Legumes Translated Deliverable Report

Deliverable 4.2

Legumes Translated Development Guide

Integration of legume production at farm level

Due date: 30 April 2021 (ammended grant agreement)

Project start date: 1 November 2018

Duration: 42 months

Work package: Economic performance (WP4)

Work package leader: Johannes Schuler, ZALF

Relevant task: Economic assessment of legume-based production systems (Task 4.2);

Relevant task leader: Johannes Schuler, ZALF

Nature of deliverable: Report

Dissemination level: Public (PU)

Legumes Translated (Translating knowledge for legume-based farming for feed and food systems) has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 817634

Objectives of the tasks supporting the deliverable

The background to this work is the need to address the comparative advantage of cereals and oilseeds that is a major factor in the locking of legumes out of farming systems and thus value chains. The overall goal is to help commercial actors identify and gain economic advantage. The findings are to be reported as development guides (practice guides) and summarised in practice abstracts. Specifcally WP4 aims to:

1. identify economic opportunities and constraints at farm level for the introduction of legumes;
2. identify economic opportunities and constraints at sector and value chain level;
3. support the synthesis of actor groups' knowledge with economic validation; and
4. support the synthesis of transition networks' knowledge with economic validation.

This contract deliverable report is supported by Task 4.2 (Economic analysis at farm level) which is led by ZALF and involving all actor group representatives. As set out in Task 4.2 of the project description of action (DoA) this deliverable report will support actor groups with knowledge on the allocation of farm resources to different production activities, the long-term impact of legumes on productivity, and the impact of farm or locally-grown feed for livestock productivity. Actor Groups' development options identified will be subject to expert validation based on exemplary net benefit calculations for crop-rotations taking into account the ecosystem service (ESS) provided by legumes (with input from Task 5.2). Knowledge of trade-offs between short-term economic performance and ESS will be compiled in the context of decision support. Benchmarking and cost-benefit analysis of production systems will identify best practices and thresholds that will support the profitable and sustainable inclusion of legumes in Actor Groups' farming systems.

Activities undertaken

A data set of case studies from project partners within Legumes Translated was compiled to perform an economic assessment of legume integration in farming systems. Additionally, information from stakeholder consultations and literature was exploited. The analysis was based on considerations of gross margins at single crop level, allocation of farm resources to legume production and economic evaluations in a rotational context which were expanded by an assessment of ESS provision in order to identify trade-offs between economic performance and ESS. The economic potential of alternative legumes in animal production was covered by considerations of two specific sectors - pig production and aquaculture.

The data set from case studies from project partners within Legumes Translated was gathered from a joint data query from ZALF and TI. The questionnaire was designed to provide data for Task 4.1, Task 4.2, Task 5.1 and Task 5.2. The objective of the data query was to compose regional cropping systems with and without legumes including economic data. It was sent out to all actor groups and processed between September 2019 and March 2020. Subsequently, an iterative process of data checking was initialized that was jointly performed with the partners who provided the data. Nine actor groups participated in the data query and provided data on regional cropping systems with and without legumes: Bulgarian Legumes Network (represented by ABI), German Soybean Association (represented by LTZ), Schwäbisch Hall Producers (represented by BESH), Soybean Cultivation Group in Southeast Europe (represented by IFVC, Europe Soya Value Chain

Development Group (represented by DS, German Pea and Bean Network (represented by LLH), Brandenburg Farmers' Network (presented by ZALF), The Irish Grain Legumes Group (represented by AST and Teagasc) and SRUC Dairy Protein Group (represented by the SRUC). A set of gross margin calculations at the single crop level and at the rotational level were calculated. In addition, exemplary illustrations of farm resources that are allocated to legume production were developed. Assessments of ESS provision from different cropping systems were implemented within Task 5.2 (led by ZALF) and integrated in calculations of costs of each unit of ESS provision which allowed identifications of trade-off and win-win situations.

Consultations with project partners and associated stakeholders that are active in pig production (Schwäbisch Hall Producers) enabled the compilation of different and experimental rations for pig feeding which were economically assessed. In the sector of aquaculture, NIREUS (now AVRAMAR) provided new experimental feed formulas containing different locally-grown legumes which enabled the economic competitiveness of regional legumes as fish feed ingredients to be assessed.

Deliverable Reports 4.1 and 4.2 will now be used for the production of published practice guides.

Results

This report assesses the profitability of legume integration in farming systems. Analysis of the short-term economic performance of legumes showed poor results for most legumes other than soybean when considering single crops. This was also reflected in proportion of arable land used for grain legumes in the case study regions. Soybean production, though, was competitive with wheat in several regions. The main contributory factor is the higher market value of soybean. Potential resource savings caused by legume production on a farm were illustrated with fertiliser and pesticide savings as well as positive effects on labour and machinery use which can directly be translated into financial effects. Moreover, protein synthesis of legumes fosters on-farm availability of valuable feed resources. The expansion of the gross margin calculations on whole rotations showed that the rotational-level profitability of legumes is higher. The non-legume rotations' gross margins were matched or exceeded by legume-supported rotations in more than half of the case study regions. The modifications of the standard gross margin with the substitution of legume market prices with their feed value, the inclusion of legume-related subsidies from the Common Agricultural Policy (CAP), and a carbon tax all increased the economic competitiveness of legume-supported systems. Besides economic considerations, the provision of ESS was integrated in the assessment and showed legumes' impacts in farming systems more comprehensively. Cropping systems with legumes had in the majority of cases better environmental performance in terms of nitrogen fertiliser use, nitrous oxide emissions and partly also in nitrate leaching. Benefits for provisioning services were also found concerning protein outputs. Relating the provision of these ESS to the economic performance of the cropping systems enabled the identification of trade-offs and win-win situations. The foregone gross margin per unit of ESS provision varied depending on the regional contexts. Win-win situations were mostly found for either regions with soybean-supported cropping systems or regions where grain legume yields were relatively high, as for example shown with high-yielding faba bean in Ireland and Scotland.

The economic evaluation of alternative feed rations in aquaculture showed promising results in terms of cost-savings as compared to the use of imported soybean meal. Furthermore, there is potential to further decrease the share of fish meal and oil in fish feed formulas. The work on pig feed rations showed economic advantages through replacing soybean in feed rations with other grain legumes. However, the nutritive quality can decrease to some extent which needs to be further evaluated through feed experiments, which BESH is performing in the next months. An advantage of the premium market that BESH is serving is the higher meat price they can achieve. This allows a focus on other factors than just pure cost-effectiveness, but also issues of animal welfare and the support of regionally produced feed stuffs.

Conclusions

A major economic challenge for legumes in European farming systems is their constant under-valuation in different relations. Market prices are not reflecting actual feeding values of grain legumes such as pea, faba bean or lupin. Assessments of economic performance at single crop level disregard essential resource benefits and hence economic advantages for the legume-supported systems. Additionally, non-market outputs depicted in the provision of various ESS are not directly reflected in standard gross margin calculations which also fosters the underestimation of legumes.

Analysis of real-world cropping systems from regions all over Europe have shown that legume-supported systems can be competitive to common non-legume systems when all rotational effects are taken into account. These competitive systems occur where soy grows well or where high legume yields of other legumes can be achieved. These high economic performances were concomitantly supported by increased ESS provision, indicating win-win situations. Cases with trade-offs between lower economic performance and higher ESS provisions in legume-supported systems can be avoided by increasing legumes' farm level profitability, either by increasing yields or by achieving higher output prices. There are trends which will automatically contribute to this increase such as rising prices of agricultural inputs or imported soybean. However, specific efforts to support market development to rise legume selling prices and to support crop performance using genetic and agronomic improvement will boost competitiveness further.

On a policy level the social benefits of legumes can be reflected through the inclusion of legumes in the upcoming eco-schemes of the EU CAP. If by such means the profitability at farm level can be increased through legume integration in cropping systems, legume production can be considerably incentivised and sustainability of European cropping systems fostered. European grain legumes can gain higher importance in the feed sector given rising soybean world market prices and changing market preferences. If such signals develop, the feed industry and livestock producers including aquaculture will invest in using alternative resources for protein.

Inka Notz, Johannes Schuler

April 30, 2021

Legume Translated practice guide

Integration of legume production at farm level

Prepared by:

Inka Notz[1], Sheila Alves[2], Dimitris Barkas[3], Thorsten Haase[4], Paul Hargreaves[5], Michael Hennessy[2], Anelia Iantcheva[6], Isabella Munder[7], Moritz Reckling[1], Jürgen Recknagel[8], Leopold Rittler[9], Kairsty Topp[5], Marjana Vasiljević[10], Fritz Wolf[7], Christoph Zimmer[7], Johannes Schuler[1]

[1]Leibniz Centre for Agricultural Landscape Research (ZALF), Germany

[2]Teagasc, Ireland

[3]Avramar, Greece

[4]Landesbetrieb Landwirtschaft Hessen (LLH), Germany

[5]Scotland's Rural College (SRUC), United Kingdom

[6]AgroBioInstitute, Bulgaria

[7]Bäuerliche Erzeugergemeinschaft Schwäbisch Hall (BESH)

[8]Agricultural Technology Centre Augustenberg (LTZ), Germany

[9]Donau Soja, Austria

[10]Institute of Field and Vegetable Crops, Serbia

April 2021

Legumes Translated (Translating knowledge for legume-based farming for feed and food systems) has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 817634

Legumes Translated

Legumes Translated (Translating knowledge for legume-based farming for feed and food systems) is an international research and development project funded by the European Union through the Horizon 2020 Programme under grant agreement number 817634. The Legumes Translated research consortium comprises 17 partners in 9 countries.

Citation

Please cite this report as follows:

Notz, I., Alves, S., Barkas, D., Haase, T., Hargreaves, P., Hennessy, M. Iantcheva, A., Munder, I., Reckling, M., Recknagel, J., Rittler, L., Topp, K., Vasiljević, M., Wolf, F., Zimmer, C., Schuler, J., 2021. Integration of legume production at farm level. Available from www.legumestranslated.eu

Funded by the European Union

Legumes Translated

Contents

Introduction

The proportion of European arable land used for legumes has been negligible for decades. Despite the range of advantages legume cultivation can provide in for the environment, resource use and protein self-sufficiency, European farmers decide against legume integration in their crop rotations. The key drivers for this situation are mainly seen in the apparent poor economic performance of legumes due to low yields and prices of most legume crops and the availability of other sources of protein for livestock feed. What is often neglected in this simplistic assessment of legumes' profitability are the positive long-term impacts of legumes on productivity and the economic opportunities at farm level for the introduction of legumes. Therefore, an evaluation at farm level is necessary to assess reliably the economic performance and options for profitable and sustainable inclusion of legumes. This guide analyses knowledge and experiences on legume cultivation and integration in livestock feed rations of project partners of the EU Horizon 2020 project Legumes Translated. The purpose is to outline the economic effects of the integration of legumes in cropping systems and how the profitability at farm level is impacted. The economic validation of the real-life practices enables the revision of perceptions of the economic value of legumes on the crop level and expand this perspective to the rotational level. Legume-supported systems are compared to non-legume reference systems in terms of economic competitiveness and ecosystem service (ESS) provision. This enables the identification of trade-offs and the direct asessment of costs and benefits. The sections on feed economics reflect the value of alternative legumes in the partners' production systems. For pig production, different rations were assessed, based on experimental rations from the Legumes Translated partner BESH. For aquaculture, the some new formulas containing different locally grown legumes were assessed together with Legumes Translated partner NIREUS (now Avramar).

Materials

A substantial part of the analysis in this report is based on a set of data collected from the Legumes Translated network. Based on a structured data query that was sent out to all partners who represent actor groups and processed between September 2019 and March 2020, a diverse set of information on regional cropping systems including economic data was obtained. A detailed description of the data sources, collection and case studies is provided in Deliverable Report 5.2. In total, data from nine countries and 17 case study regions focusing on regionally different legumes and non-legumes crops was included in the analysis. For each case study region at least one pair of cropping systems including one rotation without legumes and at least one alternative legume-based rotation was compiled (Table 1, Table 2, Table 3). This data set enables the assessment of the economic potential of legumes' integration in example cropping systems in distinct European regions.

Table 1. Crop rotations from case study regions in Central East and Central West Europe. Legumes are highlighted in bold.[1]

Region	+/- legume	Crop 1	Crop 2	Crop 3	Crop 4	Crop 5	Crop 6
Arable cropping systems[2]							
Central East Europe							
BG, BG 31	-	WW	GM	SF			
	+	**FP**	WW	GM	SF		
	+	WW	SF	**FP**	GM		
BG, BG 32	-	WOR	WW	SF	GM		
	+	**SY**	WW	SF	WW		
BG, BG 33	-	WOR	WW	SF	GM		
	+	**CB**	WW	SF	WW		
RO, RO 11	-	GM	WW				
		GM	WW	**SY**			
RO, RO 21	-	GM	SF	WW			
	+	GM	WW	**SY**			
RS, RS 12	-	GM	WW				
	+	GM	WW	**SY**			
UA, Kyiv oblast	-	GM	SF	WW			
	+	GM	**SY**	SF	WW		
Central West Europe							
AT, AT 11	-	GM	GM	WW			
	+	**SY**	WW	GM			
AT, AT 12	-	GM	WW	SF			
	+	GM	WW	**SY**			
DE, DE 11	-	WW	WB	TR			
	+	WW	WB	**FP**	TR		
DE, DE 11	-	SU	WW	WB	GM		
	+	SU	WW	WB	**FB**		
DE, DE 13	-	GM	GM	WW	WOR		
	+	GM	GM	**SY**	WW	WOR	
DE, DE 13	-	GM	GM	WW	WOR		
	+	GM	GM	**SY**	WW	WOR	
DE, DE 40 (soil type 2)	-	WW	WB	WOR			
	+	WW	**FP**	WW	WB	WOR	
	+	WW	**SY**	WW	WB	WOR	
DE, DE 40 (soil type 3)	-	WR	WR	WOR			
	+	WR	**FP**	WR	WOR		
	+	WR	**L**	WR	WOR		
DE, DE 73	-	WOR	WW	WW	SB		
	+	WOR	WW	**FP**	WW	SB	

[1] AF, Alfalfa; CB, common bean; FB, faba bean; FP, field pea; GC, grass-clover; GM, grain maize; GR, grass; LU, lupin; SB, spring barley; SF, sunflower; SFB, spring feed barley; SM, silage maize; SMB, spring malt barley; SO, spring oat; SU, sugar beet; SY, soybean; WB, winter barley; WO, winter oat; WOR, winter oilseed rape; WR, winter rye; WT, winter triticale; WW, winter wheat; [2] cropping systems that only include grain crops were categorized as arable cropping systems.

Table 2. Crop rotations from case study regions in North-West and South Europe. Legumes are highlighted in bold.[1]

Region	+/- legume	Crop 1	Crop 2	Crop 3	Crop 4	Crop 5	Crop 6
Arable cropping systems[2]							
North-West Europe							
GB, UKM 7	-	WOR	WB	WO	SB	WB	
	+	WOR	WB	WO	**FP**	WB	
	+	WOR	WB	WO	**FB**	SB	
IE, IE 05, IE, 06	-	WB	WO	WW	WB	WOR	WW
	+	WB	WO	WW	**FB**	WW	
IE, IE 05, IE, 06	-	SMB	SO	SFB	SMB	SMB	
	+	SMB	**FB**	SO	SFB	SMB	
South Europe							
IT, ITH 4	-	GM	GM	GM			
	+	GM	**SY**				

[1] AF, Alfalfa; CB, common bean; FB, faba bean; FP, field pea; GC, grass-clover; GM, grain maize; GR, grass; LU, lupin; SB, spring barley; SF, sunflower; SFB, spring feed barley; SM, silage maize; SMB, spring malt barley; SO, spring oat; SU, sugar beet; SY, soybean; WB, winter barley; WO, winter oat; WOR, winter oilseed rape; WR, winter rye; WT, winter triticale; WW, winter wheat; [2] cropping systems that only include grain crops were categorized as arable cropping systems.

Table 3. Crop rotations for forage legumes in case study regions in Central West and North-West Europe. Legumes are highlighted in bold.[1]

Region	+/- legume	Crop 1	Crop 2	Crop 3	Crop 4	Crop 5	Crop 6
Forage cropping systems[3]							
Central West Europe							
DE, DE 40	-	WW	WR	SM	SM	SM	
	+	WW	WR	**AF**	**AF**	**AF**	
North-West Europe							
GB, UKM 9	-	GR	GR	GR	SB		
	+	**GC**	**GC**	**GC**	WW		
	+	**GC**	**GC**	**GC**	SB	**FP**/SB	WW
	+	**GC**	**GC**	**GC**	SB	**FP**	WW
	+	**GC**	**GC**	**GC**	SB	**FB**	WW
	+	**AF**	**AF**	**AF**	SB		
	+	WW	**GC**	**GC**	**GC**	SB	

[1] AF, Alfalfa; CB, common bean; FB, faba bean; FP, field pea; GC, grass-clover; GM, grain maize; GR, grass; LU, lupin; SB, spring barley; SF, sunflower; SFB, spring feed barley; SM, silage maize; SMB, spring malt barley; SO, spring oat; SU, sugar beet; SY, soybean; WB, winter barley; WO, winter oat; WOR, winter oilseed rape; WR, winter rye; WT, winter triticale; WW, winter wheat; [2] cropping systems that only include grain crops were categorized as arable cropping systems; [3] cropping systems which include at least one forage crop were categorized as forage cropping systems.

Consultations with project partners and associated stakeholders that are active in pig production (Schwäbisch Hall Producers) enabled the compilation of different and experimental rations for pig feeding which were economically assessed. For aquaculture, the project partner NIREUS (now AVRAMAR) provided new experimental feed formulas containing different locally grown legumes which allowed evaluating the profitability of regional legumes in fish production in contrast to conventional feed containing larger amounts of soybean.

Methods

Quantitative and qualitative analyses based on the introduced Legumes Translated case studies, project partner and stakeholder consultations and literature were conducted for the economic assessment of legume integration in farming systems,

The main indicator for the quantitative valuation were a set of gross margin (GM) calculations which are presented below (formula 1-9). Farm-level costs and benefits were depicted in these through production costs and revenues, reflecting yields and prices. The GM calculations were at first applied at the crop level to reconsider common negative perceptions of legumes' profitability compared to dominant major crops. An analysis of utilization and provision of farm resources enabled the identification of particular costs and benefits of legume production. Using an extended approach to the GM calculations the cropping systems with and without legumes from the Legume Translated data set were considered in order to include legumes' impacts comprehensively. The comparative analysis of reference cropping systems without legumes with legume-supported cropping systems enabled the legume-systems' profitability to be examined using economic benchmarks derived from th profitability of cropping systems without legumes. For expanding the assessment to social costs and benefits, analytical results on the provision of ESS of cropping systems were retrieved from Deliverable Report 5.2.[1] Based on these assessment results a trade-off analysis between economic performance and ESS was performed by calculating the costs of each unit of ESS provision (formula 10).

Gross margin (GM) calculations

Standard gross margin

The GM is firstly calculated at the level of single crops (GM_C). Equation (1) shows the calculation:

(1) $GM_C = R_C - C_{VAR}$

with R_C as the revenue of the crop based on yields and sale prices communicated by partners, calculated with equation (2) and the total variable costs C_{VAR}, calculated with equation (3):

(2) $R_C = Y_{MP} * P_{MP} + Y_{BP} * P_{BP}$

[1] A detailed description on the background and calculations of the relevant assessment indicators is offered in Deliverable Report 5.2.

(3) $C_{VAR} = C_{seed} + C_{fert} + C_{prot} + C_{MA} + C_{irrig} + C_{ins} + C_{drycle}$

The revenue of the crop is based on Y as the harvested matter yield(s) [t/ha] and P as the product price [€/t] of main-product (MP) and by-product (BP).

The total variable costs C_{VAR} include costs of seed (C_{seed}) [€/ha], fertilisers (C_{fert}) [€/ha], crop protection (C_{prot}) [€/ha], variable costs of machinery (C_{MA}) [€/ha] as indicated by partners based on national cost estimates, where applicable costs of irrigation (C_{irrig}) [€/ha], insurance (C_{ins}) [€/ha] and drying and cleansing costs (C_{drycle}) [€/ha]. Labour costs as well as subsidies are not included.

Rotational gross margin GM_R

The rotational gross margin - GM_R (equation (4)) - is subsequently calculated by dividing the sum of all GMs by the number of crops in the rotation (No_r). Considering the average GM per year also enables comparisons between crop rotations of different length.

(4) $GM_R = \sum_{crop1\text{-}i} GM_C / No_r$

Gross margin with subsidies

The standard GM is modified with the inclusion of subsidies following the main Common Agricultural Policy (CAP) instruments supporting legume cultivation. Two from the three instruments that are relevant for legume production in the 2014-2020 period[2] are included in the calculations.[3]

Under Pillar I, the voluntary coupled support (VCS) (Regulation (EU) No. 1307/2013, Art. 52 and 53) is an option for member states to support sectors that are particularly important for economic, social or environmental reasons and which face certain difficulties in their production. Protein crops and grain legumes are included in the range of commodities that still may be granted coupled support.[4] Member states' usage of VCS for legumes differ and are integrated in the calculation where used. The following incentives that take the form of annual payments per hectare from measures shown in Table 4 are considered.

[2] European Commission 2018. Report from the Commission to the Council and the European Parliament on the development of plant proteins in the European Union; https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52018DC0757.

[3] Greening is not included in the GM calculation, as in this instrument legume production is conceptualized as one of several possible conditions that have to be met in order to ensure a share of the payments within the first pillar. To include the effects from legume production an assessment on the farm-level would be necessary.

[4] European Union 2013. Regulation (EU) No. 1307/2013 of the European Parliament and of the Council of 17 December 2013 establishing rules for direct payments to farmers under support schemes within the framework of the common agricultural policy and repealing Council Regulation (EC) No. 637/2008 and Council Regulation (EC) No. 73/2009. Official Journal of the European Union L 347: 608–670.

Table 4. Overview on measures within the voluntary coupled support for protein crops in EU member states included in case studies[5]

Country	Measure
Ireland	Coupled Aid for Protein Crops
Bulgaria	Measure for Coupled Support for Protein Crops
Romania	Schema de sprijin cuplat în sectorul soiei (Coupled support scheme in the soya sector)
Italy	Colture proteiche nel Nord Italia (soia) (Protein crops in Northern Italy (soya))

In the CAP's Second Pillar, the Rural Development Programme (Regulation (EU) No. 1305/2013)[6] includes support to producer groups, organic farming and agri-environmental-climate measures. All three approaches can potentially be relevant for the support of legumes. Payments derived from agri-environmental-climate measures (AECM) (following Art. 28 of Regulation (EU) No. 1305/2013), which support legume production and are applicable for the rotations from the case studies, are included in the GM calculations according to the states' or regions' specifics.[7]

Following the Rural Development Programmes, agri-environmental measures in two German federal states could be included (Table 5). Both measures require the cultivation of at least five crops, including legumes. Each crop is not allowed to cover more than 30% and not less than 10%. The share of cereal crops is not allowed to exceed 66%.

Table 5. Overview on agri-environmental-climate measure relevant for legume cropping within Rural Development Programmes in EU member states included in case study

Country	Programme	Measure	Payment [€/year]
Germany, Baden-Württemberg	FAKT	Crop diversification	75
Germany, Hessen	HALM	Crop diversification	110

Payments from VCS (S_{VCS}) and agri-environmental-climate measures (S_{AEM}) were added to the crop revenue in the GM_C calculation as shown in equation (5).

(5) $GM_C = R_C + S_{VCS} + S_{AEM} - C_{VAR}$

Scenario gross margins

In order to examine possible development paths, two GMs were calculated including implications of price changes in legume crops as well as implications from carbon taxes.

[5] European Commission 2019. Voluntary coupled support. Review by the Member States of their support decisions applicable as from claim year 2019. In: Informative Note: September 2019.
[6] European Union 2013. Regulation (EU) No. 1305/2013 of the European Parliament and of the Council of 17 December 2013 on support for rural development by the European Agricultural Fund for Rural Development (EAFRD) and repealing Council Regulation (EC) No 1698/2005 Official Journal of the European Union L 347: 487-548
[7] Due to the focus on conventional crop production systems, only agri-environmental-climate measures from the Rural Development Programme are included.

Gross margin incorporating feed value

Besides the standard GM and the GM with subsidies, a GM with modified legume prices is calculated. This feed value price scenario assumes legume selling prices that are equivalent to their actual feed value. With the help of a German feed calculator for pork feed ingredients[8], adapted prices for legumes are provided for the GM calculation.[9] [10] Using current wheat and soybean purchase prices[11], the software calculates the equivalent economic value of other products such as lupin or pea on the basis of their most important contribution to pig feeds – which are the essential amino acid lysine and metabolizable energy. For ruminants, a different calculation is needed.

The legume revenue calculation is replaced with:

(6) $R_C = Y_{MP} * P_{LFV}$

with P_{LFV} as the legume selling price assumed to be equivalent to the legume feed value (LFV). All other equations are similar to equation (1), (3) and (4).

Gross margin with carbon tax[12]

Another GM is calculated under the assumption of a carbon tax. The carbon tax is levied on the use of all fossil carbon sources within the manufacturing process of synthetic nitrogen fertilisers. Emissions through the use of nitrogen fertiliser are not taken into acoount, hence nitrous oxide emissions are not included. To obtain carbon emissions from nitrogen fertiliser production (N_{fert} CO_2 eq), the applied synthetic nitrogen fertiliser ($N_{synfert}$) [kg/ha] is converted using a conversion factor of 5.62 CO_2 eq/kg fertiliser nitrogen.[13]

(7) $N_{fert}\, CO_2\, eq = N_{synfert} * 5.62$

Two levels of the CO_2-tax are assumed – one carbon tax of 150 €/t $CO_{2\ eq}$ (equation (8)) and one with 50 €/t $CO_{2\ eq}$ (equation (9)). These are additionally to total variable costs deducted from the revenue:

(8) $GM = R_C - C_{VAR} - N_{fert}\, CO_2\, eq * 0.15$

[8] Landesbetrieb Landwirtschaft Hessen (LLH) 2018. Berechnung der Preiswürdigkeit von Einzelfuttermitteln für Schweine nach der Austauschmethode Löhr. Excel-based calculation tool. Landesbetrieb Landwirtschaft Hessen. Available at: https://www.proteinmarkt.de/aktuelles/schweine/rationsberechnung

[9] Corresponding to the fact that low market value of legumes is particularly an issue for legumes other than soybean, the price variations were not assumed for soybean.

[10] Also no price variations for legumes harvested for forage were assumed as in these cases on-farm use is primarily given.

[11] Retrieved from Eurostat – Prices for toasted extracted soyabean meal and fodder wheat from 2018 from the respective countries. https://ec.europa.eu/eurostat/databrowser/view/APRI_AP_INA__custom_152018/default/table?lang=en.

[12] Further details on the applied scenario of a carbon tax can be also found in Deliverable Report 4.1.

[13] Kool, A., Marinussen, M., Blonk, H. 2012. LCI data for the calculation tool Feedprint for greenhouse gas emissions of feed production and utilization. GHG Emissions of N, P and K fertilizer production. Gouda, the Netherlands: Blonk Consultants.

(9) $GM = R_C - C_{VAR} - N_{fert}\ CO_2\ eq * 0.05$

Calculations of costs of each unit of ESS provision

In order to assess trade-offs between economic performance and ESS, foregone GM per unit of ESS provision ($Cost_{ESS}$) were calculated:

(10) $Cost_{ESS} = \frac{cGM}{cESS}$

with cGM as the change in the GM and cESS as the change in ESS provision from cropping system without legumes to cropping system with legumes.

Profitability of growing legumes

Crop level

The trend towards simplified cropping systems dominated by cereals is mainly reasoned by the short-term economic performance of different crops. Farmers focus on crops that ensure high revenues and mostly do not consider legumes as profitable crops. Agronomic challenges, such as generally lower revenues resulting from lower yield levels and related prices, yield instability or poor weed competition which are still relevant for legumes due to lacking breeding efforts in these crops, are the main reasons for their lower profitability as individual crops.

This unfavourable perception of the short-term economic performance of legumes impacts on the role legumes have today in agricultural systems in Europe. Low shares of arable land are used for legume cultivation which can also be seen in the case study regions of Legumes Translated.[14] Grain legume production in 11 out of the 17 regions is below 3%.

[14] Calculations based on data from Eurostat. European Commission, Brussels, Belgium. https://ec.europa.eu/eurostat; State Statistics Service of Ukraine. https://ukrstat.org/en/operativ/menu/menu_e/cg.htm; State Service of Ukraine Geodesy, Cartography and Cadastre.

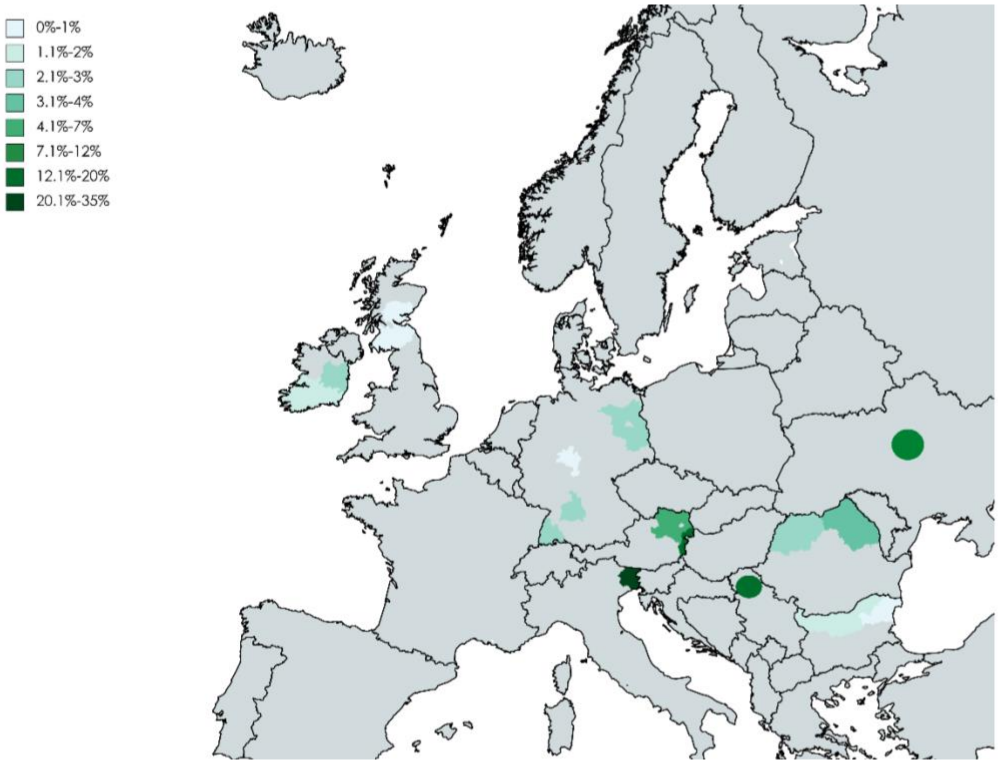

Figure 1. Proportions (%) of arable land used for grain legumes in 2019 for case study regions across Europe. These are NUTS 2 regions in cases where available (regions in Serbia and Ukraine marked separately)

The variation in the proportions of arable land used for grain legumes shows the differing importance of legume production in the countries and respective regions. It is noticable that the largest shares of arable land used for grain legumes are given in areas (ITH 4, AT 11, RS 12, Kyiv oblast) in which soybean are the most cultivated grain legume (Table 6).[15] This can also be taken as an indication of where and which grain legumes are regarded as economically profitable and therefore more popular in farmers' crop choices.

[15] Calculations based on data from Eurostat. European Commission, Brussels, Belgium. https://ec.europa.eu/eurostat; State Statistics Service of Ukraine. https://ukrstat.org/en/operativ/menu/menu_e/cg.htm; State Service of Ukraine Geodesy, Cartography and Cadastre.

Table 6. Crop choices and grain legume shares in the case study regions

Country	NUTS 2-region	Non-legume crops[1]	Legume crops[1]	% of grain legumes[2]	% of most commonly cultivated grain legume[2]
Arable cropping systems					
Central East Europe					
Bulgaria	BG 31	WW, GM, SF	FP	1.72	FP: 0.71
	BG 32	WOR, WW, SF, GM	SY	1.16	FP: 0.43
	BG 33	WOR, WW, SF, GM	CB	0.80	n.a.
Romania	RO 11	GM, WW	SY	2.41	SY: 2.08
	RO 21	GM, SF, WW	SY	3.36	SY: 2.71
Serbia	RS 12	GM, WW	SY	14.40	SY: 14.30
Ukraine	Kyiv oblast	GM, SF, WW, SF	SY	10.62	SY: 10.06
Central West Europe					
Austria	AT 11	GM, WW	SY	16.59	SY: 14.89
	AT 12	GM, WW, SF	SY	4.67	SY: 2.99
Germany	DE 11[3]	WW, WB, TR, SU, GM	FB, FP	2.16	SY: 0.93
	DE 13[3]	GM, WW, WOR	SY	2.16	SY: 0.93
	DE 13[3]	GM, WW, WOR	SY	2.16	SY: 0.93
	DE 40 (soil type 2)	WW, WB, WOR, WB	FP, SY	2.01	FP: 0.86
	DE 40 (soil type 3)	WR, WOR	L, FP	2.01	FP: 0.86
	DE 73[3]	WOR, WW, SB	FP	0.85	FB: 0.40
North-West Europe					
United Kingdom	UKM 7[3]	WOR, WB, WO, SB	FB, FP	0.30	n.a.
Ireland	IE 05, IE 06	WB, WO, WW, WOR, SMB, SO, SFB	FB	1.95	FB:1,84[4]
South Europe					
Italy	ITH 4	GM	SY	30.03	SY: 29.22
Forage cropping systems					
Central West Europe					
Germany	DE 40 (soil type 2)	WW, WR, SM	AF	-	-
North-West Europe					
United Kingdom	UKM 9	GR, SB, WW	AF, GC, FB, P/B, FP	-	-

[1] AF, Alfalfa; CB, common bean; FB, faba bean; FP, field pea; GC, grass-clover; GM, grain maize; GR, grass; LU, lupin; SB, spring barley; SF, sunflower; SFB, spring feed barley; SM, silage maize; SMB, spring malt barley; SO, spring oat; SU, sugar beet; SY, soybean; WB, winter barley; WO, winter oat; WOR, winter oilseed rape; WR, winter rye; WT, winter triticale; WW, winter wheat; [2] arable land in 2019; [3] due to limited data availability the numbers for this region are based on the NUTS 1 region; [4] due to limited data availability this value refers to arable land in 2018.

Table 7. Grain yield (t/ha), price (€/t) and gross margins (€/t) for different gross margin considerations

Region	Crop	Yield [t/ha]	Price [€/t]	GM (stand-ard) [€/ha]	Price feed calculator [€/t]	GM (feed value) [€/ha]	Subsidies (VCS) [€/ha]	GM (subsidies) [€/ha]
Arable cropping systems								
Central East Europe								
BG, BG 31	Pea	2.5	150	66	279	390	163	229
	Pea	2.5	150	68	279	391	90	158
BG, BG 32	Soybean	2.3	485	855			108	963
BG, BG 33	Common bean	2	150	-480			108	-372
RO, RO 11	Soybean	2	307	144			213	357
RO, RO 21	Soybean	2.8	307	185			213	398
RS, RS 12	Soybean	4.1	305	578				
UA, Kyiv oblast	Soybean	3	345	626				
Central West Europe								
AT, AT 11	Soybean	4.3	384	1124				
AT, AT 12	Soybean	3.0	390	667				
DE, DE 11	Pea	2.9	203	-92	256	60		
	Faba bean	2.9	185	-174	258	37		
DE, DE 13 (Kies)	Soybean	3.0	350	83				
DE, DE 13 (Löss)	Soybean	3.8	350	379				
DE, DE 40 (soil type 2)	Pea	3.0	193	121	256	309		
	Soybean	2.7	359	309				
DE, DE 40 (soil type 3)	Pea	2.5	193	60	256	217		
	Lupin	2.1	206	45	245	127		
DE, DE 73	Pea	4.0	200	-171	256	52		
North-West Europe								
GB, UKM 7	Pea	4.0	235	473	275	631		
	Faba bean	5.0	235	760	274	955		
IE, IE 05, IE, 06	Faba bean	5.4	190	197	305	819	291	488
	Faba bean	5.4	190	197	305	819	291	488
South Europe								
IT, ITH 4	Soybean	4.3	337	361			74	435

Considering the GM analysis of grain legumes from the case studies a diverse picture is shown (Table 7).[16] Overall the standard GMs range from -480 €/ha in Bulgaria for common bean to 1,124 €/ha in Austria for soybean. Distinguishing between the different

[16] Among the project partners of Legumes Translated, the gathered data on yield, prices and costs were referring to different times and scopes due to varying compilation approaches. This information is therefore not directly comparable, but it provides a range of orientation on what can be achieved in legume production. More details on the data background is presented in Deliverable Report 5.2.

legume species, most of the GMs of soybean are higher than the GMs of the other grain legumes, including pea, faba bean, lupin and common bean. This is mainly due to the higher market value of of soybean. Prices for pea range between 150 €/t in Bulgaria and 235 €/t in Scotland, for faba bean between 185 €/t in Germany and 235 €/t in Scotland. Prices for soybean range from 305 €/t in Serbia to 485 €/t in Bulgaria. The single examples of lupin in Germany and common bean in Bulgaria reported prices of 206 €/t and 150 €/t, respectively.

Besides prices, the GM is determined by yields and costs which are strongly impacted by environmental and agronomic conditions and the circumstances under which the data has been gathered (experimental plots or practical experience). The yield potential of grain legumes varies between the regions. The case studies show that faba bean production in North-West Europe is more beneficial than in Central Europe. Yields in excess of 5 t/ha display the high potential in Scotland and Ireland resulting in positive GMs. Soybeans were included in ten regions and are especially present in the eastern and southern regions where highest yields were achieved in Austria and Italy with 4.3 t/ha and in Serbia with 4.1 t/ha, ensuring high profitability.

For outlining the perceived unfavourable on-farm competitiveness of legumes, often the economic performance of major crops are compared to legumes. Despite the - in former work (Deliverable Report 4.1) - shown necessity to compare legumes with crops that have a similar agronomic role in the crop rotation, the comparison is here made with winter wheat to illustrate the common argumentation basis and due to the mostly common presence of winter wheat in all regions. The examples from the case studies where winter wheat is grown show that grain legumes other than soybean are less profitable in all regions (Table 8).[17] This is mostly due to lower yields resulting in low or even negative GMs of pea, faba bean, lupin and common bean. Prices of these legumes - which are between 150 €/t to 235 €/t - are comparable or slightly higher to the recorded wheat prices that range between 120 €/t to 170 €/t, but cannot compensate the lower yields and therefore result in GMs which are only a fraction of those from winter wheat.

With the exception of regions where soybean is grown profitably, no other single grain legume accounts for more than 2% of the cropped area. However, winter wheat accounts for at least 20% in almost all regions. In regions where soybean reaches GMs comparable to winter wheat, the share of soybean in arable land is considerable (more than 10%). In both case study regions in Austria, Ukraine, Serbia and the soybean example from Bulgaria, the regional GMs of winter wheat were considerably lower than from soybean. Considering the proportions of soybean and wheat (and spelt) in the total arable land, the results from Serbia with 14.30% vs. 21.11% and the Burgenland (AT 11) in Austria with 14.89% vs. 25.67% for soybean and wheat, respectively, also show the higher interest in this grain legume. Soybean prices which are twice as high as those of winter wheat strengthen the chances that soybean production is competitive with wheat production. Especially with the currently rising soybean price due to lower harvested

[17] Calculations based on data from Eurostat. European Commission, Brussels, Belgium. https://ec.europa.eu/eurostat; State Statistics Service of Ukraine. https://ukrstat.org/en/operativ/menu/menu_e/cg.htm; State Service of Ukraine Geodesy, Cartography and Cadastre.

production in the US and South America and rising demand from Asia, cropping decisions for soybean could be further promoted.[18]

Table 8. Wheat grain yield (t/ha), price (€/t) and standard gross margin (€/t) and wheat share of cropped area (%) in 2019. Wheat crops include spelt in some cases.

Region	Yield [t/ha]	Price [€/t]	GM (standard) [€/ha]	% of common wheat and spelt in arable land
Central East Europe				
BG, BG 31	5.5	135	456	n.a.
BG, BG 32	5.6	150	540	n.a.
BG, BG 33	5.4	150	205	37.25
RO, RO 11	6.0	156	464	16.56
RO, RO 21	5.9	156	361	12.48
RS, RS 12	6.4	144	183	21.11
UA, Kyiv oblast	6.0	164	432	14.67
Central West Europe				
AT, AT 11	7.2	170	565	25.67
AT, AT 12	5.0	170	440	23.74
DE, DE 11	8.6	120	129	26.27
DE, DE 13 (Kies)	7.0	170	295	26.27
DE, DE 13 (Löss)	9.0	170	564	26.27
DE, DE 40 (soil type 2)	6.5	159	445	17.58
DE, DE 73	8.4	165	308	16.06
North-West Europe				
IE, IE 05, IE 06	10.3	155	597	15.10

Feed value

As described above, low producer prices are a main argument against further cultivation of grain legumes other than soybean. Insufficient market structures are one essential barrier for reaching reasonable price levels.[19] As a consequence the actual value of the crops in terms of their value-determining ingredients is often considerably higher which can be shown when related to reference feed components in wheat or soybean.[20] Considering the case studies from Legume Translated, the extent of the under-valuation varied depending on the reported legume market prices and the national prices for wheat and soybean that were taken as a basis in the calculation.[21] The greatest effect was found for pea in Bulgaria for which the calculated feed value was almost double as high as the market price. A very high soybean meal price of 419 €/t and the very low market price of

[18] Weber, M. 2021. Teures Soja – das sind die Alternativen. In Top Agrar, 3, p. S20-S23.
[19] Kezeya Sepngang, B., Stute, I., Stauss, W., Schäfer, B.C., Mergenthaler, M., 2018. Möglichkeiten zur Bildung von verwertungsorientierten Preisindikatoren für Futtererbsen und Ackerbohnen im Vergleich zur veröffentlichten Marktpreisberichterstattung. Berichte über Landwirtschaft, Zeitschrift für Agrarpolitik und Landwirtschaft; https://buel.bmel.de/index.php/buel/article/view/226/pdf.
[20] Preissel, S., Reckling, M., Bachinger, J., Zander, P. 2017. Introducing legumes into European cropping systems: farm-level economic effects, in: Murphy-Bokern, D., Stoddard, F.L., Watson, C.A. (Eds.), Legumes in cropping systems. CABI Publishing, 209–225.
[21] Prices for alternative feed ingredients (toasted extracted soybean meal and fodder wheat) were retrieved from Eurostat, 2018; https://ec.europa.eu/eurostat/data/database.

pea caused the extreme difference. Pea market prices in Germany were between 20%-25% lower with 193 €/t, 200 €/t and 203€/t compared to 256 €/t for the calculated feed value. The difference between feed value with 275 €/t and market price with 235 €/t was smallest in the case study from Scotland.

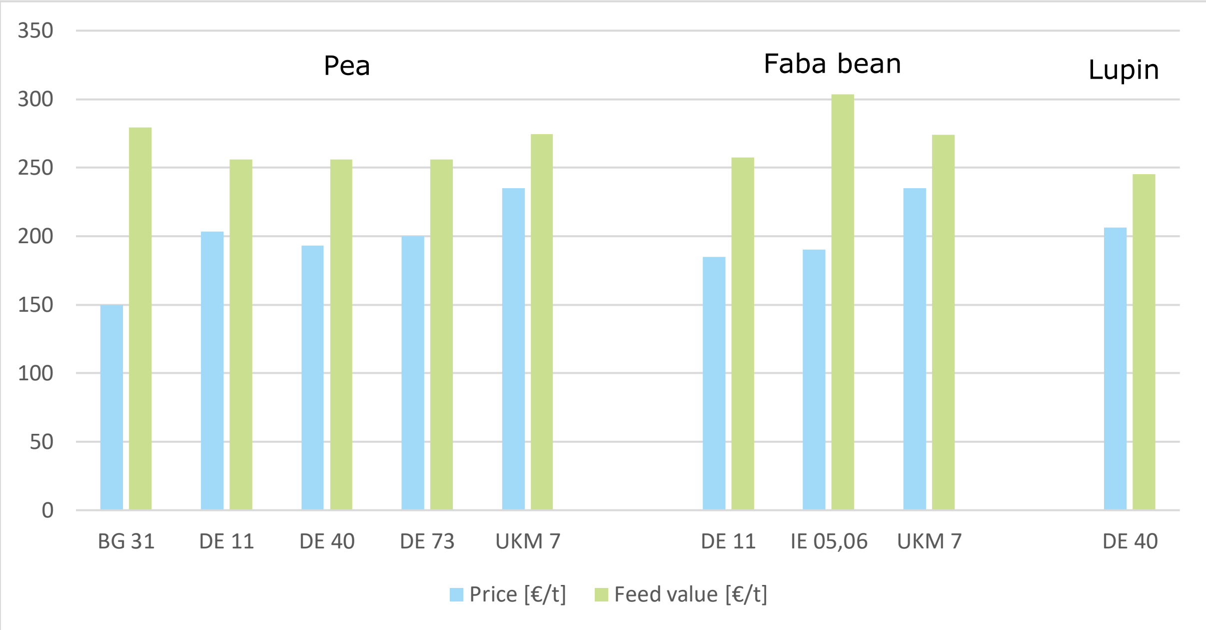

Figure 2. Reported market prices of pea, faba bean and lupin and calculated feed value based on purchase prices for alternative feed ingredients

The faba bean price reported from German project partners was lowest with 185 €/t. The Irish price with 190 €/t was slightly higher and in both cases the comparison with the calculated feed value showed a significant under-valuation of faba bean on markets. While the German price was 28 % lower than the calculated feed value which was equal to 258 €/t, the Irish example showed an even more extreme difference with a 38% higher feed value, adding 115 €/t to the reported price. Higher prices for the alternative feed ingredients with 409 €/t for soybean meal and 221 €/t for fodder wheat were the reason for the severe gain for faba bean in the feed value. In Scotland, the reported price for faba bean was also only 14 % lower than the calculated feed value. The lupin price of 206 €/t given from the case study in Brandenburg was 39 €/t lower than its calculated equivalent economic value of 245 €/t, which shows the same issue for lupin in receiving adequate prices on markets.

When these feed values were integrated in the GM calculations of the grain legumes, it had significant effects. The results from Table 7 show that all modified GMs based on feed value were raised to positive values and some legume crops were now competitive with the economic performance of winter wheat. Faba bean production in Ireland became extremely profitable due to the highly raised price and the already high yield. In Scotland the pea and faba bean GMs were also increased by 158 €/ha and 195 €/ha, respectively. Concerning the economic performance of pea in Bulgaria, the substitution of market price with feed value changed the GM from below 70 €/ha to over 390 €/ha, displaying the extreme difference between reported price and calculated feed value.

The analysis showed how the interest and incentives for using locally grown grain legumes as feed ingredients is directly connected to the development of purchase prices for soybean meal and fodder wheat. Considering the current price developments of soybean with sharply increasing prices that are expected to continue because of the growing international demand, it is likely that other grain legumes become more and more interesting as an alternative, which will also impact their price levels. Moreover, the market demand for genetically modified free products is another driver for better market values of faba bean, pea and lupin.

Subsidies

Besides the fictional application of prices according to the feed value of grain legumes, the lower GM of legumes can also be reduced with subsidies. Farmers noticeably react to the introduction of subsidies on legume cultivation, which can be seen in the effects from the reform of the CAP in 2013. Following the introduction of several instruments that support legumes as part of the greening or legume-supporting agri-environmental and climate measures that can be part of national Rural Development Programmes, areas cultivated with legumes have increased when considering whole Europe.[22] However, the fragility and dependence on the specificities of the funding measures, is also clearly visible when considering the change of the greening with the ban of plant protection agents on Ecological Focus Areas in 2018. In the example of Germany the share of pea and lupin on arable land promptly decreased again.[23]

The changes of the CAP allowed European member states also to provide VCS for legumes under Pillar I since 2014. The measure was heterogeneously implemented across the member states and, among the considered case studies, four countries have introduced the VCS. The annually adaptions of the payment height are adjusted to total budget and number of applicants and vary in the case studies between payments of 74 €/ha (Italy) up to 291 €/ha (Ireland).[24] Considering the realized GMs including the VCS, the already high GMs of soybean in Italy and Bulgaria increase even more. Also the Romanian soybean examples and the Irish results for faba bean benefit considerably from the payments which are particularly high in these countries.

By adding the Romanian and Irish coupled supports of 213 €/ha and 291 €/ha, respectively, the grain legumes become competitive with the economic performance of the regionally grown winter wheat. The examples show that the additional incentive mechanisms with the VCS are a useful tool under current regional cropping conditions in order to support legumes' profitability and decrease the comparative advantage of cereal crops.

[22] European Commission 2018. Report from the Commission to the Council and the European Parliament on the development of plant proteins in the European Union; https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52018DC0757.

[23] Böhm, H. Dauber, J., Dehler, M., Gallardo, D., de Witte, T., Fuß, R., Höppner, F., Langhof, M., Rinke, N., Rodemann, B., Ruehl, G., Schittenhelm, S. 2020. Crop rotations with and without legumes: a review. Journal für Kulturpflanzen 72, 489-509. doi: 10.5073/JFK.2020.10-11.01.

[24] The case study in Italy refers for the soybean cultivation to the year of 2019. The Irish case study is based on average data from 2015-2019, which is why the payments for the VCS was also averaged over this period.

Conclusion on crop level profitability

The analysis of legume GMs from the Legumes Translated data set showed that there is a GM deficit for most legumes other than soybean. This remaining GM deficit can be compensated in the short-term with policy support such as the VCS and in the long-term with the development of value chains which has positive effects on legume market prices as well as breeding efforts for increasing legume yields. However, for a reliable assessment of legumes profitability it is needed to integrate legumes' pre-crop effects and resulting resource benefits to farmers which are discussed in the following.

Allocation of farm resources

The profitability of different production activities at the farm level is impacted by the allocation of farm resources to these activities and their interactions. When considering legume production and farm resources it is essential to include the effects from agro-ecological processes, which are inherent to legumes as these are having significant impacts on the consumption as well as expansion of a range of farm resources. The following section discusses the implications of four key processes of legumes – biological nitrogen fixation (BNF); weed, disease, pest suppression; soil improvement and protein production – and their implications on farm resources contrasting to other crop production activities. Next to economic implications this also influences other dimensions of sustainability of farming (see also section 'ESS provided by legumes').

The most prominent advantage of legumes is their capacity for biological nitrogen fixation. By forming a symbiotic relationship with soil bacteria, legumes are nitrogen self-sufficient and require only little or no nitrogen fertiliser. In addition, the subsequent crop in the crop rotation also benefits from the BNF process, as nitrogen is left behind with the crop residues of the legumes which is then available for the following crop. Therefore there is a substantial potential for reducing nitrogen fertiliser inputs in cropping systems including legumes. The amount of nitrogen fixed depends on environmental factors and legume species, as field pea for example was found to fix on average 130 kg/ha while for faba bean it was 153 kg/ha.[25] Forage legumes are able to fix even more nitrogen because of their high biomass production and longer growth period. [26] Comparing a grain legume to a cereal crop, nitrogen fertiliser savings of 100 kg/ha up to 200 kg/ha can be achieved, considering alone the year of the legume cultivation.[27] The absence of nitrogen fertiliser use or the minimal application of some starter nitrogen fertiliser – which some farmers and agronomists recommend[28] – contrasts sharply with the nitrogen intensive management practices in cereals. This was also visible in the cropping data provided by

[25] Peoples, M.B., Brockwell, J., Herridge, D.F., Rochester, I.J., Alves, B.J.R., Urquiaga, S., Boddey, R.M., Dakora, F.D., Bhattarai, S., Maskey, S.L., Sampet, C., Rerkasem, B., Khan, D.F., Hauggaard-Nielsen, H., Jensen, E.S. 2009. The contributions of nitrogen-fixing crop legumes to the productivity of agricultural systems. Symbiosis 48, p. 1–17. doi: 10.1007/BF03179980.

[26] Carlsson, G., Huss-Danell, K. 2003. Nitrogen fixation in perennial forage legumes in the field. *Plant and Soil, 253*(2), 353-372. doi:10.1023/A:1024847017371.

[27] Bues A., Preissel, S., Reckling, M., Zander, P., Kuhlmann, T., Topp, K., Watson, C., Lindström, K., Stoddard, F.L., Murphy-Bokern, D. 2013. The environmental role of protein crops in the new common agricultural policy, in: Agriculture and rural development. European Parliament, Brussels; http://edepot.wur.nl/262633.

[28] Watson, C., Reckling, M., Preissel, S., Bachinger, J., Bergkvist, G., Kuhlman, T., Lindström, K., Nemecek, T., Topp, C., Vanhatalo, A., Zander, Z., Murphy-Bokern, D., Stoddard, F. 2017. Grain legume production and use in European agricultural systems. Adv. Agron. 144, 235–303.doi: 10.1016/bs.agron.2017.03.003.

Legume Translated project partners (Table 9). While in most legumes zero nitrogen fertiliser was applied, the application rates in winter wheat was up to 235 kg/ha.

Table 9. Nitrogen fertilisation of legumes and winter wheat in case study regions

Crop	Yield [t/ha]	Regional mineral N fertiliser applied [kg/ha]
Soybean (BG, RO, RS, AT, DE, IT)	2.0 - 4.3	0 - 60
Faba bean (DE, GB, IE)	2.9 - 5.4	0
Pea (BG, DE, GB)	2.5 - 4.0	0 - 22
Lupin (DE)	2.1	0
Common bean (BG)	2.0	70
Forage legumes, dry matter (DE, GB)	6 – 13.0	0 - 14
Winter wheat (all except Italy, Scotland)	4.7 - 10.25	81 - 235

Considering the fertiliser savings in the crop following the legume, a number of surveys among farmers and experts and research efforts have been undertaken to generally assess the saving amount. Reductions between 20-32 kg/ha are mostly reported in literature,[29] [30] [31] however, actual values depend on region-specific growing conditions and the trade-off that is made between securing maximum yields and maximizing fertiliser savings.[32] If nitrogen fertilization is significantly reduced in the subsequent crop, the yield benefit is smaller, but if nitrogen fertilisation is kept at the same level as without legumes, the yield benefit can be raised to highest levels. Current prices of nitrogen fertilisers are highly relevant in this consideration and therefore ultimately determine the value of the BNF. In practice, farmers not always take the nitrogen effect of legumes into account for the management of the subsequent crops and hence do not adapt the fertilization rates. However, with rising costs of crop inputs this is likely to change and the resource savings on a farm through the reduced need for purchases and application of nitrogen fertiliser are higher valued.

Legumes are also considered to have resource-conserving effects with respect to the use of pesticides. Following the break-crop effect, the risk of weed, pest and disease development is reduced when legumes are integrated into crop rotations. Life cycles of diseases can be broken and pressures from weed and pests are minimized due to the susceptibility of legumes to different pathogens. This benefit is not legume-specific, it can also be achieved by other break crops as for example sunflower or rapeseed. But in the context of repeated cereal cropping, the diversification with legumes was reported to allow the saving of one fungicide application and one herbicide application in the cereal

[29] Alpmann, D., J. Braun and B.C. Schäfer, 2013. Analyse einer Befragung unter erfolgreichen Körnerleguminosenanbauern im konventionellen Landbau. Erste Ergebnisse aus dem Forschungsprojekt LeguAN. In: DLG Wintertagung, Im Fokus: Heimische Körnerleguminosen vom Anbau bis zur Nutzung. Berlin: pp: 20.

[30] Preissel, S. et al. 2017. Introducing legumes into European cropping systems: farm-level economic effects, in: Murphy-Bokern, D., Stoddard, F.L., Watson, C.A. (Eds.), Legumes in Cropping Systems. CABI Publishing, p. 209–225

[31] Zerhusen-Blecher, P., Stevens, K., Schäfer, B.C., Braun, J. 2019. Wirtschaftlichkeit. Erbsen und Ackerbohnen – lohnenswerte Kulturen; www.demoneterbo.agrarpraxisforschung.de/fileadmin/user_upload/Bilder/Artikel_Wirtschaftlichkeit_2016_2017_190121.pdf.

[32] Preissel, S., Reckling, M., Schläfke, N., Zander, P. 2015. Magnitude and farm-economic value of grain legume pre-crop benefits in Europe: a review. Field Crops Res. 175, 64–79. doi:10.1016/j.fcr.2015.01.012.

crop following the legume which enables pesticide costs reductions of 20-25% in the succeeding crop.[33] Although the use of pesticides in the year of grain legumes should not be underestimated since the majority of broad-leaved break crops receive similar amounts of pesticides as most cereals[34], the reductions in the following crop have the potential for overall farm resource savings.

Agro-ecological processes inherent to legumes also have specific effects on soils, thereby impacting the most important asset of a farmer. Beneficial contributions of legumes to soil organic matter and short-term carbon storages, advantages to soil structure and composition, fostering water-absorbing capacities and reducing risks for soil erosion are possible due to legume features as deep rooting of some legume species, low C/N ratios of legume residues (that are more similar to that of soil properties than of other non-legume crops) and legume-specific changes in soil microorganisms.[35] [36] Moreover, legumes enable an increased mobilization of soil phosphorus, improving the nutrient availability in the soil for following crops.[37] These soil improving effects facilitate and are themselves further supported by reduced tillage operations before and after legumes. Reduced tillage systems then again allow savings of farm resources in machinery, energy use and labour. The cost saving potential depends on the actual adaption of management practices, which can vary from reduced standard tillage operations following the legume crop to applying conservation tillage on the whole farm.[38] When taking into account reduced tillage operations in the crop following the legume, savings of 20-60 €/ha can be assumed.[39] It was also shown that the introduction of spring sown legumes into cropping systems focusing on winter crops can balance demand for labour in autumn and spring and reduces workload peaks on farms.[40]

The above described processes were also summarized under the pre-crop effect of legumes, including nitrogen and break-crop effect[41] and provide yield benefits for the subsequent crops in rotations as well as the described potential for resource savings on a farm. The process of the protein synthesis on the other hand, enhance farm resources, namely the on-farm supply with protein. Grain legumes have a high protein content ranging from 20% to 25% in common bean, lentil and pea and to over 40% increasing up to 45% in soybean and yellow lupin. Compared to cereals with a protein content of

[33] Zander, P. Amjath-Babu, T.S., Preissel, S., Reckling, M., Bues, A., Schläfke, N., Kuhlman, T., Bachinger, J., Uthes, S., Murphy-Bokern, D., Stoddard, F., Watson, C.A. 2016. Grain legume decline and potential recovery in European agriculture: a review. Agron. Sust. Dev. 36,1–20. doi: 10.1007/s13593-016-0365-y.

[34] Kirkegaard, J.A., Christen, O., Krupinsky, J., Layzell, D., 2008. Break crop benefits in temperate wheat production. Field Crops Res. 107, p. 185–195, http://dx.doi.org/10.1016/j.fcr.2008.02.010.

[35] Jensen, E.S., Peoples, M.B., Boddey, R.M., Gresshoff, P.M., Hauggaard-Nielsen, H., Alves, B.J.R., Morrison, M.J. 2011. Legumes for mitigation of climate change and the provision of feedstock for biofuels and biorefineries. A review. Agronomy for Sustainable Development 32, 329–364. doi:10.1007/s13593-011-0056-7.

[36] Watson, C., et al. 2017. Grain legume production and use in European agricultural systems. Adv. Agron. 144, 235–303.doi: 10.1016/bs.agron.2017.03.003.

[37] Watson, C., et al. 2017; see above.

[38] Preissel, S., et al. 2015. Magnitude and farm-economic value of grain legume pre-crop benefits in Europe: a review. Field Crops Res. 175, 64–79. doi:10.1016/j.fcr.2015.01.012.

[39] Alpmann, D., Schäfer, B.C. 2014. Der Wert von Körnerleguminosen im Betriebssystem. UFOP-Praxisinformation. Union zur Förderung von Öl- und Proteinpflanzen e. V.; https://www.ufop.de/files/9013/9593/2050/RZ_UF-OP_1157_Praxis_Koernerleguminosen_web.pdf.

[40] von Richthofen, J.S. 2006. Economic impact of grain legumes in European crop rotations. Grain Legumes 45, p. 16–19.

[41] Chalk, P.M. 1998. Dynamics of biologically fixed N in legume-cereal rotations: a review. Aust. J. Agric. Res. 49, p. 303–316. doi: 10.1071/A97013.

7% to 17% and a differing amino acid profile, legumes present a highly valuable resource for food and feed.[42] The – in comparison to cereals – increased potential for high-quality protein provision was also visible in the Legumes Translated data set. Despite lower yields levels, soybean protein outputs were in all case studies higher compared to the regional protein yield of wheat (Figure 3).

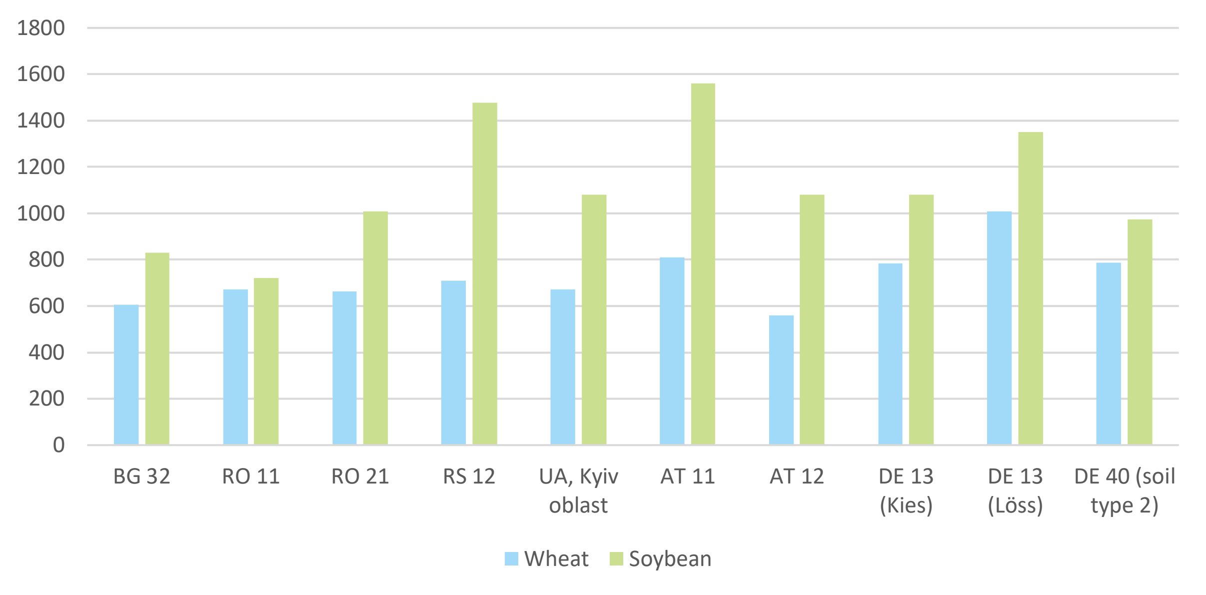

Figure 3. Protein output (kg/ha) of soybean and wheat in case study regions

The provision of plant proteins for animal feed is particularly relevant for mixed farms. Additional purchases of protein feed can be reduced which becomes increasingly valuable with rising prices for common feed ingredients as soybean meal which can currently be observed. Hence, the interest and benefits of on-farm feeding of home-grown legumes is presently growing and the potentials of legume supported animal feeding are manifold discussed (see also sections 'Practical experience from actor groups on feeding legumes in pig sector' and 'Practical experience from actor groups on feeding legumes in aquaculture').

Conclusion on allocation of farm resources

Legume production is beneficial for the resource use at the farm level. Several agro-ecological processes are enabling farm resource savings of seasonal inputs as nitrogen fertilisers, plant protection products or labour intensity, but also of long-term assets as soil structure or nutrient conservation. The legume inherent processes also foster an increased availability of farm resources as protein (feed). Considering the farm economic productivity, these resource expansions and savings have considerable beneficial effects, particularly when compared to other production activities. However, the comprehensive effects are only visible at the farm level which is why the economic evaluation of legume production also has to be implemented on the scale of rotations rather than of single crops.

[42] Watson, C., et al. 2017. Grain legume production and use in European agricultural systems. Adv. Agron. 144, 235–303.doi: 10.1016/bs.agron.2017.03.003.

Cropping system level

In order to implement a reliable assessment of legume profitability, the economic evaluation was extended to the rotational context. Thereby legumes' impacts with yield effects and hence increased revenues in following crops and savings in production costs due to nitrogen and break crop effects were reflected in the calculations. The Legume Translated cropping systems were evaluated with the set of GM calculations to assess the economic performance of legume-supported cropping systems compared to reference cropping systems without legumes. An overall average was calculated to summarize effects and local considerations were applied to assess the economic potential of alternative cropping strategies in the case study regions.

Gross margin calculations

Assessment across all regions

Considering at first the overall picture from the arable cropping systems, the standard GMs of the legume-supported rotations are on the same level as compared to the rotations without legumes. On average across all regions cropping systems with legumes had a 3% lower standard GM, a minimal difference that is not relevant (Table 10, Table 11, Table 12, Table 13; percentages not shown in the tables). When taking into account the modifications of the standard GMs, the GMs increased and were 5% higher than those of the non-legume rotations when considering the feed value. The advantage increased up to 8% higher GMs when including the legume relevant subsidies of VCS and AECM. When levying a carbon tax of 150 €/t $CO_{2\ eq}$, the economic performance of the cropping systems with legumes became considerable more profitable with on average 17% higher GMs. However, a lower carbon tax of 50 €/t $CO_{2\ eq}$ led to no significant difference between the cropping systems with and without legumes.

The forage cropping systems including legumes had on average distinctly higher standard GMs. The mean difference from all comparisons showed almost 50% higher gross margins. In five out of seven compared sets legume-supported cropping systems had higher rotational gross margins. This economic advantage of legume-supported cropping systems was even higher when applying the scenarios of legume prices that are raised to their actual feeding value or carbon taxes. Cropping systems achieved 51% higher GMs in the feed value scenario and even 68% and 152% higher GMs in the scenarios of carbon taxes with a height of 50 €/t $CO_{2\ eq}$ and 150 €/t $CO_{2\ eq}$, respectively.

Table 10. Gross margins of arable cropping systems with and without legumes in case study regions in Central East Europe

Region	+/- leg.	C 1	C 2	C 3	C 4	C 5	C 6	GM (stand-ard) [€/ha]	GM (feed value) [€/ha]	GM (sub-sidies) [€/ha]	GM (CO_2tax I) [€/ha]	GM (CO_2tax II) [€/ha]
Arable cropping systems												
Central East Europe												
BG, BG 31	-	WW	GM	SF				472	472	472	352	432
	+	FP	WW	GM	SF			366	447	407	280	338
	+	WW	SF	FP	GM			394	475	417	308	365
BG, BG 32	-	WOR	WW	SF	GM			656	-	656	555	622
	+	SY	WW	SF	WW			643	-	670	596	627
BG, BG 33	-	WOR	WW	SF	GM			589	-	589	487	555
	+	CB	WW	SF	WW			-71	-	-43	-166	-102
RO, RO 11	-	GM	WW					266	-	266	161	231
		GM	WW	SY				256	-	327	190	234
RO, RO 21	-	GM	SF	WW				540	-	540	470	516
	+	GM	WW	SY				605	-	676	535	582
RS, RS 12	-	GM	WW					361	-	-	266	329
	+	GM	WW	SY				612	-	-	535	586
UA, Kyiv oblast	-	GM	SF	WW				650	-	-	556	619
	+	GM	SY	SF	WW			683	-	-	608	658

AF, Alfalfa; CB, common bean; FB, faba bean; FP, field pea; GC, grass-clover; GM, grain maize; GR, grass; LU, lupin; SB, spring barley; SF, sunflower; SFB, spring feed barley; SM, silage maize; SMB, spring malt barley; SO, spring oat; SU, sugar beet; SY, soybean; WB, winter barley; WO, winter oat; WOR, winter oilseed rape; WR, winter rye; WT, winter triticale; WW, winter wheat.

Table 11. Gross margins of arable cropping systems with and without legumes in case study regions in Central West Europe

Region	+/- leg.	C 1	C 2	C 3	C 4	C 5	C 6	GM (stand-ard) [€/ha]	GM (feed value) [€/ha]	GM (sub-sidies) [€/ha]	GM (CO_2tax I) [€/ha]	GM (CO_2tax II) [€/ha]
Arable cropping systems												
Central West Europe												
AT, AT 11	-	GM	GM	WW				440	-	-	298	393
	+	SY	WW	GM				688	-	-	605	660
AT, AT 12	-	GM	WW	SF				507	-	-	403	472
	+	GM	WW	SY				544	-	-	457	515
DE, DE 11	-	WW	WB	TR				172	172	172	107	150
	+	WW	WB	FP	TR			136	173	211	92	121
DE, DE 11	-	SU	WW	WB	GM			331	331	331	283	315
	+	SU	WW	WB	FB			214	266	289	174	201
DE, DE 13 (Kies)	-	GM	GM	WW	WOR			326	-	326	206	286
	+	GM	GM	SY	WW	WOR		284	-	359	192	253
DE, DE 13 (Löss)	-	GM	GM	WW	WOR			711	-	711	574	665
	+	GM	GM	SY	WW	WOR		652	-	727	545	616
DE, DE 40 (soil type 2)	-	WW	WB	WOR				448	448	-	331	409
	+	WW	FP	WW	WB	WOR		388	426	-	298	358
	+	WW	SY	WW	WB	WOR		431	431	-	341	401
DE, DE 40 (soil type 3)	-	WR	WR	WOR				390	390	-	291	357
	+	WR	FP	WR	WOR			332	371	-	258	307
	+	WR	L	WR	WOR			328	349	-	254	303
DE, DE 73	-	WOR	WW	WW	SB			250	250	250	107	202
	+	WOR	WW	FP	WW	SB		190	234	300	76	152

AF, Alfalfa; CB, common bean; FB, faba bean; FP, field pea; GC, grass-clover; GM, grain maize; GR, grass; LU, lupin; SB, spring barley; SF, sunflower; SFB, spring feed barley; SM, silage maize; SMB, spring malt barley; SO, spring oat; SU, sugar beet; SY, soybean; WB, winter barley; WO, winter oat; WOR, winter oilseed rape; WR, winter rye; WT, winter triticale; WW, winter wheat.

Table 12. Gross margins of arable cropping systems with and without legumes in case study regions North-West and South Europe

Region	+/-leg.	C 1	C 2	C 3	C 4	C 5	C 6	GM (stand-ard) [€/ha]	GM (feed value) [€/ha]	GM (sub-sidies) [€/ha]	GM (CO_2tax I) [€/ha]	GM (CO_2tax II) [€/ha]
Arable cropping systems												
North-West Europe												
GB, UKM 7	-	WOR	WB	WO	SB	WB		819	819	-	683	774
	+	WOR	WB	WO	FP	WB		820	852	-	718	786
	+	WOR	WB	WO	FB	SB		831	870	-	733	798
IE, IE 05, IE, 06	-	WB	WO	WW	WB	WOR	WW	502	502	502	333	445
	+	WB	WO	WW	FB	WW		464	589	523	332	420
IE, IE 05, IE, 06	-	SMB	SO	SFB	SMB	SMB		337	337	337	218	298
	+	SMB	FB	SO	SFB	SMB		360	484	418	263	328
South Europe												
IT, ITH 4	-	GM	GM	GM				292	-	292	91	225
	+	GM	SY					562	-	599	459	528

AF, Alfalfa; CB, common bean; FB, faba bean; FP, field pea; GC, grass-clover; GM, grain maize; GR, grass; LU, lupin; SB, spring barley; SF, sunflower; SFB, spring feed barley; SM, silage maize; SMB, spring malt barley; SO, spring oat; SU, sugar beet; SY, soybean; WB, winter barley; WO, winter oat; WOR, winter oilseed rape; WR, winter rye; WT, winter triticale; WW, winter wheat.

Table 13. Gross margins of forage cropping systems with and without legumes in case study regions in Central West and North-West Europe

Region	+/-leg.	C 1	C 2	C 3	C 4	C 5	C 6	GM (stand-ard) [€/ha]	GM (feed value) [€/ha]	GM (sub-sidies) [€/ha]	GM (CO_2tax I) [€/ha]	GM (CO_2tax II) [€/ha]
Forage cropping systems												
Central West Europe												
DE, DE 40 (soil type 2)	-	WW	WR	SM	SM	SM		420	-	-	336	392
	+	WW	WR	AF	AF	AF		360	-	-	320	347
North-West Europe												
GB, UKM 9	-	GR	GR	GR	SB			128	128	-	62	106
	+	GC	GC	GC	WW			266	266	-	232	255
	+	GC	GC	GC	SB	FP/SB	WW	218	218	-	186	208
	+	GC	GC	GC	SB	FP	WW	211	211	-	178	200
	+	GC	GC	GC	SB	FB	WW	299	332	-	270	289
	+	AF	AF	AF	SB			5	5	-	1	3
	+	WW	GC	GC	GC	SB		213	213	-	174	200

AF, Alfalfa; CB, common bean; FB, faba bean; FP, field pea; GC, grass-clover; GM, grain maize; GR, grass; LU, lupin; SB, spring barley; SF, sunflower; SFB, spring feed barley; SM, silage maize; SMB, spring malt barley; SO, spring oat; SU, sugar beet; SY, soybean; WB, winter barley; WO, winter oat; WOR, winter oilseed rape; WR, winter rye; WT, winter triticale; WW, winter wheat.

Arable cropping systems

Central East Europe

In the seven different case studies results from Central East Europe that were provided from project partners in Ukraine, Bulgaria, Romania and Serbia, the majority of legume-supported rotations included soybean, displaying the high suitability of the crop to the agro-climatic conditions in many parts of Eastern European countries. On average across these regions, the cropping system with legumes had 9% lower standard GMs, 7% lower GMs in the scenario of a carbon tax of 50 €/t CO_{2eq} and 4% lower GMs when considering the legume feed value. The economic deficit was removed when including subsidies or levying a carbon tax of 150 €/t CO_{2eq}.

In four of the five examples including soybean, the standard GMs were higher or equivalent for the legume-supported rotations. In Serbia, the economic gain of expanding the two-year rotation of winter wheat and maize with soybean was particularly high due to an extreme yield benefit on the cereal crops. Moreover, reduced costs of crop protection for maize following soybean as well as the high profitability of soybean cultivation itself increased the rotational GM up to 612 €/ha. The Ukrainian as well as North East Romanian (RO 21) example showed also 12% and 5% higher standard GMs, respectively. In both cases the integration of soybean had also positive effects on the yield level of the following crops. In the Romanian case, this positive yield effect can outbalance the loss of higher earnings from sunflower compared to soybean which replaced the former. The Bulgarian soybean alternative rotation to the four-year non-legume rotation had a similar standard GM even though two profitable crops – winter rape and maize – were replaced in the legume-supported rotation. Here, the major contribution factor was the very high soybean price resulting in a very high GM. Contrary to this beneficial economic performance, the Bulgarian cropping systems involving pea and common bean were less profitable or even highly loss-making. This was mainly caused by low prices as well as low yields for pea and common bean. Also the additional substitution of a profitable year of maize in the common bean rotation was disadvantageous.[43] Expanding the three-year rotation of winter wheat-maize-sunflower with pea had positive effects on yield and could decrease the fertiliser costs of the following crops, however, these benefits could not offset the low GM of pea. The important role of the legume prices could be shown in this example when the pea price was replaced by the actual feed value – the rotational GM deficit was reduced from 106 €/ha to 25 €/ha or in case of the second pea alternative even turned into a (minimal) advantage of 3 €/ha. Including the VCS in the Bulgarian as well as Romanian examples that was paid for the respective years of the rotations, positive effects on GM deficits could be seen. However, due to the higher differences in the standard GM and the lower payments with 90 €/ha and 163 €/ha in Bulgaria compared with the 213 €/ha in Romania, the Bulgarian VCS could not compensate the difference to the non-legume rotation, leaving a deficit of 65 €/ha and 56 €/ha in the pea-rotations. Both Romanian soybean supported rotations had a considerable economic advantage when the subsidies

[43] There are more aspects in the Bulgarian example of the common bean-supported rotation that caused the extreme difference such as high differences in yield levels and in variable machinery costs between the legume-supported and non-legume rotation.

were included with 61 €/ha and 136 €/ha higher GMs, which shows the relevance of adequate payments when supporting legumes' profitability.

Central West Europe

In the broader region of Central West Europe cropping systems from Austria and Germany were considered in a total of six case study regions. In both countries, a range of legume species can be grown and the provided data also enclosed different cool-season grain legumes as well as soybean. The average results from the Central West Europe showed 8 % lower standard GMs for the cropping systems with legumes. This deficit could be slightly reduced to 6% lower GMs when levying a carbon tax of 50 €/t CO_{2eq}. When including the feed value and the higher carbon tax the GM level was on the same level as for the non-legume rotations. The inclusion of subsidies led to 5% higher GMs of the systems including legume.

The findings of a higher competitiveness of rotations including soybean compared to rotations including other legumes to the respective non-legume rotations were also supported in the examples from Central West Europe. Both Austrian case studies showed that the integration of soybean in cropping systems can improve the economic performance of non-legume rotations. The diversification of the cereal rotation in the Burgenland (AT 11) could increase the profitability due to a high GM of soybean caused by high yield and price and reduced production costs in winter wheat following soybean. In the example from Niederösterreich (AT 12) the substitution of sunflower with soybean increased the rotational GM by 38 €/ha, because of the higher price level of soybean compared to sunflower. These economic advantages of the soybean rotations in the Austrian case study regions were even higher with the carbon tax applied. Three soybean cropping systems in two German regions were also included in the data set. In the North-Eastern region of Brandenburg a three-year cereal and winter rapeseed based rotation was expanded with soybean and an additional year of winter wheat, resulting in a 4% lower standard GM. The minimal deficit was caused by a slightly lower GM of soybean compared to the other rotational crops that could not be compensated with saved production costs in the following winter wheat. Nevertheless, the only 17 €/ha lower rotational GM shows the potential of soybean integration in cropping systems in this region where it is still a rather novel crop. In the very Southern regions of Germany soybean cultivation is much more common. The provided soybean involving cropping systems from the area around Freiburg (DE 13) had – depending on the considered soil type – 8% and 13% lower standard GMs. However, including the support from the measure for crop diversification paid under the funding program FAKT, this deficit was offset and the systems with soybean were more profitable with 16 €/ha and 33 €/ha higher GM.[44]

Considering the cropping systems with legumes other than soybean the relative profitability to the respective non-legume cropping systems was less favourable. Especially the faba bean including system in Southern Germany (DE 11) performed worse

[44] As outlined in section Methods' the crop diversification measure requires the cultivation of at least five crops and each crop is not allowed to cover more than 30% and not less than 10%. Since these requirements can be met on the area of the whole farm, the additional assumption was made that a fifth crop is cultivated on top of the four crops in the rotation and the proportions are balanced.

than its reference system with a 35 % lower standard GM. The major contributory factor was the replacement of the highly profitable maize with faba bean which had a negative GM on the crop level. The other pair of cropping systems provided for this region, included a cereal rotation that was expanded by the introduction of pea. Despite yield benefits and reduced fertiliser costs in triticale following pea, the standard rotational GM was 21% lower in the legume-supported rotation due to the unprofitable GM of pea. The same effect was found for the other pea including examples from Hessen (DE 73) where the rotational GM was also reduced by 60 €/ha due to similar reasons and Brandenburg (DE 40) for both soil types. In Brandenburg another grain legume was included in the cropping system on the worse soil type. The lupin-supported rotation, however, also had a 16% lower GM, which illustrates reasons for the decreasing farmers' interest in a formerly relevant crop and declining lupin shares in cultivated areas in Brandenburg. Exchanging the provided prices for faba bean, pea and lupin with their calculated actual feed value resulted in a decrease of the GM from the legume-supported rotations and could raise the GM of the pea-supported rotation in Southern Germany (DE 11) to 173 €/ha, being equivalent to the reference rotation with 172 €/ha.

Not only the above mentioned FAKT program in Baden-Württemberg encloses the possibility to support legume cultivation, also the HALM program in Hessen offers the option to support crop diversification with legume crops. The even higher payment of 110 €/ha had a considerable effect on the GM of the pea including rotation and led to an economic advantage of 50 €/ha.[45]

North-West Europe

In North-West Europe, pea and faba bean are the most important spring-sown grain legumes and were both included in the provided cropping systems from the case study regions in Eastern Scotland and Southern Ireland combined with Eastern and Midland Ireland. Considering the average results from this part of Europe, there was no decrease in the standard GM found for cropping systems with legumes. When taking into account the feed value instead of the market prices of legumes 18% higher GMs were achieved. Applying the lower carbon tax, a minimal advantage of 2% higher GMs and 8% higher GMs when levying the higher carbon tax were found. Focusing on the Scottish cropping systems, it can be shown that the equal GM level of all three included rotations is given due to the comparable profitability of the included legumes to spring barley which they replace and their positive pre-crop effects on the following cereal. When exchanging the market price with the feed value, resulting in additional 40 €/t, the pea and faba bean rotations had 4% and 6% higher GMs, respectively. Including a carbon tax of 150 €/t $CO_{2\ eq}$ had a similar effect leading to 5% and 7% higher GMs.

The Irish six-year rotation focused on winter cereals, where winter rapeseed was changed by skipping one year of winter barley and substituting winter rapeseed with faba bean. This resulted in a 7% decreased standard GM. The major contributory factors for this 35 €/ha lower GM were the loss of one profitable year of winter barley and the - compared to winter rapeseed - lower GM of faba bean. In the second Irish example the focus was put on spring crops and the five-year cereal rotation was again diversified with

[45] Additional assumptions in order to grant the payments from the crop diversification measure were also made in this example.

faba bean that replaced one year of spring feed barley. This substitution improved the standard GM by 7%. Thanks to a significantly higher revenue of spring oats after faba bean than after spring malt barley the rotational GM could be increased by 22 €/ha. By inserting a break-crop before spring oat, it is possible to market oats as gluten free. This upgrade of the cereal to a premium grain enables a price increase of 48 €/t. When introducing the calculated faba bean feed value there was a high economic advantage of both spring bean supported rotations, with 87 €/ha and 146 €/ha higher GM. These strong effects were given as the calculated feed value and the declared market price of faba bean was very high (see section 'Crop level'). In Ireland there is also a VCS for protein crops, the Irish Protein Aid Scheme which was introduced in 2015. The average payment of the support in the 2015-2019 was 291 €/ha. Taking into account this financial support the GMs of the legume-supported rotations were 4% and 24% higher than the reference systems.

South Europe

A single example from South Europe could be included in the data set with the region of Friuli-Venezia Giulia in Northern Italy. The agricultural area in the region is mainly used for arable crops and pastures and soybean cultivation is very relevant as shown in section 'Crop level'.

In this case study region, two rotations were compared using a three-year maize monoculture as a reference system and a two-year soybean-maize rotation as an alternative. Considering the standard GM it was shown that the legume-rotation had a very high economic advantage, resulting in an almost double as high GM than from the reference system. This was caused by an extreme yield benefit for maize and decreased production costs, particularly in crop protection measures, of maize. Through the integration of soybean as a break-crop, two pesticide treatments could be avoided, reducing not only the input costs of the chemicals, but also variable costs of machinery. The high yield level of soybean could also ensure a high revenue. In Northern Italy there is also a VCS specifically for soybean - Colture proteiche nel Nord Italia (soia). This funding is granted for the entire area of the first five hectares and for 10% of the additional area. As the average farm size is ten ha in the region[46], the area with soybean cultivation was assumed not to be exceeding five ha and the payment of 74 €/ha were included for soybean increasing the economic advantage even further. Due to the considerably lower mineral fertiliser inputs in the soybean rotation (reduced by over 110 kg/ha), the difference between the rotational GM of the maize monoculture and the soybean rotation increased further.

Forage cropping systems

Exemplary forage cropping systems from Brandenburg in the North-East of Germany and south-western parts of Scotland were also analysed. Both regions were provided by actor groups interested in mixed farming systems for dairy production.

[46] European Commission 2020. Factsheet on 2014-2020 Rural Development Programme for Friuli Venezia Giulia.

Both of the five-year rotations in Brandenburg included winter wheat and winter rye which are typical cereal crops on this more favourable soil type in the region.[47] As a non-legume forage crop silage maize is predominant and has a favourable economic performance due to satisfactory yields in light of the conditions and high economic value for feed and biogas.[48] Replacing silage maize with alfalfa in the rotation in Brandenburg resulted in a 14% reduction of the standard GM. The advantage of 60 €/ha of the rotation without legume can be explained with higher revenues due to higher yields from silage maize compared to alfalfa. Even though silage maize comes along with considerably higher production costs than alfalfa, due to the higher costs in fertilization and plant protection measures, the savings in variable costs can not compensate the lower revenues. Additionally, the yield benefit of wheat after alfalfa with a yield increase of 1.1 t/ha could not lead to an economic benefit in terms of the rotational GM. With the introduction of a carbon tax the GM deficit of the legume-supported rotation could be decreased due to the lower usage of nitrogen fertiliser with 53 kg/ha less inputs. However, a GM deficit of 5% - for the higher carbon tax - and 12% - for the lower carbon tax - still remained.

The Scottish rotation without legume involved three years of grass and subsequently spring barely. Several legume-supported alternative rotations were provided. The inclusion of grass-clover instead of pure grass stands resulted in considerably higher standard GMs. The economic benefits from the grass-clover rotations compared to the grass-rotation ranged between 82 €/ha to 171 €/ha. This was caused by lower variable costs in grass-clover than in pure grass stands due to reduced fertiliser costs and yield benefits in cereals after grass-clover as well as after the grain legumes included in three of the grass-clover rotations. Additionally, fertilization costs in cereals after legumes were also slightly lower due to implemented savings in nitrogen fertilization. Substituting grass with alfalfa, however, resulted in an almost negative GM. Since the revenue of alfalfa is small in the first year, due to reduced yields during the establishment of the stand and at the same time higher variable costs because of costs of seeds and costs for the establishment, the gross margin of the first year of alfalfa was highly unprofitable. Yield benefits and reduced fertilization costs of spring barley after alfalfa compared to the spring barley after grass could not outbalance the economic disadvantage. The modification of the standard GM by including the carbon tax resulted in even higher advantages of the grass-clover rotations compared to the grass-rotation, as the mineral N inputs were reduced by 32 kg/ha to 43 kg/ha. The alfalfa-rotation, however, could also not benefit in the comparison of the GMs including the carbon tax due to the initially very low economic return.

Conclusion on cropping system profitability

Taking the standard GM of cropping systems without legumes as the economic benchmark has illustrated that in nine out of the 17 case study regions, legume-

[47] There are five types of arable land or agro environmental zones in Brandenburg, formed by different soil and weather condition. Type 1 has the most favorable conditions resulting in highest yield potential while type 5 involves the most sandy and marginal soils. See also: Hanff, H., Lau, H. 2016. Datensammlung für die betriebswirtschaftliche Bewertung landwirtschaftlicher Produktionsverfahren im Land Brandenburg. Landesamt für Ländliche Entwicklung, Landwirtschaft und Flurneuordnung (LELF), Potsdam.
[48] Amt für Statistik Berlin-Brandenburg 2020. Bodennutzung der landwirtschaftlichen Betriebe im Land Brandenburg 2020.Vorläufiges Ergebnis. Potsdam.

supported cropping systems were economically viable and competitive to the reference systems when considering their standard GM. Several aspects were shown to impact the profitability of the regional legume-supported cropping systems. The economic performance of the legume crop influenced the rotational profitability which is why cropping systems with soybean were mostly competitive to their reference systems, with higher standard GMs in five case study regions. But as outlined before, the inclusion of pre-crop effects of legumes, financially expressed in increased revenues or decreased production costs or both, is essential in the economic evaluation of legume systems and also had significant effects on the considered rotations. The actual extent of the effects were diverse in the case study regions depending on local site conditions, management decision and design of the cropping systems.

Farmers will only integrate legumes into cropping systems, if the profitability of the legume-supported systems reach the economic benchmarks of the reference systems. Decisive elements in order to reach these benchmarks were shown with the inclusion of the feed value, subsidies and a carbon tax which all contributed to the economic competitiveness of the cropping systems with legumes.

ESS provided by legumes

As outlined in section 'Allocation of farm resources' legume cultivation is combined with several agro-ecological processes, which directly impact the resource use of a farming system and the effects on the environment. These impacts are also reflected when applying the concept of ESS[49] on legume-supported cropping systems. Legumes can directly as well as indirectly contribute to multiple ESS within the three categories of provisioning, supporting and regulating services.[50]

Agricultural cropping systems are regarded as provisioning services to humans and in this context legume crops have a major role in the protein supply for food and feed products. The significance of protein supply through legumes in the feed sector is evident when considering current market flows of legumes.[51] Due to population growth and the need for dietary changes the importance of the provisioning service of legumes for food is likely to increase in the future.[52] Supporting services as for example the improvement of soil quality can be seen as the basis of all other services while regulating services enclose for instance control of soil erosion or the reduction of emissions. Supporting and regulating services provided from legumes include BNF, other rotational effects as improvement of the soil structure and control of pests, diseases and weeds,

[49] Daily, G. 1997. Nature's Services: Societal Dependence on Natural Ecosystems. Island Press, Washington, DC.

[50] Everwand, G., Cass, S., Daubner, J., Williams, M., Stout, J. 2017. Legume Crops and Biodiversity, in: Murphy-Bokern, D., Stoddard, F.L., Watson, C.A. (Eds.), Legumes in cropping systems. CABI Publishing, p. 55-69.

[51] Agrosynergie 2018. Market developments and policy evaluation aspects of the plant protein sector in the EU. Final report. European Commission; https://ec.europa.eu/info/sites/info/files/food-farming-fisheries/plants_and_plant_products/documents/plant-proteins-study-report_en.pdf

[52] Henchion, M., Hayes, M., Mullen, A.M., Fenelon, M., Tiwari, B., 2017. Future protein supply and demand: strategies and factors influencing a sustainable equilibrium. Foods 6 (7). doi: 10.3390/foods6070053.

enhancement of nutrient management, GHG emission reductions and biodiversity conservation.[53]

The delivery of these services provided by legumes to cropping systems is due to multiple interactions and complexity of the effects, often not well recognized and hence under-valued. Therefore, it is needed to illustrate and inform on the provided services by assessing the effects with suitable indicators. This more comprehensive view on legumes' impacts in farming systems allows then to go beyond the assessment of commercial market outputs and enables to include also non-market outputs as negative and positive externalities.[54] Due to market failures the economic returns of these services are under- or not valued at all and therefore it is a first step to make these services more accessible through depicting them in assessment indicators as done in Deliverable Report 5.2.

Based on the Legumes Translated data set, an evaluation of ESS provision[55] by legume-supported and reference cropping systems was performed, enclosing indicators on nitrogen fertiliser use, nitrate leaching, nitrous oxide emissions and protein output. The average results of arable and forage cropping systems showed that crop rotations with legumes reduced nitrous oxide emissions by 21% and 26% and nitrogen fertiliser use by 26% and 45%, respectively (Table 14, Table 15, Table 16). Nitrate leaching was slightly increased in forage cropping systems with legumes, no increase was found for arable legume-supported systems. Protein output was increased by 13% and 5%, in arable and forage systems, respectively.

[53] Watson, C., et al. 2017. Grain legume production and use in European agricultural systems. Adv. Agron. 144, 235–303.doi: 10.1016/bs.agron.2017.03.003.
[54] Zander, P., et al.. 2016. Grain legume decline and potential recovery in European agriculture: a review. Agron. Sust. Dev. 36,1–20. doi: 10.1007/s13593-016-0365-y.
[55] Only a small share of ESS that legumes can provide are included in the assessment, as the complexity of the effects are not easily to illustrate and were hence beyond the scope of D5.2.

Table 14. ESS provision of arable cropping systems with and without legumes in case study regions in Central East Europe

Region	+/- leg-ume	C1	C2	C3	C4	C5	C 6	NO_3-N [kg/ha]	N ferti-liser use [kg/ha]	N_2O emissions [kg/ha]	Protein output [kg/ha/ year]
Arable cropping systems											
Central East Europe											
BG, BG 31	-	WW	GM	SF				40	143	5	530
	+	FP	WW	GM	SF			34	102	3.8	551
	+	WW	SF	FP	GM			36	102	3.8	533
BG, BG 32	-	WOR	WW	SF	GM			22	120	4.1	628
	+	SY	WW	SF	WW			20	55	2.2	631
BG, BG 33	-	WOR	WW	SF	GM			22	120	4.1	628
	+	CB	WW	SF	WW			41	114	4.1	481
RO, RO 11	-	GM	WW					20	125	4.2	545
		GM	WW	SY				18	79	2.9	615
RO, RO 21	-	GM	SF	WW				30	83	3.2	613
	+	GM	WW	SY				37	83	3.5	879
RS, RS 12	-	GM	WW					50	112	4.3	636
	+	GM	WW	SY				45	91	4	1000
UA, Kyiv oblast	-	GM	SF	WW				37	111	4.2	657
	+	GM	SY	SF	WW			41	89	3.7	763

AF, Alfalfa; CB, common bean; FB, faba bean; FP, field pea; GC, grass-clover; GM, grain maize; GR, grass; LU, lupin; SB, spring barley; SF, sunflower; SFB, spring feed barley; SM, silage maize; SMB, spring malt barley; SO, spring oat; SU, sugar beet; SY, soybean; WB, winter barley; WO, winter oat; WOR, winter oilseed rape; WR, winter rye; WT, winter triticale; WW, winter wheat.

Table 15. ESS provision of arable cropping systems with and without legumes in case study regions in Central West, North-West and South Europe

Region	+/- leg-ume	C1	C2	C3	C4	C5	C 6	NO_3-N [kg/ha]	N ferti-liser use [kg/ha]	N_2O emissions [kg/ha]	Protein output [kg/ha/year]
Arable cropping systems											
Central West Europe											
AT, AT 11	-	GM	GM	WW				34	169	5.7	849
	+	SY	WW	GM				34	99	3.9	1057
AT, AT 12	-	GM	WW	SF				30	123	4.3	557
	+	GM	WW	SY				39	103	4	776
DE, DE 11	-	WW	WB	TR				29	173	4.7	794
	+	WW	WB	FP	TR			26	123	3.6	770
DE, DE 11	-	SU	WW	WB	GM			12	153	4.2	979
	+	SU	WW	WB	FB			21	95	3.4	977
DE, DE 13 (Kies)	-	GM	GM	WW	WOR			14	175	5.2	788
	+	GM	GM	SY	WW	WOR		14	136	4.2	847
DE, DE 13 (Löss)	-	GM	GM	WW	WOR			17	195	6	960
	+	GM	GM	SY	WW	WOR		17	152	4.9	1038
DE, DE 40 (soil type 2)	-	WW	WB	WOR				43	139	5	663
	+	WW	FP	WW	WB	WOR		35	107	4	681
	+	WW	SY	WW	WB	WOR		36	107	4	745
DE, DE 40 (soil type 3)	-	WR	WR	WOR				47	118	4.4	531
	+	WR	FP	WR	WOR			38	86	3.4	559
	+	WR	L	WR	WOR			40	86	3.4	584
DE, DE 73	-	WOR	WW	WW	SB			51	170	6.4	711
	+	WOR	WW	FP	WW	SB		43	135	5.3	753
North-West Europe											
GB, UKM 7	-	WOR	WB	WO	SB	WB		44	174	5.8	707
	+	WOR	WB	WO	FP	WB		33	121	4.4	775
	+	WOR	WB	WO	FB	SB		32	128	4.3	820
IE, IE 05, IE, 06	-	WB	WO	WW	WB	WOR	WW	62	200	7.2	1097
	+	WB	WO	WW	FB	WW		47	157	5.8	1241
IE, IE 05, IE, 06	-	SMB	SO	SFB	SMB	SMB		52	142	5.3	761
	+	SMB	FB	SO	SFB	SMB		48	114	4.6	930
South Europe											
IT, ITH 4	-	GM	GM	GM				65	265	9.1	990
	+	GM	SY					46	123	3.4	1338

AF, Alfalfa; CB, common bean; FB, faba bean; FP, field pea; GC, grass-clover; GM, grain maize; GR, grass; LU, lupin; SB, spring barley; SF, sunflower; SFB, spring feed barley; SM, silage maize; SMB, spring malt barley; SO, spring oat; SU, sugar beet; SY, soybean; WB, winter barley; WO, winter oat; WOR, winter oilseed rape; WR, winter rye; WT, winter triticale; WW, winter wheat.

Table 16. ESS provision of forage cropping systems with and without legumes in case study regions in Central West and North-West Europe.

Region	+/- leg-ume	C1	C2	C3	C4	C5	C 6	NO_3-N [kg/ha]	N ferti-liser use [kg/ha]	N_2O emissions [kg/ha]	Protein output [kg/ha/year]
Forage cropping systems											
Central West Europe											
DE, DE 40	-	WW	WR	SM	SM	SM		42	168	5.2	801
	+	WW	WR	AF	AF	AF		16	47	3.5	1245
North-West Europe											
GB, UKM 9	-	GR	GR	GR	SB			9	151	4.5	1781
	+	GC	GC	GC	WW			11	114	3.9	1960
	+	GC	GC	GC	SB	FP/SB	WW	12	97	3.6	1650
	+	GC	GC	GC	SB	FP	WW	11	97	3.6	1690
	+	GC	GC	GC	SB	FB	WW	11	94	3.4	1695
	+	AF	AF	AF	SB			6	19	1.7	1543
	+	WW	GC	GC	GC	SB		13	117	3.9	1731

AF, Alfalfa; CB, common bean; FB, faba bean; FP, field pea; GC, grass-clover; GM, grain maize; GR, grass; LU, lupin; SB, spring barley; SF, sunflower; SFB, spring feed barley; SM, silage maize; SMB, spring malt barley; SO, spring oat; SU, sugar beet; SY, soybean; WB, winter barley; WO, winter oat; WOR, winter oilseed rape; WR, winter rye; WT, winter triticale; WW, winter wheat.

Considering the single case studies, it was shown that in all included comparisons the fertiliser use was higher in the non-legume rotations, except for one case in which the same amount of fertilization was applied. Only in two cases, nitrous oxide emissions were higher for legume-supported arable rotations. The higher nitrate leaching in several forage legume systems was due to the inclusion of winter wheat in these rotations which was not included in the reference system. This was also the main contributory factor for the lower protein output of these systems (more details in Deliverable Report 5.2). Arable cropping systems achieved higher protein yields in all but three comparisons, of which two had a similar protein output as their reference systems. Nitrate leaching was higher for legume-supported rotations in five out of 24 comparisons of arable cropping systems.

These results point out to the potential that legumes have for positive environmental impacts and provisioning services, although the findings are site specific and variable in terms of the extent of the effects. Further details and additional information are provided in Deliverable Report 5.2.

In order to integrate ESS in economic analyses, several approaches for the valuation of ESS were made as contingent valuation or the application of restoration costs.[56] For the data set from Legumes Translated the analysed provision of ESS were also connected to the economic analysis outlined in section 'Gross margin calculations'. But instead of the

[56] Loft, L., Lux, A. 2010. Ecosystem Services – Eine Einführung. Knowledge Flow Paper Nr. 6. Frankfurt a.M.: BiKF (Biodiversität und Klima Forschungszentrum).

direct monetarization of the services, the trade-offs between the economic performance of the cropping systems and their provision of ESS were evaluated.

Trade-offs between economic performance and ESS

The major advantages of diversification of cropping systems with legumes were outlined in many ways with their environmental performance improving and resource-saving effects, depicted also in their contribution to ESS. However, the often lower revenues from legumes are the essential disadvantage of legumes. These sharply contrasting costs and benefits of legume cropping are commonly the key explanation for the current European situation with low legume cropping shares. In order to examine to what extent these trade-offs between economic performance and ESS were also visible in the Legumes Translated case studies, the changes of GMs from cropping systems without to cropping systems with legumes were related to the changes in the ESS depicting indicators (nitrogen-related impacts and protein output). Thereby indirect costs through foregone economic returns or win-win effects with potential higher ESS provisions can be analysed (Table 17, Table 18, Table 19, Table 20). Moreover, relating changes of economic performance through the introduction of legumes to the changes in provision of ESS also give at least rough indications on the height of payments for ESS needed to offset potential foregone economic returns in case such payments will become part of policy instruments.

As outlined above integrating legumes into arable cropping systems had advantages on the environmental performance and protein output in all regions. In section 'Gross margin calculations'. It was shown that cropping systems with legumes also had economic benefits – depicted with the standard GM - in nine out of 24 comparisons within the regional examples from Romania, Serbia, Ukraine, Austria, Scotland, Ireland and Italy. The integration of legumes in these case studies improved the ESS provision without any economic costs, on the contrary with increased economic returns. These win-win situations in which the legume-supported cropping systems had better economic performances than their reference systems and increased protein supply and environmental advantages – depicted with the nitrogen-related indicators – were given without any exceptions for the case study with spring crops from Ireland, as well as the rotations from Serbia, Scotland and Italy. In the regional examples from Ukraine and Austria this win-win situation was only given in terms of the protein output, nitrogen fertiliser use and nitrous oxide emissions, however, the modelled results on nitrate-leaching showed no improvement with the integration of legumes or even increased nitrate leaching. In the North-Eastern Romanian example (RO 21) the win-win situation was only given for the protein output and trade-offs between the higher economic performance and reduced environmental benefits were made.

The inclusion of grain legumes in arable cropping systems in the regional examples from Bulgaria, North-Western Romania (RO 11), Germany and Ireland increased the ESS provision, but resulted also in lower standard GMs. Therefore these case studies illustrated situations in which trade-offs occured between decreased economic returns and ESS provision. The extent of the trade-offs varied between the regions and the analysed indicators. Each kg of saved nitrogen fertiliser was connected to a loss in the GMs between 0.2 €/ha to 2.6 €/ha in all regions except for Severoiztochen (BG 33). The trade-off in this Bulgarian example was extremely high with costs of 104.5 €/ha for each kg of saved nitrogen fertiliser. This was caused by the extreme difference in the GMs and the minimal reduction in nitrogen fertiliser use. No difference was found in the nitrous oxide emissions in the example from Severoiztochen, but concerning the other considered ESS with nitrate leaching and protein output, the cropping system with legumes illustrated the situation of a lose-lose situation. No gain was made in economic performance nor in lower nitrate leaching or higher protein output. Legume-supported cropping systems from all other regions were more beneficial in terms of nitrous oxide emissions than their reference systems. Savings of one kg nitrous oxide emissions were linked to a loss in GMs between 7.50 €/ha up to 143.6 €/ha.

Table 17. Foregone or additional revenues for each unit ESS provision through legume integration [€/ha] (no or negative effects on ESS provision through legume integration were not quantified) in arable systems in case study regions in Central East Europe

Region	+/- leg	C1	C2	C3	C4	C5	C 6	GM (standard)	GM difference	NO3-N	N fertilizer use	N_2O emissions	Protein output
Arable cropping systems													
Central East Europe													
BG, BG 31	-	WW	GM	SF				472					
	+	FP	WW	GM	SF			366	-106	-16.3	-2.6	-90.3	-4.9
	+	WW	SF	FP	GM			394	-78	-17.7	-1.9	-66.8	-21.4
BG, BG 32	-	WOR	WW	SF	GM			656					
	+	SY	WW	SF	WW			643	-14	-4.8	-0.2	-7.5	-4.9
BG, BG 33	-	WOR	WW	SF	GM			589					
	+	CB	WW	SF	WW			-71	-659	-	-104.5	-	-4.5
RO, RO 11	-	GM	WW					266					
		GM	WW	SY				256	-10	-6.0	-0.2	-7.5	-0.1
RO, RO 21	-	GM	SF	WW				540					
	+	GM	WW	SY				605	65	-	-	-	0.2
RS, RS 12	-	GM	WW					361					
	+	GM	WW	SY				612	251	47.0	11.6	888.2	0.7
UA, Kyiv oblast	-	GM	SF	WW				650					
	+	GM	SY	SF	WW			683	33	-	1.5	66.3	0.3

AF, Alfalfa; CB, common bean; FB, faba bean; FP, field pea; GC, grass-clover; GM, grain maize; GR, grass; LU, lupin; SB, spring barley; SF, sunflower; SFB, spring feed barley; SM, silage maize; SMB, spring malt barley; SO, spring oat; SU, sugar beet; SY, soybean; WB, winter barley; WO, winter oat; WOR, winter oilseed rape; WR, winter rye; WT, winter triticale; WW, winter wheat.

The absolute differences between nitrous oxide emissions were smaller between cropping systems with and without legumes, however, have huge effects due to the fact that nitrous oxide is a greenhouse gas that is 300 times more potent than carbon dioxide.[57] Next to the outlined Bulgarian example and one German case study region in which nitrate leaching was also higher in the legume-supported system, two cropping systems with legumes had a similar risk for nitrate leaching than their reference system. In all

[57] Del Grosso, S. J., Wirth, T., Ogle, S. M., Parton, W. J. 2008. Estimating Agricultural Nitrous Oxide Emissions. Eos Trans. AGU, 89 (51), 529– 529. doi: 10.1029/2008EO510001.

other regions trade-offs between lower economic performance and more beneficial nitrate leaching results were found. The foregone economic returns per each saved kg of nitrate leaching were ranging between 2.6 €/ha and 17.7 €/ha. Despite three examples in which the protein output of the legume-supported rotations were similar or smaller, all arable cropping systems with grain legumes resulted in higher protein output. The costs for each extra kg of protein ranged between 0.30 €/ha up to 21.4 €/ha.

Table 18. Foregone or additional revenues for each unit ESS provision through legume integration [€/ha] (no or negative effects on ESS provision through legume integration were not quantified) in arable systems in case study regions in Central West Europe

Region	+/- leg-ume	C1	C2	C3	C4	C5	C 6	GM (stan-dard)	GM differ-ence	NO_3-N	N ferti-lizer use	N_2O emis-sions	Protein output
Arable cropping systems													
Central West Europe													
AT, AT 11	-	GM	GM	WW				440					
	+	SY	WW	GM				688	248	-	3.6	139.5	1.2
AT, AT 12	-	GM	WW	SF				507					
	+	GM	WW	SY				544	38	-	1.9	139.3	0.2
DE, DE 11	-	WW	WB	TR				172					
	+	WW	WB	FP	TR			136	-36	-10.0	-0.7	-32.1	-
DE, DE 11	-	SU	WW	WB	GM			331					
	+	SU	WW	WB	FB			214	-117	-	-2.0	-143.6	-
DE, DE 13 (Kies)	-	GM	GM	WW	WOR			326					
	+	GM	GM	SY	WW	WOR		284	-42	-	-1.1	-41.6	-0.7
DE, DE 13 (Löss)	-	GM	GM	WW	WOR			711					
	+	GM	GM	SY	WW	WOR		652	-59	-	-1.4	-54.2	-0.8
DE, DE 40 (soil type 2)	-	WW	WB	WOR				448					
	+	WW	FP	WW	WB	WOR		388	-61	-7.9	-1.9	-62.8	-3.4
	+	WW	SY	WW	WB	WOR		431	-17	-2.8	-0.5	-17.9	-0.2
DE, DE 40 (soil type 3)	-	WR	WR	WOR				390					
	+	WR	FP	WR	WOR			332	-58	-7.2	-1.9	-61.8	-2.1
	+	WR	L	WR	WOR			328	-62	-9.0	-2.0	-65.9	-1.2
DE, DE 73	-	WOR	WW	WW	SB			250					
	+	WOR	WW	FP	WW	SB		190	-60	-7.3	-1.7	-55.0	-1.4

AF, Alfalfa; CB, common bean; FB, faba bean; FP, field pea; GC, grass-clover; GM, grain maize; GR, grass; LU, lupin; SB, spring barley; SF, sunflower; SFB, spring feed barley; SM, silage maize; SMB, spring malt barley; SO, spring oat; SU, sugar beet; SY, soybean; WB, winter barley; WO, winter oat; WOR, winter oilseed rape; WR, winter rye; WT, winter triticale; WW, winter wheat.

Table 19. Foregone or additional revenues for each unit ESS provision through legume integration [€/ha] (no or negative effects on ESS provision through legume integration were not quantified) in arable systems in case study regions in North-West and South Europe

Region	+/- leg-ume	C1	C2	C3	C4	C5	C 6	GM (stan-dard)	GM differ-ence	NO3-N	N ferti-lizer use	N2O emiss ions	Protein output
Arable cropping systems													
North-West Europe													
GB, UKM 7	-	WOR	WB	WO	SB	WB		819					
	+	WOR	WB	WO	FP	WB		820	1	0.1	0.0	0.9	0.0
	+	WOR	WB	WO	FB	SB		831	11	0.9	0.3	8.0	0.1
IE, IE 05, IE, 06	-	WB	WO	WW	WB	WOR	WW	502					
	+	WB	WO	WW	FB	WW		464	-37	-2.6	-0.9	-27.5	-0.3
IE, IE 05, IE, 06	-	SMB	SO	SFB	SMB	SMB		337					
	+	SMB	FB	SO	SFB	SMB		360	22	5.3	0.8	29.6	0.1
South Europe													
IT, ITH 4	-	GM	GM	GM				292					
	+	GM	SY					562	270	13.9	1.9	47.3	0.8

AF, Alfalfa; CB, common bean; FB, faba bean; FP, field pea; GC, grass-clover; GM, grain maize; GR, grass; LU, lupin; SB, spring barley; SF, sunflower; SFB, spring feed barley; SM, silage maize; SMB, spring malt barley; SO, spring oat; SU, sugar beet; SY, soybean; WB, winter barley; WO, winter oat; WOR, winter oilseed rape; WR, winter rye; WT, winter triticale; WW, winter wheat.

With the assessment of the standard GM of the forage cropping systems it was shown that there were cropping systems with forage legumes which performed economically better than their reference systems. In five out of seven compared sets in Scotland, grass-clover-supported cropping systems had higher rotational gross margins which resulted in combination with the increased environmental performances in terms of nitrogen fertiliser use and nitrous oxide emissions in the situation of a win-win situation. This dual profiting was also found in terms of the protein output for the four-year rotation with grass-clover and winter wheat. Trade-offs were made in the other four grass-clover rotations between higher economic performance and nitrate leaching as well as protein output. Both other compared sets of forage cropping systems integrated alfalfa in the legume alternative and had lower economic performances. This resulted in a high trade-off in the Scottish alfalfa-supported rotation between economic return and nitrate leaching with foregone economic returns of 40.1 €/ha per each saved kg of nitrate leaching, since the absolute savings in nitrate-leaching were small compared to a huge difference in the standard GM. Due to a considerably reduced application of nitrogen fertiliser in the alfalfa rotation, this trade-off was lower with only 0.9 €/ha. Each kg of saved nitrous oxide emissions was connected to a loss in the GM of 45.1 €/ha which was caused again by the smaller difference in these emissions, however, as outlined above, with an essential environmental impact. The protein output was lower in the alfalfa-supported rotation, leading to a lose-lose situation in this field. In the case study region of Brandenburg there were also trade-offs made between higher economic performance and ESS provision. Each kg of saved nitrogen fertiliser was connected to a loss in the GM of 0.5 €/ha, which was reflecting the high fertiliser savings through the introduction of alfalfa. The foregone economic returns per each saved kg of nitrous oxide emissions were higher with 37.0 €/ha. Each kg of extra protein output was connected to a loss in the GM of 0.1 €/ha and each saved kg of nitrate leaching was combined to a forgone GM of 2.2 €/ha.

Table 20. Foregone or additional revenues for each unit ESS provision through legume integration [€/ha] (no or negative effects on ESS provision through legume integration were not quantified) in forage systems in case study regions in Central West and North-West Europe

Region	+/- leg-ume	C1	C2	C3	C4	C5	C 6	GM (stan-dard)	GM differ-ence	NO3-N	N ferti-lizer use	N2O emiss ions	Protein output
Forage cropping systems													
Central West Europe													
DE, DE 40	-	WW	WR	SM	SM	SM		420					
	+	WW	WR	AF	AF	AF		360	-60	-2.2	-0.5	-37.0	-0.1
North-West Europe													
GB, UKM 9	-	GR	GR	GR	SB			128					
	+	GC	GC	GC	WW			266	138	-	3.7	243	0.8
	+	GC	GC	GC	SB	FP/SB	WW	218	90	-	1.7	99	-
	+	GC	GC	GC	SB	FP	WW	211	82	-	1.5	90	-
	+	GC	GC	GC	SB	FB	WW	299	171	-	3.0	154	-
	+	AF	AF	AF	SB			5	-124	-40.1	-0.9	-45.1	-
	+	WW	GC	GC	GC	SB		213	85	-	2.5	160.1	-

AF, Alfalfa; CB, common bean; FB, faba bean; FP, field pea; GC, grass-clover; GM, grain maize; GR, grass; LU, lupin; SB, spring barley; SF, sunflower; SFB, spring feed barley; SM, silage maize; SMB, spring malt barley; SO, spring oat; SU, sugar beet; SY, soybean; WB, winter barley; WO, winter oat; WOR, winter oilseed rape; WR, winter rye; WT, winter triticale; WW, winter wheat.

The analysis of trade-offs between economic performance and ESS provision showed that there were actually four kind of situations given in the Legumes Translated data set – win-win situations, trade-offs in legume-supported systems between lower economic performance and enhanced ESS provision and in some examples between higher economic performance and decreased ESS provision, and in four case study regions also lose-lose situation for some single indicators. The identification and quantification of the trade-offs showed that the extent of the trade-offs varied between the case studies and in some regional examples only small trade-offs were found, indicating valuable alternative strategies for securing ESS provision as well as economic benefits. Considering the included crops in the win-win situations the presence of soybean in five out of the nine examples is notable and indicates that under current market situations the reconciliation of economy and provision of ESS can be rather facilitated with soybean-supported cropping systems than with other legumes, due to their higher profitability.

Practical experience from actor groups on feeding legumes in pig sector

The feed sector is the main consumer of plant-based protein in the EU. More than 94 % of protein-rich plants and materials used in the EU are utilised in the feed sector and the major market is here the compound feed market.[58] 33% of the compound feed market goes into the production of pig feed – which is the second largest market after poultry - and the key driver of this market is 'value for money', meaning satisfying nutritional requirements of pigs at least costs.[59] Oilseed meals and especially soybean meal is a key component in feed formulation, because it is widely available all year and contributes high-quality protein with a favorable amino acide profile that has a higher digestibility by pigs than many other protein sources.[60] Considering the numbers from the feed use of all livestock within the EU, soybean meal already accounts for 16% of the total feed use, representing the mostly used protein source in feedstuff (Table 21).[61] While soybean meal is almost completely sourced from imports, pulses are mainly of EU origin, however these have only a small share in the total feed use.

Table 21. Selected protein sources in feedstuff in the EU livestock sector (2019/20)

Unit	Million tonnes of feedstuffs	Million tonnes (crude protein)		
	Feed use	Feed use	Share in total feed use	Share EU origin (not imported)
Pulses	3.6	0.90	1%	87%
Field peas	1.9	0.43		
Broad beans	1.2	0.32		
Lupins	0.4	0.16		
Oilseed: whole seed wihtout crushing	1.6	0.46	1%	100%
Soybeans	1.2	0.40		
Rapeseed	0.2	0.03		
Sunflower seed	0.2	0.03		
Oilseed meals	52.8	21.07	25%	24%
Soybean meal	29.6	13.51	16%	3%
Rapeseed meal	12.5	4.11	5%	72%
Sunflower meal	8.0	2.90	3%	52%

Besides compound feed manufacturers, livestock farmers are essential drivers in the feed sector by deciding how their pigs are fed and whether to use feed produced on the farm. When comparing the shares of manufactured on-farm feed with 37% of total feedstuffs consumed by livestock and compound feed with 63%, the relevance of livestock farmers choices is shown and particularly given for pig farmers since on-farm feeding is more

[58] Agrosynergie 2018. Market developments and policy evaluation aspects of the plant protein sector in the EU. Final report. European Commission; https://ec.europa.eu/info/sites/info/files/food-farming-fisheries/plants_and_plant_products/documents/plant-proteins-study-report_en.pdf
[59] European Commission 2018. Report from the Commission to the Council and the European Parliament on the development of plant proteins in the European Union; https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52018DC0757.
[60] European Commission 2018, see above.
[61] European Commission 2020. EU + UK Feed Protein Balance Sheet. https://ec.europa.eu/info/sites/info/files/food-farming-fisheries/farming/documents/eu-uk-feed-protein-balance-sheet_2019-2020_en.pdf

developed in the pig sector.[62] Rising consumer demands for sustainable animal products without genetically modified feed and regional supply chains can be met by local livestock farmers associations focussed on regional feed production, such as BESH.

BESH – the actor group in the pig sector

Within Legumes Translated, the association "Bäuerliche Erzeugergemeinschaft Schwäbisch Hall e.V." –BESH–, a Farmer Producers' Association of independent livestock farmers is focussing on how regionally grown legumes can more widely be used in their farmers' feed rations.

BESH Farmer Producers' Association is a farmer self-help organisation, owned by the farmers and running for almost 30 years. Today, the association owns a slaughterhouse and a meat processing enterprise. BESH markets its products to retailers, restaurants and consumers. Mandatory for membership and use of BESH sales channels are sustainable animal production schemes that prohibit the use of GM feed, demand the production of most feed on-farm and oblige animal welfare protection. Especially in the supply of protein for pigs, this is a big challenge. A wide set of essential acids is necessary and usually only soybean meal is able to meet this demand. Therefore, the use of local alternatives seems to be the only sustainable way to provide a feed supply for the pigs that meets the meat consumers' demand.

Feed experiments

As part of the Legumes Translated work on feed economics, an economic analysis of exemplary pig feed rations based on different European grain legumes was done to gain valuable insights on the competitive use of these feed ingredients. Nutrition physiology of adapted rations as well as fattening performance have to be thoroughly examined – however feeding trials in other studies have shown that satisfying results can be achieved in terms of growth and carcass quality. Moreover, the success of BESH shows that a price premium for its meat products is feasible through marketing of more regional, sustainable and GM-free production processes.

Nutritional perspective

Nutritional value is mainly determined by a range of aspects such as crude protein, energy content and the amino acid composition. The value-determining ingredients vary between pea, faba bean and soybean as well as between the varieties in each species, which can be influenced by factors such as soil, climate and the production process. Besides, there are feed-specific restrictions such as maximum intake amounts for each legume species and the phase of production of the pig. Anti-nutritional factors such as protease inhibitors or tannin can negatively impact the animal metabolism and feed intake of the pig. For soybean and its by-products a thermal treatment is indispensable, however modern varieties of pea and faba bean can be fed without heat treatment. A

[62] Agrosynergie 2018. Market developments and policy evaluation aspects of the plant protein sector in the EU. Final report. European Commission; https://ec.europa.eu/info/sites/info/files/food-farming-fisheries/plants_and_plant_products/documents/plant-proteins-study-report_en.pdf

careful combination of different protein crops allows to balance requirements and hence enables a nutrient and cost efficient usage of European grown legumes. Supplemental additions of synthetic amino acids can also complement nutritional requirements that the included legume species could not provide, although this also raises ethical questions about genetically engineered feed ingredients.

Economic perspective

Price and availability varies considerably between grain legumes. As the European grain legume production is still at a very low level, insufficient marketing structures are the main arguments for (regionally) low market prices of pea and faba bean. These low market prices could be attractive to the feed industry, however there is low usage of these grain legumes from feed compounders due to their limited availability and the related low planning security for the feed industry.

For farmers with the option of on-farm feed mixing, the production of grain legumes (e.g. faba beans and peas) is attractive given lower production costs and the species' suitability to regional site conditions. Such economic benefits are feasible, which can be shown with simple "value for money" analysis offered by various excel tools that are easy to operate and freely available online (see further information). However, these rough figures indicating cost advantages have to be further evaluated as only precise ration calculations allow to illustrate real cost differences. An inclusion of further parameters as additional costs from storage, mixing, heat treatment if necessary, feed analysis or - depending on the ration and grain legumes used - additions of synthetic amino acids, enables exact results.

Exemplary feed rations

In order to assess the economic suitability of European grain legumes for pig feeding four differing feed rations are compared. The exemplary feed rations refer to the early mast period of pigs from 28 kg upwards and are presented in Table 22. The four examples are analyzed with an excel-based calculation tool in order to examine a comparable "value for money" of each ration. The rations have to comply with a set of nutritional requirements, including a certain share of metabolizable energy, crude protein, essential amino acids as lysine, methionine, threonine, tryptophan, cysteine and crude fiber. Price data is valid for January 2021.

Considering the costs per ration the price advantage of the ration without European soybeans is noticeable. The soybean free ration (FR4) is 4.73 euro cheaper per 100kg than the ration with only soybean as a legume ingredient (FR1). Reducing soybeans only partially with pea (FR2 and FR3) can still reduce feed costs by 2.10 € or 2.02 € per 100 kg, respectively. FR2 and FR3 are rations to be tested by BESH farmers, while FR4 remains a hypothetical mix which will not be tested, due to concern about palatability and the low energy content.

Table 22. Feed ration composition with European GMO-free soybeans (FR1), a ration with reduced share of soybeans, replaced by peas (FR2), a pea, soybean mix (FR3) and a soybean-free ration based on peas, faba beans and rapeseed expeller (FR4)

feed		FR 1: only soy	FR 2: reduced soy share, with peas	FR 3: pea soy mix	FR 4: peas, faba beans, rapeseed expeller
	Price/100kg	%			
Barley	16.3	35	30	33.5	30
Wheat	18.3	43	40	9	34
Maize	16.0			20.5	
Rye	12.7			9	
Soy (GMO-free)	56.5	19	12	13.5	-
Peas	21.5	-	15	10	10
Faba beans	21.0	-	-		8
Rapeseed expeller	30.9				15
Feed concentrate	63.9	3	3	3	3
Rapeseed oil	66.0			1.5	
Total price/100kg		26.23	24.13	24.21	21.50

Table 23 shows the nutrient composition of the rations and illustrates that some of the minimal requirements for nutrients are not met by the alternative feed rations. While the standard ration with soybean (FR1) fulfills all nutritional requirements, the rations with alternative formulas (FR2, FR3, FR4) are slightly under the recommended value for crude protein, however some farmers state that this is still within an acceptable range. The soybean free ration (FR4) has also a lower than recommended energy content which could potentially lead to a lower growth of the pig. Additionally, particularly with this ration the feed intake of the pigs should be closely monitored, given the high share of rapeseed expeller which could lead to the rejection or low intake. Hence, this ration should not be understood as a standard feed ration, but rather as a more experimental ration that needs thorough observation of the pigs' feeding and growing behavior. In general, BESH farmers and feed consultants state that animals sometimes also compensate a lower energy or protein content with potentially higher feed intakes, which then also lead to good results. FR 3 is currently analyzed within a feeding trial by BESH which will show the effect on meat quality and performance.

Table 23. Nutrient composition of feed rations compared to recommended values

nutrient	Recommen-dation	FR 1 soy	FR 2 reduced soy with peas	FR 3: pea soy mix	FR 4: peas, faba beans, rapeseed expeller
ME ** MJ/kg	13	13.2	13.1	13.4	12.4
Crude protein (XP) g/kg	170	174.3	167.8	160	168.9
Lysine (Lys) g/kg	10	11.2	11.0	10.9	10.5
Methionine g/kg	3	3.2	2.7	2.8	2.7
Met & Cyst g/kg	6	6.6	5.9	4	6.3
Tryptophan g/kg	2	2.2	2.0	1.8	1.93
Threonine g/kg	6.6	7.6	7.1	7.1	7.1
Crude fiber (XF) g/kg	30	33.4	36.6	34.7	51.9

Conclusion on feeding legumes in pig sector

It is possible to compose adequate feed rations without or a lower share of soybean. Especially for farmers that take part in premium meat production, on-farm feed mixing allows the use of regional or on-farm produced legumes which allows cost savings and price premiums through targeted marketing.

Small deviations from nutrient recommendations are likely being offset by variations in nutrient contents in the used feed components. The exemplary economic analysis has shown that farmers should dare to experiment with different shares of legumes. Individual cost analysis of rations including farm specific conditions and thorough consideration of pigs' feed intake and meat quality allows cost-efficient pig feeding based on regional legumes.

Practical experience from actor groups on feeding legumes in aquaculture

Aquaculture in the EU

Aquaculture, also known as aquafarming, refers to the farming of aquatic (freshwater or saltwater) organisms, such as fish, molluscs, crustaceans and plants, under controlled conditions. Salmon, trout, oysters, European seabass, gilthead seabream and mussels are the main commercial species in the EU, representing over 90% of aquaculture production. In 2017, the EU production from aquaculture was 1.4 Mio tons. Although the production volume from aquaculture is much lower than that of fishery, the value of aquaculture is considerable.[63]

Figure 4 shows the total fish production from aquaculture in EU countries in 2017. Note that the total production of Norway is as high as of all EU member states together. The most important EU countries in aquaculture are Greece, Spain, Italy and France.

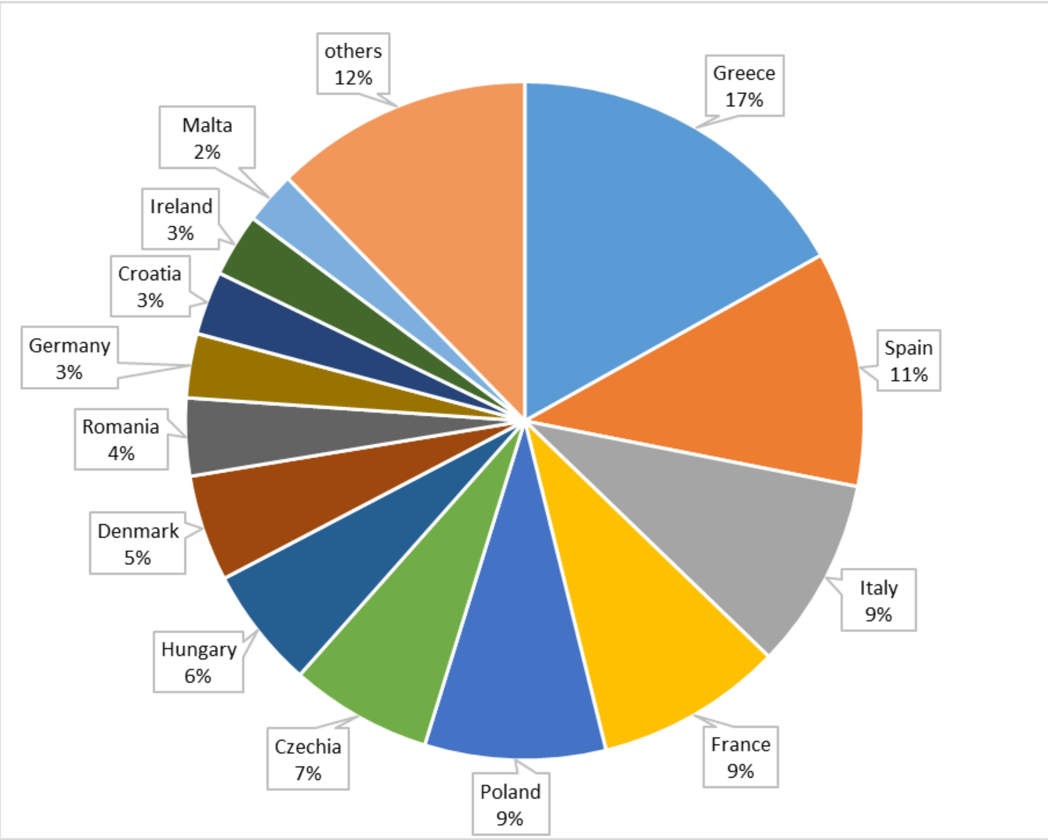

Figure 4. Fish production from aquaculture excluding hatcheries and nurseries (2017) in selected EU countries; Tons live weight; countries with production < 15,000 t summarized in others

[63] https://ec.europa.eu/eurostat/web/products-eurostat-news/-/EDN-20191015-2

Aquaculture is of different importance in the EU member states. Figure 5 shows the geographical distribution of the total production in all member states, including the production of UK.

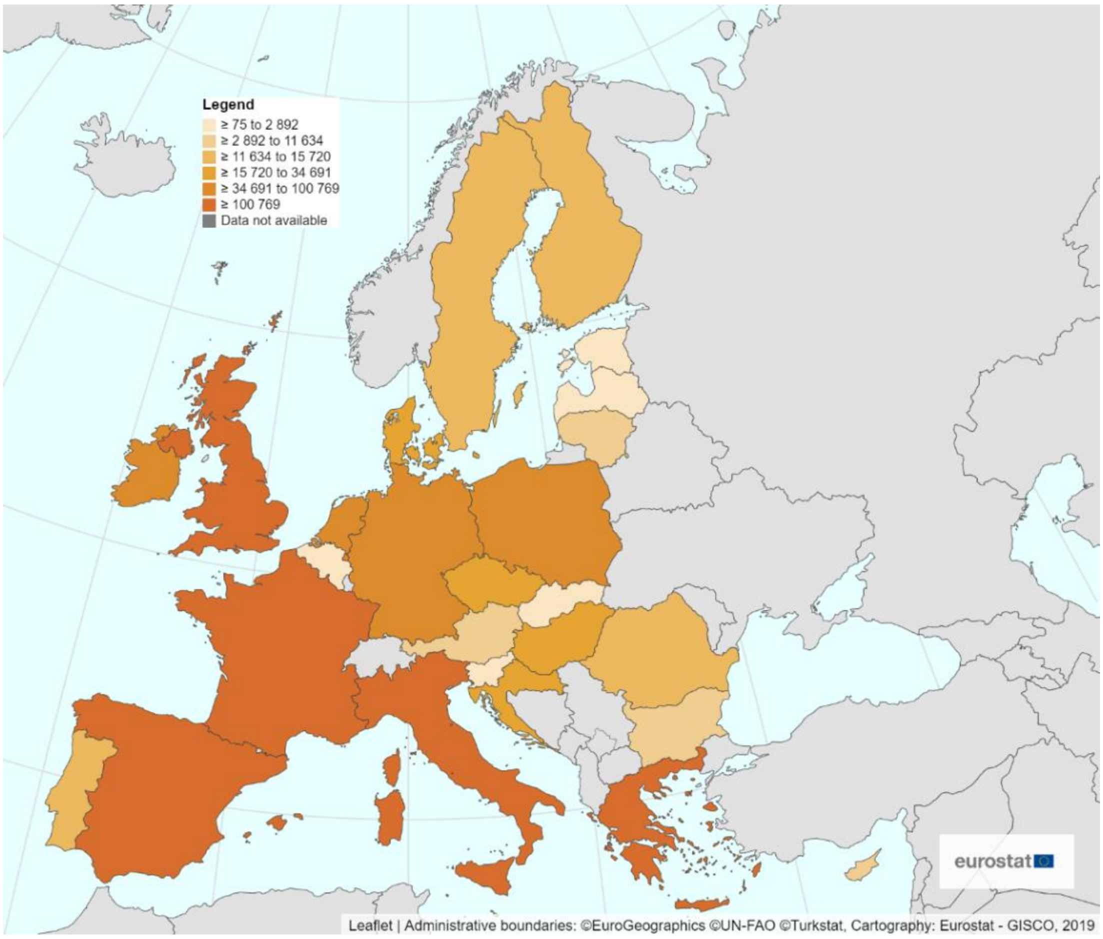

Figure 5. Production (in tons per year) from aquaculture in the EU excluding hatcheries and nurseries (2017), quantiles (online data code: FISH_AQ2A) [64]

Figure 6 reflects the importance of different types of aquaculture products in the EU member states. While mediterranean countries have high shares of marine fish production, others have a more diverse set of production from freshwater and diadromous (species living in sea and freshwater, e.g. salmon) fish. Countries like Spain and France are famous for their mollusc production, such as mussels and oysters.

[64] Eurostat; Data extracted on 01/03/2021 17:08:59 from [ESTAT]; Dataset: Production from aquaculture excluding hatcheries and nurseries (from 2008 onwards); [FISH_AQ2A__custom_626581] Tonnes live weight Last updated: 23/02/2021 23:00
https://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=fish_aq2a&lang=en

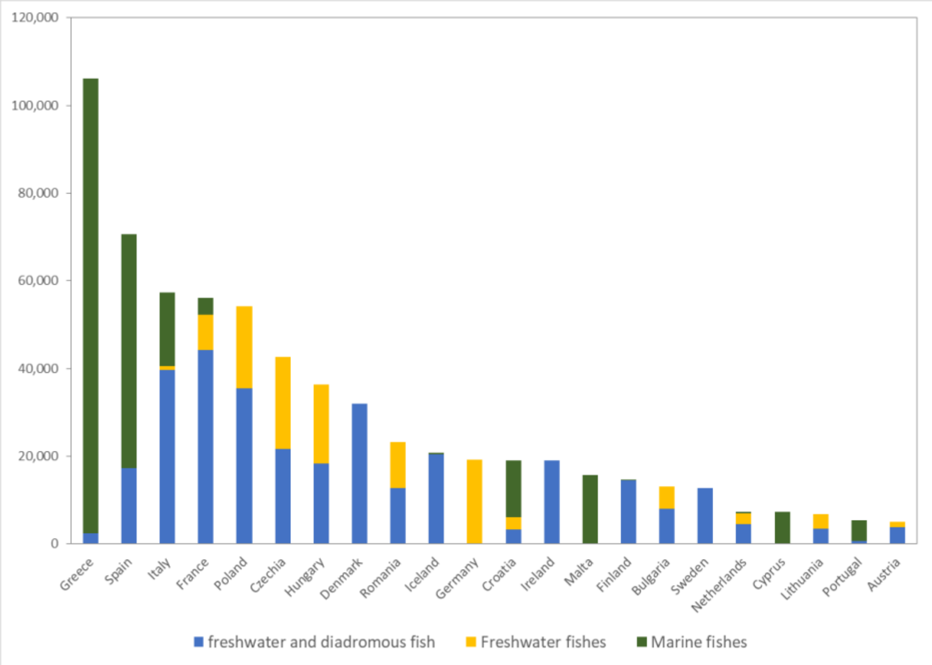

Figure 6. Share of different types of fish aquaculture products in the EU in t/year; countries with production < 5,000 t are not included [65]

Feed types used in aquaculture

Aquaculture, especially fish and shrimp production, rely heavily on fish meal and fish oil produced from marine fishery.[66] Given rising prices in fish meal and fish oil and the ethic considerations of "feeding fish to fish", producers in aquaculture are seeking alternative protein sources (e.g., plant-based ingredients, aquaculture by-products, animal by-products) for their aquafeed products. Therefore, alternative protein sources that can compete, nutritionally, with the high protein level and essential amino acid profile of high-quality fish meal are needed.[67] Although not the best indicator, the share of fish products in fish feed is shown in the fish in:fish out ratio (FIFO). However, it is still a widely used benchmark to show the environmental performance in feed use in aquaculture. FIFO depends highly on species produced in aquaculture; carnivores need more fish meal compared to omnivores. Breeding efforts and research on substitutes have improved FIFO for most species over the years.For salmon, FIFO for fish meal has been reduced from 4.4 in 1990 to 0.8 in 2016, and for fish oil from 7.2 in 1990 to 1.5 in 2016, respectively.[68] For mediterranean fish, such progress has not yet been achieved, with a FIFO of 1.78 for sea bream or Sea Bass. However, breeding efforts and improvements in fish nutrition show a positive trend.[69]

[65] Eurostat; Data extracted on 01/03/2021 17:08:59 from [ESTAT]; Dataset: Production from aquaculture excluding hatcheries and nurseries (from 2008 onwards); [FISH_AQ2A__custom_626581] Tonnes live weight Last updated: 23/02/2021 23:00

[66] FAO Fisheries & Aquaculture 2021. Fishery Statistical Collections; http://www.fao.org/fishery/statistics/global-capture-production/en

[67] https://burdockgroup.com/protein-sources-in-aquaculture-feed-quality-and-nutrition/

[68] Aas, T. S., Ytrestøyl, T., & Åsgård, T. 2019. Utilization of feed resources in the production of Atlantic salmon (Salmo salar) in Norway: An update for 2016. Aquaculture Reports, 15. doi: 10.1016/j.aqrep.2019.100216.

[69] NIREUS 2016. Sustainable Development Report; http://www.nireus.com/files/koinwniki_efthini/APOLOGISMOS2016_EN.pdf

The following factors need to be considered when choosing a protein source for use in aquaculture feed:

- Ingredient quality
- Target species protein requirements
- Regulatory challenges
- Prices

Since feed costs make up the highest share in fish production, a strong focus is placed on an optimal cost-effective formulation of fish feeds. As part of the Legumes Translated project, the actor group LegumesforFish is looking into more options on how to use more European legumes in their feed formulas.

LegumesforFish – the actor group on aquaculture

LegumesForFish promotes the inclusion of legumes in sustainable cropping systems for use in the production of fish feeds. It is based around three members: an agricultural cooperative and legume producer (THESGI), a group of fish feed and fish farming companies (NIREUS) and the University of Thessaly. In Greece, they are leading in the legume production, processing, and quality control incorporation in the fish feed, respectively.

LegumesForFish is a relatively young actor group based around three members which form the main part of the legume production, processing, and quality control incorporation in the NIREUS fish feeds-fish production value chain. In Legumes Translated, the group develops a prototype value chain and aspires to develop a transition path to overcome specific constraints and dependency of European fish farming on imported soybean of varying availability, quality and price.

THESGI is a dynamic agricultural cooperative of young farmers that cultivate and aggregate the production of 3,300 hectares in the region of Thessaly, which is the biggest plain in Greece. THESGI members experiment with local legume cultivars meant for human and/or animal consumption. These cultivars are the product of a local breeding programme run by the Greek National Agricultural Research Foundation to perform optimally at local conditions and function in rotation farming systems as the second (cool season) crop within the cropping year.

The Nireus Group (now part of Avramar) is the biggest Mediterranean fish producer with an annual fish production of 30,000 tonnes. The Nireus Group operates two fish feed factories, with an production of 75,000 tons of fish feed annually, which are based exclusively on imported soybean – mainly from non-EU countries. The use of plant-based proteins in fish feed as a substitute of fish meal is steadily increasing, to the extent that legumes have become essential in fish feed formulations.

The Department of Biochemistry & Biotechnology, University of Thessaly (UTH), supports the qualitative control of legumes to be used in fish feeds. OptiFeed Services is a unique set of tests that defines the bioavailability of dietary proteins of raw materials and fish feed formulations as well as the content of antinutritional factors that are accumulated in legume seeds and impair the digestive process.

Feed experiments with locally produced legumes

As part of the project objectives, the actor group tested the production and conducted a feed trial with locally produced legumes. The resulting agronomic and economic data at crop level are summarized in Table 24. In this report, we describe mainly the economic implications of using legumes in fish feed formulas. Further descriptions on the nutritional details are part of other Legumes Translated reports.

The nutritional value of the legumes were tested both chemically and *in vitro* using enzyme extracts from sea bream. Since digestible protein is an important fish feed performance indicator, the analysis focuses on the cost per kg of digestible protein. Based on the high crude protein content and the high digestibility, lupin has the lowest cost per digestible protein (1.38 €/kg DP), followed by faba bean (1.58 €/kg DP) and vetch (1.69 €/kg DP).

Table 24. Agronomic and economic data of production trials with locally grown legumes for LegumesForFish

legume type	Vetch kalliroi	Vetch Evinos	Lupin multitala	Faba bean Tanagra	Faba bean Scuro	Pea Eliza	Pea Dodoni
yield production t/ha	1.2	1.2	1.0	1.8	1.8	0.9	0.9
agricultural inputs €/MT	100	100	150	130	130	180	180
energy needs €/MT	200	200	270	200	200	270	270
labour costs €/MT	30	33	33	33	33	33	33
total production cost €/MT	330	330	450	360	360	480	480
logistics €/MT	10	10	10	10	10	10	10
final cost of legume meals €/MT	340	340	460	370	370	490	490
crude proteins %	31.1	28.3	43.2	30.7	29.7	25.5	26.8
protein Digestibility %	0.65	0.45	0.77	0.76	0.56	1.00	0.86
digestible protein %	20.15	12.74	33.39	23.45	16.69	25.50	23.16
cost per crude protein €/kg	1.09	1.20	1.06	1.21	1.25	1.92	1.83
cost per digestible protein €/kg	1.69	2.67	1.38	1.58	2.22	1.92	2.12

Based on a ranking method which includes costs per crude protein, costs per digestible protein and *in vitro* digestibility, lupin, faba bean and both pea variants were chosen to be tested in a feeding trial with sea bream during a 86 day period. Each treatment received a feed formula with a relatively high share (10%) of legumes in order to see the nutritional effects in the feeding trials, replacing a part of the most plant origin raw materials used like soybean meal, sunflower meal and wheat flour. A typical commercial formula was used as a control.

In order to meet the nutritional requirements, each ration had to be formulated separately, with fish meal and fish oil staying constant. The final feed mix and the resulting costs per kg are shown in Table 25. The lowest feed costs can be achieved with lupin, followed by faba bean. The feed mix with both pea are slightly more expensive since the lower protein content of peas had to be balanced with shares of soy protein concentrate.

Table 25. Feed ingredients in % of raw material/kg fish feed, resulting feed costs per kg and cost difference with control

Raw materials	€/kg	Control	Lupin	Faba bean	Pea eliza	Pea dodoni
Fishmeal	1.45	20.0%	20.0%	20.0%	20.0%	20.0%
Soy protein concentrate	0.85	12.0%	8.7%	11.2%	14.1%	14.1%
Corn gluten	0.75	19.8%	19.8%	19.8%	19.8%	19.8%
Soybean meal	0.55	12.0%	10.0%	8.4%	7.0%	7.0%
Sunflower meal	0.50	11.0%	8.1%	8.1%	8.0%	8.0%
Wheat flour	0.25	10.9%	9.7%	8.3%	7.0%	7.0%
Fish oil	1.65	6.0%	6.0%	6.0%	6.0%	6.0%
Salmon oil	1.00	6.9%	6.3%	6.8%	6.7%	6.7%
Premix	3.50	1.0%	1.0%	1.0%	1.0%	1.0%
Phosphorus	0.48	0.4%	0.4%	0.4%	0.4%	0.4%
Lupin	0.46		10.0%			
Faba bean	0.37			10.0%		
Pea eliza	0.49				10.0%	
Pea dodoni	0.49					10.0%
Total		100.00%	100.00%	100.00%	100.00%	100.00%
Recipe cost €/kg		0.894	0.877	0.882	0.906	0.906
Recipe cost difference to control €/kg			-0.02	-0.01	0.01	0.01

The results of the feed experiment are shown in Table 26. The trial with the lupin formula was not started since preliminary taste experiments showed that the fish did not feed on this formula, very likely due to a unpleasant taste related to the lupins. The faba bean mix which had a slightly lower feed cost resulted in almost equal feed costs as the control mix. Both pea mixes had higher feed costs per kg fish produced due to higher recipe costs and lower standard growth rates.

Table 26. Results of feed experiment with sea bream after a 60 day period; SGR: specific growth rate (per day); FCR: food conversion rate

	g/day	SGR	FCR	feed cost €/kg fish produced	Difference nutrient cost
Control	0.45	1.09	1.18	1.06	
Faba bean	0.43	1.06	1.21	1.07	1.4%
Pea eliza	0.37	0.97	1.42	1.29	21.6%
Pea dodoni	0.42	1.05	1.26	1.14	8.3%

Conclusion on feeding legumes in aquaculture

The feed experiments show further potential for including legumes at considerable shares in fish feed for aquaculture. The prices of legumes assumed in the feed mixes are partly higher than the ones observed on commodity markets. For example, faba bean is traded at below 200 €/t in Ireland, lupin slightly above 200 €/t and pea is often marketed at prices far below 200 €/t (see section 'Crop level'). Assuming rising soybean prices, the advantage of alternative legumes is more and more obvious.

Discussion

Analysing costs and benefits of legume production at farm level considers the lower economic output per hectare and the recognition of legumes' rotational effects and the combined economic benefits due to increased revenues from following crops and decreased production costs.

The analysis of regional case studies from the Legumes Translated data set showed that the economic performance of individual legume crops other than soybean was in most case studies lower or at least not attractive compared to winter wheat. This major drawback in form of foregone income has to be borne by farmers. Soybean, however, was found to be profitable also on the single crop level. Considerably higher prices that in some cases were more than 50% higher than those of other grain legumes led to this advantage.

However, legumes impact the production of other crops in a rotation which results in resource benefits on a farm in form of potential yield benefits of subsequent crops, savings in fertiliser, pesticides, machinery and labour costs. Therefore, when considering whole cropping systems the benefits of legumes are worth the costs for a farmer if the rotational gross margin is competitive to common non-legume systems. The analysis of the Legumes Translated case studies showed that when taking the economic performance of reference cropping systems without legumes as a benchmark, legume-supported systems were in over half of the considered case study regions competitive. In these regions either soybean-supported cropping systems were cultivated or rotations in which grain legume yields were relatively high, as it was shown with high-yielding faba bean in Ireland and Scotland. The high profitability of the soybean-supported systems is also reflected in the actual cropping shares in these case study regions. Proportions of over 10% up to almost 30% of soybean in arable land which are given for instance in the Burgenland (AT 11), North Italy (ITH 4) or the Kyiv oblast, clearly indicate that farmers perceive soybean as a viable crop choice and integrate the legume in rotations. The competitive GMs of the legume-supported systems in Scotland and Ireland are, however, not reflected in the regional land use patterns, indicating further barriers as marketing issues, risk aversion due to assumed higher yield variations in legumes or missing knowledge on legume cultivation. The economic potential of legume-supported systems varied in the other considered case study regions. In various regions GM deficits were found that indicate the need to support the economic performance through policy measures or development of value chains which could increase market prices. The effectiveness of such efforts could be shown with the reduced GM deficits when introducing modifications in the GM calculations such as the substitution of legume market prices with their feed value, the inclusion of legume-related subsidies from the CAP and a carbon tax.

The economic potential of legumes on mixed farms can be clearly increased compared to arable farms through on-farm feeding. Analyses of the reported legume market prices of pea, faba bean and lupin in relation to the actual feed value showed a considerable under-valuation. As long as the threshold of the calculated feed value is not achieved on the market, farmers economically benefit from feeding home-grown grain legumes. Forage legumes as grass-clover in Scotland were also found to be economically viable and can be a valuable feed for ruminants. Moreover, benefits of European-grown legumes in livestock production are linked to the increasing prices of conventional protein sources as imported soybean and could be shown to be interesting components for rations in livestock sectors as pig production and aquaculture.

The integration of costs and benefits in the analysis that go beyond the individual farming enterprise - those that have to be borne by society – showed that legume-supported systems have benefits that do not directly appear on the balancesheet of a farm. The comparison of ESS provision outlined that cropping systems with legumes had in the majority of cases better environmental performances in terms of nitrogen fertiliser use, nitrous oxide emissions and partly also in nitrate leaching. Benefits for provisioning services were also found concerning protein outputs. The analysis covered only partly the contribution of legumes to ESS, also because not all benefits in this context can be easily quantified. However, it allowed to identify trade-off, lose-lose or win-win situations. The latter illustrated systems that combined high profitability and ESS provision which indicated best practices for the respective regional context. In order to achieve profitable and sustainable inclusion of legumes in farming systems, the exploitation of rotational effects is a key factor and depends on several factors as environmental and agronomic conditions as well as farmers' management decisions.

The evaluation of experiences on legume cultivation and integration in livestock feed rations of project partners led to some limitations in the analysis. The regional case studies on cropping systems were collected with diverse compilation approaches of project partners which is why there were cropping systems which represented actually cultivated rotations on farms or research stations, but also expert-derived data based on regional statistics. These diverse data backgrounds prevent not only direct comparisons, but also a common approach for the quantification of legumes' pre-crop effects.[70] Feed rations were provided based on experimental rations and new formulas which allowed first insights, but prevent generalizations. Therefore, the considerations can only provide a range of orientation on what can be achieved in legume production and integration in livestock production and offer decision support only in the regional context.

The economic evaluation of alternative feed rations in aquaculture showed promising results for faba beans in terms of cost-savings as compared to the use of imported soybean meal. If lower prices for other European legumes are assumed, also other legumes such as peas and lupins can be competitive. Furthermore, there is potential to further decrease the share of fish meal and oil in fish feed formulas.
The work on pig feed rations showed economic advantages through replacing soybean in feed rations with other grain legumes. However, the nutritive quality can decrease to some extent which needs to be further evaluated through feed experiments, which BESH is performing in the next months. An advantage of the premium market that BESH is serving is the higher meat price they can achieve. This allows a focus on other factors than just pure cost-effectiveness, but also issues of animal welfare and the support of regionally produced feed stuffs.

[70] More details on the compilation of the data set and consequences are provided in Deliverable Report 5.2.

Conclusion

A major economic challenge for legumes in European farming systems is their constant under-valuation in different relations. Market prices are not reflecting actual feeding values of grain legumes such as pea, faba bean or lupin. Assessments of economic performance at single crop level disregard essential resource benefits and hence economic advantages for the legume-supported systems. Additionally, non-market outputs depicted in the provision of various ESS are not directly reflected in standard gross margin calculations which also fosters the underestimation of legumes.

Analysis of real-world cropping systems from regions all over Europe have shown that legume-supported systems can be competitive to common non-legume systems when all rotational effects are taken into account. These competitive systems occur where soy grows well or where high legume yields of other legumes can be achieved. These high economic performances were concomitantly supported by increased ESS provision, indicating win-win situations. Cases with trade-offs between lower economic performance and higher ESS provisions in legume-supported systems can be avoided by increasing legumes' farm level profitability, either by increasing yields or by achieving higher output prices. There are trends which will automatically contribute to this increase such as rising prices of agricultural inputs or imported soybean. However, specific efforts to support market development to rise legume selling prices and to support crop performance using genetic and agronomic improvement will boost competitiveness further.

On a policy level the social benefits of legumes can be reflected through the inclusion of legumes in the upcoming eco-schemes of the EU CAP. If by such means the profitability at farm level can be increased through legume integration in cropping systems, legume production can be considerably incentivised and sustainability of European cropping systems fostered. European grain legumes can gain higher importance in the feed sector given rising soybean world market prices and changing market preferences. If such signals develop, the feed industry and livestock producers including aquaculture will invest in using alternative resources for protein.

ACKNOWLEDGEMENTS

We also thank Blackert, B., Fricke-Müller, M., Heimel, P., Hufnagel, J., Korchahina, I., Lazzari, F., Milev, G., Nußbaumer, H., Pochiscanu-Isticioaia, S., Radiuk, A., Rosner, G., Rezi, R., Todorova, R., Rüdiger, G., Vasileva, V., Wille, R. for providing and discussing data on cropping systems.