	98.25 A	249.96 A	3.32 A	4.26 A
Faba100/Barley50	37.06 AB	34.19 BC	1.19 B	0.72 BC
Faba50/Barley50	6.89 B	26.77 BC	0.18 B	0.46 BC
Pea sole crop (100)	59.80 AB	91.70 B	0.96 B	1.46 B
Pea100/Barley50	2.91 B	Ng	0.07 B	Ng
Pea50/Barley50	13.00 AB	31.87 BC	0.35 B	0.54 BC

Within each column letters indicate significant difference $P \leq 0.05$ (Tukey test); Ng negligible

Table 11. Grain yield and nitrogen uptake of subsequent wheat. Means and S.E. (Data from LF experiment at S. Marco Argentano (CS) 2012-13.

Pre crops	Grain yield (t ha ⁻¹)	N uptake (kg ha ⁻¹)	
		Grain	Crop
Barley sole crop	2.35 ±0.45	39.7 ±0.76	47.1 ±0.12
Barley sole crop (F)	3.40 ±0.67	59.8 ±0.65	72.4 ±0.22
Faba sole crop	3.72 ±0.89	60.5 ±0.34	71.4 ±0.20
Faba100/Barley50	3.22 ±0.34	53.0 ±0.33	61.7 ±0.45
Faba50/Barley50	3.08 ±0.23	50.7 ±0.12	59.4 ±0.19
Pea sole crop (100)	4.38 ±1.07	76.3 ±1.23	90.9 ±1.02
Pea100/Barley50	3.90 ±0.88	67.4 ±1.01	79.9 ±0.97
Pea50/Barley50	3.55 ±0.22	57.2 ±0.38	67.4 ±0.81

F N-fertilised wheat [50 kg ha⁻¹]

Table 12. Grain and straw yields, Land Equivalent Ratio of pea intercropped with different cereals in additive (100/50) and substitutive series (50/50) compared with respective sole crop (SC). Values are two-years mean. (Experimental data by UDM, Reggio Calabria 2009-2010)

	IC _{CEREAL} t ha ⁻¹	IC _{PEA} t ha ⁻¹	IC _{CEREAL} t ha ⁻¹	IC _{PEA} t ha ⁻¹	LER _{GY}	LER _{STRAW}
W100P50	3,34	0,22	7,27	0,97	0,92	1,07
W50P50	2,99	0,34	6,47	1,39	0,92	1,06
WSC	4,17		8,29			
B100P50	3,99	0,30	5,79	1,11	1,09	1,23
B50P50	4,25	0,47	4,94	1,60	1,26	1,20
BSC	4,63		5,72			
O100P50	2,91	0,20	7,35	1,04	1,07	1,14
O50P50	2,63	0,33	6,02	1,45	1,08	1,07
OSC	3,18		7,95			
T100P50	3,52	0,17	8,46	0,87	0,92	1,06
T50P50	3,59	0,30	7,53	1,31	1,03	1,05
TSC	4,41		9,65			
<i>LSD P 0.05</i>	<i>0,92</i>	<i>0,11</i>	<i>1,05</i>	<i>0,65</i>	<i>0,21</i>	<i>0,14</i>
PSC		1,46		4,79		

W Wheat; B Barley; O Oat; T Triticale; P Pea.

Table 13. Dry matter production (tha⁻¹) in intercropping and pure stand of Vetch (*Vicia sativa*) and Berseem Clover (*Trifolium alexandrinum*). Data from UDM experiments in Calabria 2010-13.

	Pure stand	Intercropping (50% of pure stand)		
		Annual Rye-grass	Triticale	Oat
Vetch	6.81	3.78	2.66	3.69
Clover	7.34	2.89		

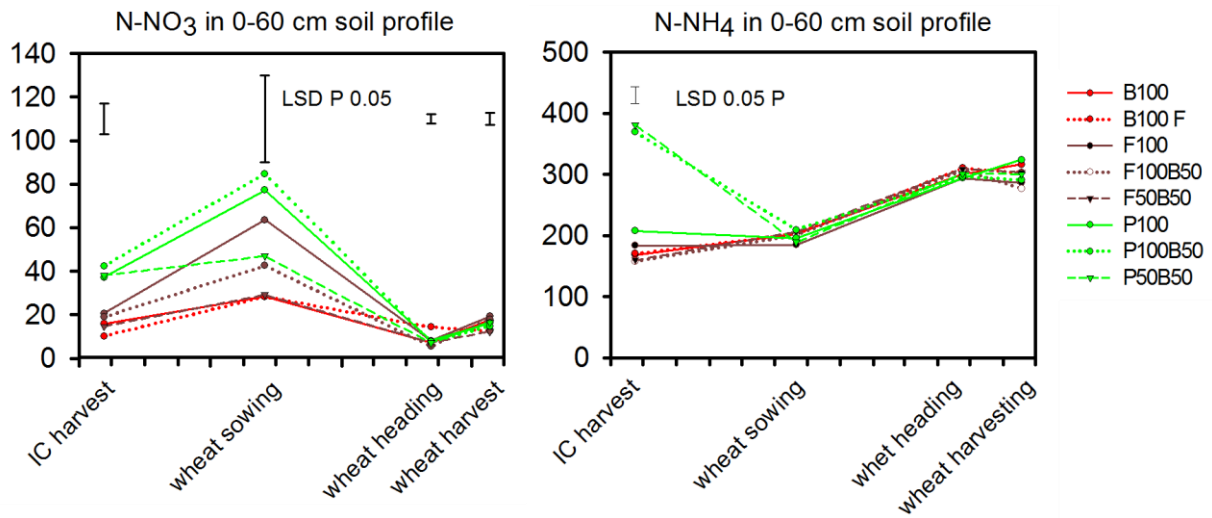


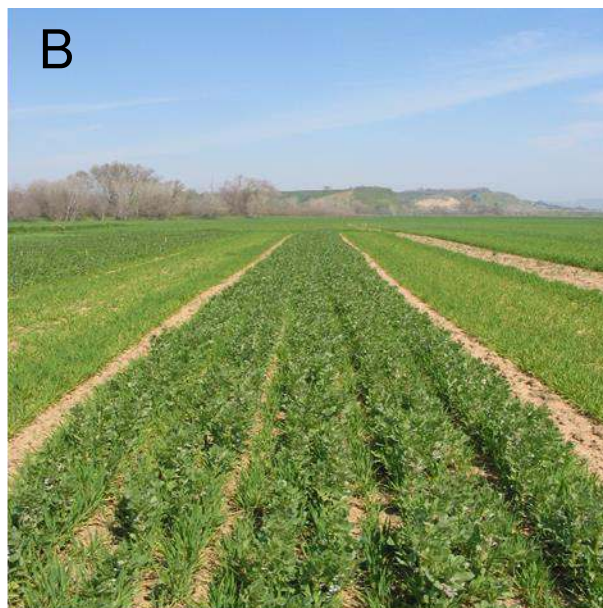
Fig. 18 Changes in N-mineral soil (kg ha⁻¹) after IC and SC and during wheat cycle. Data from LF experiment at S. Marco Argentano (CS) 2011-2012

Insight into how this potential may be realised:

Engagement of commercial interests (seed companies) in awareness raising.

Perform some demonstrative field experiments introducing new legume species (grain and forage) and new cultivars (earlier, more productive, more resistant to pest).

Use of public policy to promote legume cultivation.



Intercropping pea/ barley (A) and faba bean/barley (B) and sowing operations (C and D) at UDM experimental fields in S.Marco Argentano (CS)

BOREAL-NEMORAL REGION

This region is characterised by short summers with very long days, and long winters. The range of crop species and cultivars is narrower than in the other regions and crop yields are generally lower than further south, because of the short growing season. The main grain legumes are pea and faba bean and the main forage legume is red clover. Our correspondents are in Finland, Sweden and Denmark, and the region includes the Baltic states. The Danish sites are at the junction of the Boreal-Nemoral, Continental and Atlantic regions, but still have much in common with the Boreal-Nemoral region except for the possibility of more numerous harvests of grass-legume forages during the summer.

Finland

Fred Stoddard, University of Helsinki, and Arja Nykänen, Agrifood Research Finland

History of legume cultivation

- Known on a small scale for 1500 years.
- Seldom grown on more than 3% of land.
- As elsewhere, declining usage since the end of horse-powered farming.
- Food pea in west, faba bean in southeast.
- Clover is found throughout, red clover historically important
- Breeding programmes sporadic in 20th century, all now shut down.
- Cheap nitrogen fertiliser replaced red clover except for in the organic sector.

Current status of legumes

- Increased interest following increases in prices of soy bean meal and N fertiliser.
- Now up to 1% of land under grain legumes, both pea and faba bean for feed. Narrow-leaved lupin is a new crop.
- No change detected in clover, still primarily used in the organic sector.
- Main “protein” crop is turnip rape, average yield 1.5 t / ha of oilseed so about 0.5 t / ha of protein.
- Current average protein yields of faba bean exceed 1 t / ha, pea nearly 1 t / ha
- Faba bean breeding resurrected in 2010

Current local public policy and commercial circumstances regarding legumes

- Growers are generally unfamiliar with legume crops.
- Markets are needed for growers to grow the crops. Duopoly of large feed buyers, and contract growing, restricts access to markets. New markets needed (food ingredients).
- Cultivars are adapted mainly to the south of the country. The main faba bean cultivar is old, late maturing, and has limited disease resistance. Real feed-type pea cultivars are needed.
- “Real farmers don’t have time to wait for legumes, they need N now”.
- Lack of local information on the value of legumes as break crops and the value of ecological services.
- Need for post-harvest drying of almost all crops here, so small-seeded cultivars are preferred.

Legume-supported cropping systems for Europe

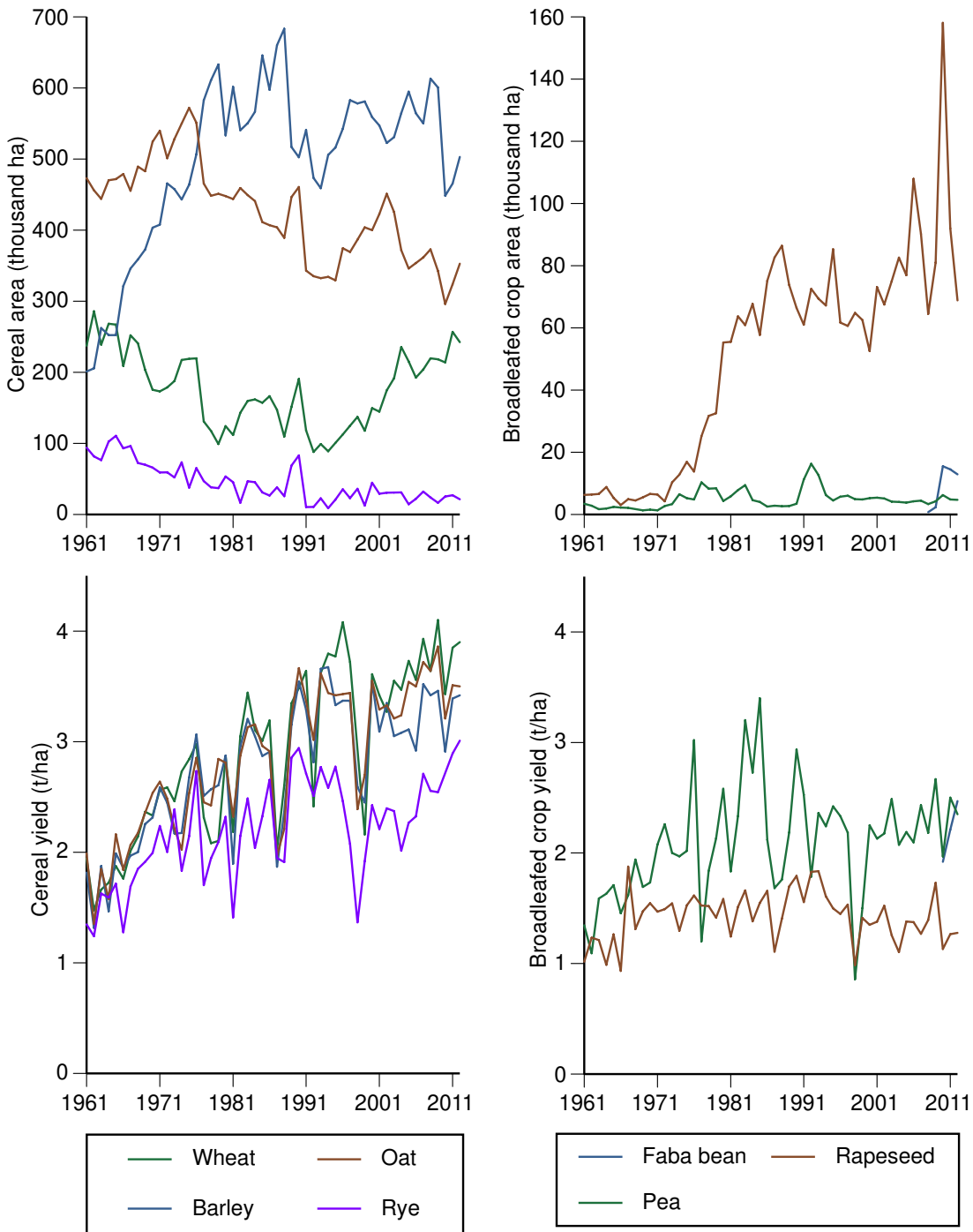


Figure 19. Harvested areas (thousand ha) and average yields (t/ha) of the main cereals, grain legumes and oilseeds in Finland, 1961-2012 (data from the national database Tike).

Current experiments in Finland

- Bioenergy experiment to test potential for grass-legume perennial mixtures to sequester C, maintain N and provide bioenergy: At least one seed mixture blend seems to provide yields equal to 100% grass but without fertiliser input.
- Bioremediation experiment to test potential for grass-legume perennial mixtures to remediate oil contamination. This experiment shows that blends of grass and clover are greatly superior to either species grown alone. Oil together with plant growth-promoting bacteria results in increased biomass.
- Crop introduction experiments and cultivar trials to determine suitability of “novel” legumes for boreal conditions, also with a view to climate change adaptation. Narrow-leafed lupin have potential as grain legume. White lupin have been shown to have potential for biomass (silage, green manure, bioenergy). Lentil have potential. Winter faba bean has not survived winters yet. Winter lentil survived its first winter test. Novel sources of drought tolerance and earliness have been identified in faba bean.
- Responses of soy bean to day length precludes satisfactory ripening.
- Demonstration of feed value of faba bean and narrow-leafed lupin as protein supplements in conjunction with standard national hay and silage.

Potential for legumes in Finnish cropping systems

- An increase to 10% of land area sown to feed-quality grain legumes would reduce soy bean imports by at least 50%.
- Different species suit different soil types.
- Earlier maturity needed, especially in faba bean.
- Better feed quality (low vicine-convicine faba bean, low trypsin inhibitor pea) will increase market demand
- Potential for whole-crop use for silage.
- Perhaps novelties needed to attract attention to forage legumes.
- Galega demonstrated to be suitable, some claim it to be invasive when evidence shows otherwise.
- Would novel white clover hybrids help?
- Are there other clover species?
- Expectation that alfalfa will soon be grown here as winter hardiness increase and winters become milder.
- Investigations on novel food uses will lead to increased demand for grain legumes for ingredient purposes.

Insight into how this potential may be realised

- Existing knowledge could be better communicated to improve on-farm performance.
- Improved cultivars will attract both growers and processors.
- Support for protein crops, on account of their public benefits, could level gross margins with those of cereals.

Sweden

Bodil Frankow-Lindberg and Göran Bergkvist, Swedish Agricultural University, Uppsala

History of legume cultivation

Peas

- Known cultivation for 1000 years, but probably much longer.
- Legumes accounted for about 0.2% of total acreage during the sixteenth century. Increased during the eighteenth century to 3.2% in 1805. Today, legumes cover between 0.5 – 1 %.
- The area used for grain legumes in the mid nineteenth century was about 35 000 ha. The area peaked around 1980 with 60 000 ha. During the 1990s when subsidies were reduced and the import of soya increase, the area declined to 10 000 ha. Since then there has been some recovery with the area increasing to 17,000 ha in 2008 and 36,000 ha in 2010 due to a higher demand due to concerns about soy bean production in South America and due to revival of EU subsidies.
- There have been larger acreages in wartime, when subsidies were high, when protein prices were high.
- Yield levels for peas and barley were similar in 1900-1910. Thereafter barley yield increased faster than the growth in yield of peas. The stability of yield has been improved since then due to successful plant breeding. New semi-leafless cultivars with better stem stability have been introduced.
- Pea grown in a mixture with other species and used as green fodder i.e. the crop is harvested before the pea reaches maturity was grown on 120,000 ha in 1950, but is only grown on 40,000 at present.

Perennial leys with legumes

One important reason why forage crops were included in the crop rotation was the introduction of nitrogen-fixing legumes such as clover and alfalfa in the 1700s. Previously farmers harvested hay from low-yielding fields that were never fertilised. Manure from animals that were fed on the meadow hay during the winter was used to fertilise cereals and other crops. In the 1800s, when a cropping system with rotational grass/red clover leys were included as a natural part of the crop rotation, the yield of both forage and cereal crops increased. The area grown with rotational leys was at its largest just after the second world war, exceeding 1.5 M ha. This has decreased to about 1.1 M ha at present. There is a long tradition of forage legume breeding (>100 years).

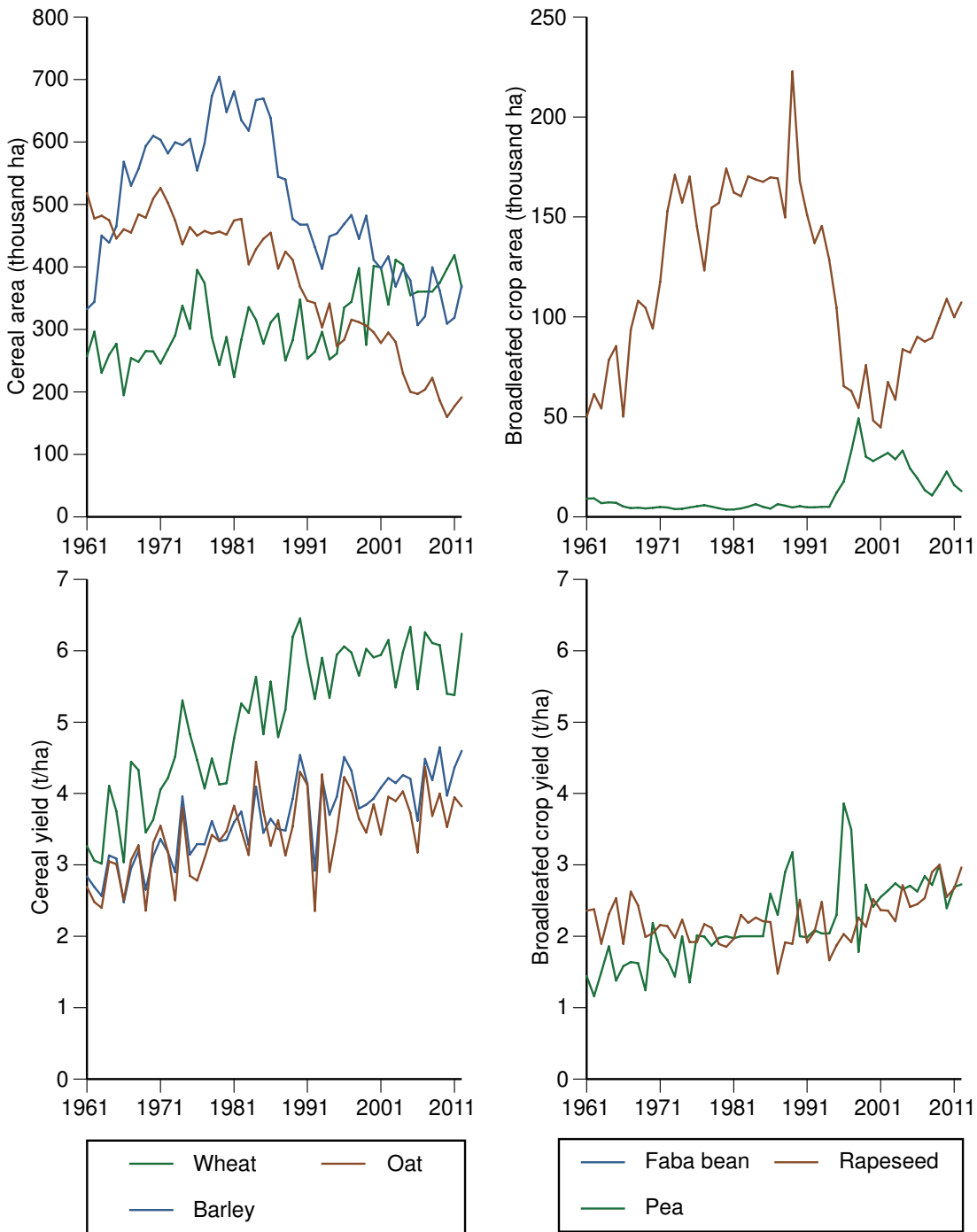


Figure 20. Harvested areas (thousand ha) and average yields (t/ha) of the main cereals, grain legumes and oilseeds in Sweden, 1961-2012 (FAOstat data).

Current status of legumes

Annual crops

In 2011 annual legumes were grown on 41 000 ha. Peas and faba beans used as fodder are the two biggest crops, 32 000 ha

The mean pea yield during the period 2005-2009 was 2.8 t / ha, the mean faba bean yield 2.4 t / ha.

Peas for human consumption was grown on 8 000 ha, brown beans, a local cultivar of *Phaseolus vulgaris* from the island of Öland, c. 500 ha.

Green fodder, usually with 30 – 40 % peas, was grown on 40 000 ha

Breeding of grain legumes such as pea and faba bean was discontinued

Perennial leys with legumes

In 2011 perennial leys were grown on 1.1 M ha, which is about 40 % of arable land, and ley for seed production was grown on 15 000 ha. Intensively managed leys produce 7 – 12 t / ha depending on latitude, but the mean yield is considerable lower due to extensive management, so during the period 2005-2009 the mean dry matter yield was 4.9 t / ha. There is long continued use of especially red clover in forage crops, with white clover now increasing in grass/legume mixtures. Generally, leys are grown for 2-4 years. Depending on climate, choice of forage plants, fertilisation and objectives of cultivation (mainly trade-off between quantity and quality) the number of harvests per year is between 2 and 4. Early first harvest results in higher energy levels and more digestible protein per kg dry matter, while the harvest will be greater if you wait longer. It is quite common that leys are used for grazing after the first harvest.

Current local public policy and commercial circumstances regarding legumes

Markets are needed for growers to increase the cultivation of grain crops. According to the advisory service an increased price to the farmer of about 0.06 € would increase the cultivation. Grain legume cultivars are adapted mainly to the south of the country. Poorer protein quality of adapted peas and faba beans for especially monogastric animals but also dairy cows in comparison with imported soya bean limit the inclusion in feeding rations, or if used, contribute to excess protein feeding and results in N losses to the environment. The large market for organic milk production favours legume production.

The market wants to handle large quantities which excludes handling of many different species.

Current experiments of the partners

- Official cultivar trials with peas, faba beans and lupins

- Effect of *Brassica* cover crops on *Aphanomyces* root rot.
- *Phytophthora* root rot on peas and faba beans
- Crop introduction experiments and cultivar trials to determine suitability of “novel” legumes e.g. evaluation of soya bean cultivars in southernmost Sweden
- Legumes are important to keep up the protein content in leys, so experiments on how to achieve a stable legume proportion of around 30% of the harvested dry matter is conducted.

Potential for legumes in Sweden

There are no land limitations for increased cultivation for domestic needs. Soil borne diseases limit production locally. Cultivars, species and cropping methods that make legumes more tolerant or resistant to e.g. *Aphanomyces* would increase production. Better feed quality will increase market demand. The use of cereal/legumes intercropping for production of whole crop silage is not used much on conventional farms, but has potential and interest may increase if price of soya bean and N-fertilisers increases.

Annual crops

Earlier maturing cultivars of faba bean have made it possible to grow grain legumes in areas with clay soil, high precipitation and compacted soil even if the growing season is quite short. Earlier maturity would still be useful with faba bean, particularly north of 59°N. The interest in growing faba beans increases if it is possible to sow a winter wheat crop after harvest of faba bean.

Grain legume yield has not increased as much over time compared with other crops. One reason might be that increased compaction reduces pea yields. Grain legumes of various species for human consumption have potential on a small acreage. Narrow-leafed lupin has a potential as a crop in southernmost Sweden – the earliness of the current plant material limits its utilization.

Perennial leys with legumes

Legumes (red and white clover, alfalfa) are used in short rotation leys on dairy and cattle farms, but generally high rates of nitrogen fertiliser makes the clover content low and the potential of the clover is therefore not always fully utilized. By reducing N-fertiliser rates to the leys, the N-fixing of the ley would increase and almost the same biomass could be achieved.

Alfalfa has opportunities for restoring compacted subsoils and has great yield potential. It establishes slower than red or white clover, which restricts acreage.

Galega grows well but is difficult to establish and has a poor feeding quality. It could be an alternative on sandy soils in situations with little precipitation. Esparsett has good feeding quality but is difficult to establish and the use is probably limited by climatic conditions. Birdsfoot trefoil may be useful in extensively managed leys.

The increased maize production reduces grass/clover leys.

Denmark

Kirsten Schelde, University of Aarhus

History of legume cultivation

- Production of grain legumes has always been low in Denmark due to unstable yields and a lack of robust cultivars.
- During the 18th and 19th centuries production was limited to 2% of the agricultural area, decreasing to below 0.5% of the agricultural area at the start of the 20th century. From 1965-85 about 0.1% of the area has been grown with grain legumes. There was an increase starting in the 1980's to 3-5% of the agricultural area, primarily due to EU subsidies.
- The current level of grain legume production is, however, back to 0.1-0.2% of the area (7000 ha), largely dominated by peas (>80%), part of which is green pea for human consumption. Over the recent decade there was an interest, in particular from organic farmers, in growing grain legumes, but most of these farmers have given up the production due to yield instability.
- Red clover and white clover have been grown since around 1750. At around 1900, 29% of the agricultural area was under grass-clover grassland grown in rotation. This decreased to 18% in 1965. During the last 30 years, the area of grass-clover grown in rotation has been 8-12% of the agricultural area (~300,000 ha).
- Production of clover seeds, for domestic use and later for export (after 1930), has been going on since the 18th century. Since 1965 the area for clover seeds has been on the order of 0.1% of the agricultural area. Danish farmers account for more than 50% of European clover seed production.

Current status of legume production

Annual crops

Pea dominates annual legume cropping with over 80% of the grain legume area (Figure 14). There are small areas of lupins and faba bean. The species are very different with respect to yields (lower for lupins), protein contents, competitiveness towards weeds, drought tolerance (low for faba bean), and susceptibility to various diseases and pests. Intercropping with wheat or barley has led to more stable yields. However, total-yields under intercropping are often lower than the sum of corresponding monoculture yields. The average yield during 1991-2011 (field peas) was 3.5 t / ha. In field trials, yields of faba bean have been relatively stable over the last few years, being (on loamy or irrigated sandy soils) on the order of 5 t / ha. This level of yield could encourage (organic) farmers to increase faba bean production.

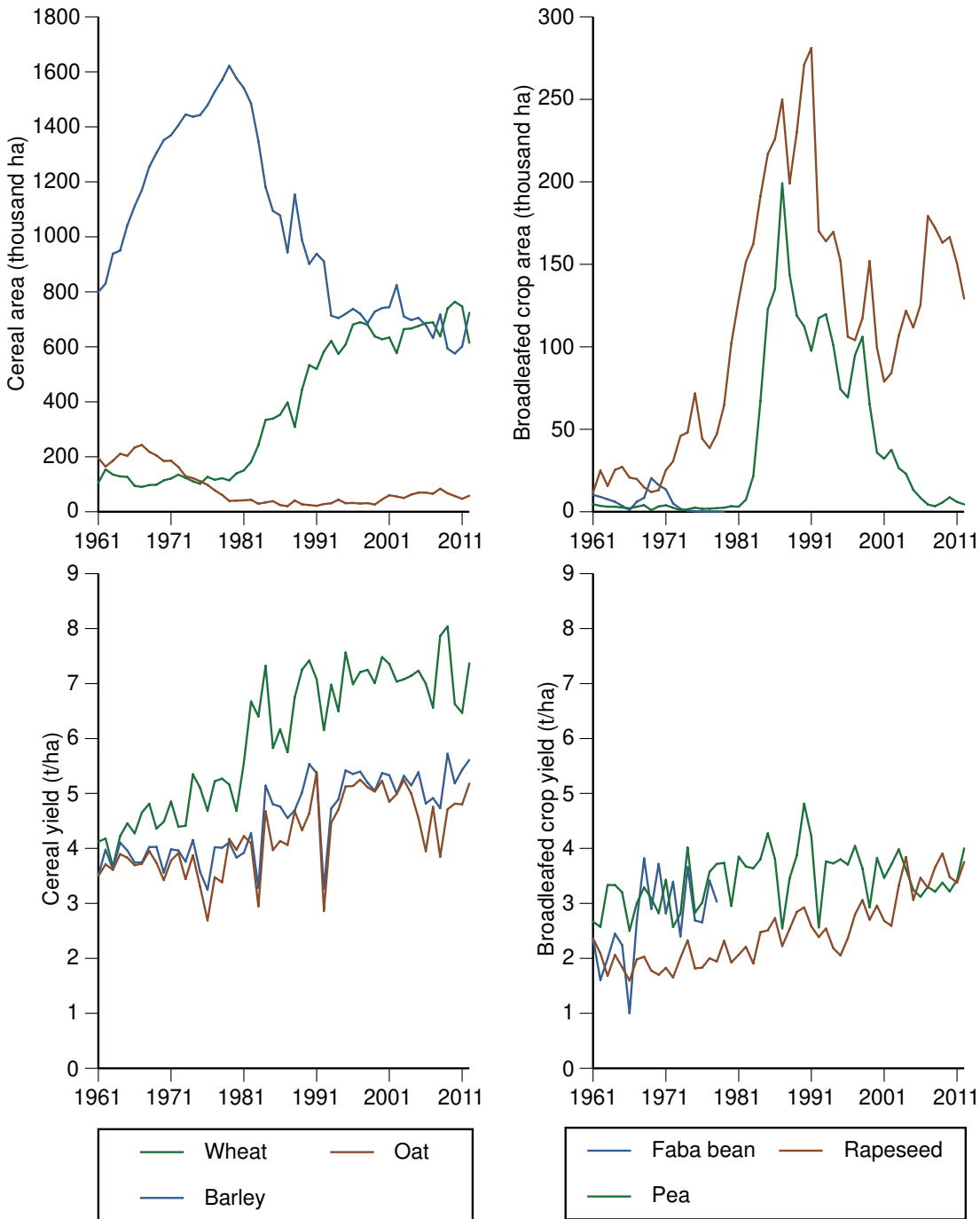


Figure 21. Harvested areas (thousand ha) and average yields (t/ha) of the main cereals, grain legumes and oilseeds in Denmark, 1961-2012 (FAOstat data).

Due to pests and diseases, farmers are advised to allow 4-6-year intervals between grain legumes in a cropping system.

In organic farming systems, the share of land grown with grain legumes is on the order of 1%.

Autumn-sown legumes (lupins and faba bean) have been tested over the past few years with generally poor results due to winter damage. However, in a successful trial the yield of faba bean was on the order of 7 t / ha, showing a high yield potential.

Perennial leys with legumes

There is a high share of (rotational) grass-clover leys in organic dairy farming (~60-65% of the total organic area). The share of grass-clover is particularly high in fields near the milking parlour. This has led to increasing problems with 'clover fatigue' so new red clover does not establish well. Minimum 1-year clover-free intervals between sequences seem to be needed.

Generally, grass-clover leys are grown for 2-4 years. Depending on climate, choice of forage species, fertilisation and objectives of cultivation (mainly trade-off between quantity and quality) the number of harvests per year differs between 4 and 6.

More than 90% of ley seed mixtures sold to farmers contain clover seeds. Typically 10-20% of the seeds in a mixture are clover seeds.

White clover is used in leys for grazing, while leys grown for cutting may contain white clover or a mixture of red and white clover. In leys for cutting generally four cuttings are made over the season in white clover based leys, while five cuttings are made in red clover based leys. The difference is due to the higher growth potential of red clover, which is however accompanied by a lower feeding value compared to that of white clover.

Current local public policy and commercial factors affecting legumes in Denmark

- Seed quality: Since organic seeds are not treated with fungicides they often have a low quality, leading to poor germination rates.
- High yield variability: Problems with weeds on organic farms due to low competitiveness of legumes towards weeds. Problems with pests (aphids) and diseases (lupin/grey mould; faba bean/chocolate spot & rust; peas/Ascochyta leaf and pod spot).
- Markets: Farmers experience difficulties in selling their grain legume products as grain companies are little interested and prices are low. Grain companies have difficulties in handling small and mixed amounts of grain legumes.
- Feed quality: The amino acid composition of Danish grain legumes is not optimal for animal feeding and techniques for processing of the raw material (such as roasting/toasting) are being tested

Current experiments in Denmark

- Research on robust/reliable legume crops focusing on developing a concept for robust cultivation of legumes (decreasing risk of crop failure) in Danish organic farming.
- Organic Protein Project: Research aimed at promoting organic cultivation of protein crops for animal feed in Denmark. Improving the nutritional value of grain legumes for animal feed by processing the raw materials before using for feed.
- Increasing the quality of organic dairy production through natural sources of vitamins and minerals and non-antibiotic health control.
- Sources and characteristics of DON leaching from perennial grass-clover mixtures in Northern Europe.
- Grass-clover in organic dairy farming.
- Developing multispecies grasslands.
- Ecosystem functions and services of biodiversity in grasslands.
- The role of enchytraeids in the turnover of dissolved organic nitrogen in grasslands
- Does white clover induce biennial bursts in N leaching from grassland?
- Cutting strategies in different grass-clover mixtures.
- Prognosis for growth and herbage quality of grass-clover under grazing and cutting
- NIR calibration of clover proportion in fresh and ensiled grass-clover.

Potential for legumes in Danish cropping systems

Continued wide use of grass-clover in organic dairy systems can be sustained by the development of management tools for optimising a balanced grazing of pastures and optimizing ley quality.

Increased maize production reduces grass-clover leys.

In terms of yield, lupins and faba bean are interesting, but more robust cultivars with stable yields in the humid Danish climate are needed. Intercropping of pea, lupins or faba bean with wheat or barley has led to more stable, but not high, grain legume yields. Some grain companies are now starting to accept cereal/grain legume mixtures from organic farming.

From 2015 all animal feed at organic farms must be 100% organic. This will be a driver for increasing the area of grain legumes to replace imported protein. There are concerns that in the future imported organic soy will not be 100% free from GMO material; this is another driver towards a local production of legumes.

The introduction of locally produced soya bean would require optimization of cropping systems and cultivars suited for Danish growing conditions with a relatively short growing season.