LEGUMINOSE

the way to a green transition

Report on barriers and opportunities towards intercropping

16/01/2024

D2.2

Tiffanie Faye Stone and Martin Hvarregaard Thorsøe

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Summary

LEGUMINOSE (Legume-cereal intercropping for sustainable agriculture across Europe) is a research and innovation project funded by the European Commission (EC) under the Horizon Europe research program with the aim to identify the obstacles to intercropping and enhance farmers' acceptance by providing knowledge and demonstrations that promote economic, environmental, and social benefits of legume-cereal intercropping. The project is based on the premise that intercropping has the potential to reduce pesticides and improve plant-microbe mediated element cycling, soil health, and crop quality and health.

Summary of Deliverable

The purpose of this report is to provide a synthesis of barriers and opportunities based on surveys of farmers in 7 European countries (Czech Republic, Denmark, Germany, Italy, Poland, Spain, and the United Kingdom) as well as Egypt and Pakistan.

The current report (D2.2) is part of a series of reports under LEGUMINOSE WP2. Other deliverables of the WP include Establishment of Dynamic Partnership Map (D2.1), Report on opportunities for intercropping species mixtures (D2.3), Report on dynamics of transition pathways and socio-technical lock-ins in arable farming (D2.4).

List of abbreviations

Technical	D	Deliverable
	EC	European Commission
	LL	Living Lab
	WP	Work Package
Partners (including sub-contractors)	APR	Agritec Plant Research S.R.O., Czech Republic
	AU	Aarhus Universitet, Denmark
	CIA	Confederazione Italiana Agricoltori Toscana, Italy
	CSIC	Agencia Estatal Consejo Superior De Investigaciones Científicas, Spain
	DSV	Deutsche Saatveredelung AG, Germany
	ECOLOGICA	ECOLOGICA For Environmental Consultants and Studies Co. L.L.C., United Arab Emirates (sub-contractor of UNIFI)
	GCUF	Government College University Faisalabad, Pakistan
	IAPAS	Instytut Agrofizyki Polskiej Akademii Nauk, Poland
	LUH	Gottfried Wilhelm Leibniz Universitaet Hannover, Germany
	UNIFI	Universita Degli Studi Di Firenze, Italy
	UPA	Unión de Pequeños Agricultores y Ganaderos, Spain
	UREAD	University of Reading, UK
	SA	The Soil Association, UK
Countries	DE	Germany
	DK	Denmark
	ES	Spain
	IT	Italy
	PK	Pakistan
	PL	Poland
	CZ	Czech Republic
	UK	United Kingdom
	EG	Egypt

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1 Introduction

LEGUMINOSE (Legume-cereal intercropping for sustainable agriculture across Europe) is a research and innovation project funded by the European Commission (EC) under the Horizon Europe research program with the aim to identify the obstacles to intercropping and enhance farmers' acceptance by providing knowledge and demonstrations that promote economic, environmental, and social benefits of legume-cereal intercropping. The project is based on the premise that intercropping has the potential to reduce pesticide use and improve plant-microbe mediated element cycling, soil health, and crop quality and health.

The purpose of this report is to identify barriers and opportunities seen by stakeholders towards intercropping. The report is part of a series of reports of WP2 of the LEGUMINOSE project that assess the foundations for intercropping in farming systems across Europe and beyond. These reports include the D2.1 *Map of Establishment of Dynamic Innovation Partnership (DIP),* that establishes the foundations for selection of participants in a stakeholder forum. Further the D2.3 *Report on opportunities for Intercropping species mixtures,* which assesses the opportunities, strategies and enabling conditions for legume-cereal intercropping. Finally, the D2.4 *Report on dynamics of transition pathways and socio-technical lock-ins in arable farming*, which conducts a more thorough assessment of the survey data presented in this report using Structural Equation Modelling (SEM).

Although each with a different focus, these reports are all based on feedback from stakeholders in various forms. The primary focus is to gather and improve the understanding of the enabling conditions for upscaling the adoption of intercropping.

1.1 Purpose

The purpose of the WP2 of LEGUMINOSE is to identify the knowledge gap between research and on-farm intercropping practices, to support subsequent research, experimental activities, and work dissemination. More specifically, the objectives of D2.2 is to:

1. Summarise farmers' responses in each participating country to identify current farm system characteristics, infrastructure, and management practices.

2. Identify survey results that could guide field experiments, training, and the study of decision-making in WP7.

3. Assess farmers' opportunities and barriers with respect to adoption of intercropping practices.

1.2 Structure

Chapter 1 provides an introduction to the report.

Chapter 2 presents the methodology that has been used by partners to acquire data based on national contact points and methodology applied in the compilation of results in this report.

Chapter 3 presents a synthesis of results from a survey of farmers regarding their perspectives on barriers and opportunities to integrate intercropping on their farming systems. The chapter is organised in six sections each representing different considerations for intercropping across the national partners.

Chapter 4 summarises the main conclusions.

2 Methodology

This report is written as a synthesis of the 9 national surveys that were disseminated by partners in 2023. In this chapter we describe the approach and content of the survey, the data that has been produced, and finally, our approach to the comparison of the individual national survey results.

2.1 Survey development and dissemination

Before the survey was administered, AU requested that consortium partners identify existing studies, which together with the initial review of existing projects and research by AU partners provided a basis for the survey design (initiated as part of T2.4). A joint meeting of all partners was conducted to present the survey draft and receive and integrate input and suggestions. A survey template for this concise survey (~10-15 min) was provided to each partner country and was administered on a country basis. The survey included five sections, 1) Background information, 2) Crop choice, 3) Crop management 4) Intercropping and 5) General feedback. The survey contain qualitative as well as quantitative elements, thus providing different types of complementary information, offering a rich picture on farmers perspectives of a transition to intercropping (Creswell, 2014).

The survey template was made available in English and was completed by participants in English or using a translated version with the same questions and categories, the full survey template is available (Appendix A). The survey included a combination of open questions (with optional written input) and closed questions (with multiple choice options). The template also included a GDPR statement and an informed consent form.

2.2 Data collection

Identifying a useful sample of farmers was central to accomplishing our study aims. Given the diversity of farms and opportunities for accessing farms, partners were able to decide the best approach to reach farmers in their country, either online, by phone or face to face. Each partner country identified a sampling frame appropriately sized to reach a sample of at least 200 farmers. As response rates for email surveys are typically low, more participants needed to be identified in this approach. Best practices for establishing points of contact and sending reminders were also considered. The farmers surveyed did not need to be intercropping at present but were selected to represent the prevailing production systems across the surveyed countries. Since some partner countries cover a large geographical area, farming practices would be incoherent, so particular regions within these countries were selected to participate in this survey.

Farmer surveys were conducted in each of the nine countries with total participation of 2051 with an average of 228 respondents per country (median 180). The number of respondents by country ranged from 818 in Denmark to 44 in the United Kingdom (Figure 1). The sampling frame was established on a country basis. Given the variation of farming systems across the surveyed countries, partners employed various approaches to gather data. For the most part, the survey was administered as an email survey, either through a direct contact or as a pop-up survey on a homepage or in a newsletter. The web-based format naturally gives preference to farmers that are younger, and less resource constrained, hence it may be more likely that the farmers responding are more open to engaging with academic research than average farmers and more open to adopting innovation, although this participation bias is difficult to account for. This variation in the number of informants and their related stakeholder categories is a minor shortcoming reflecting that the perspective and methods of stakeholder consultation varied slightly across countries. In Spain, farmers mentioned on several occasions that the survey was too long, and this could have affected obtaining more responses.

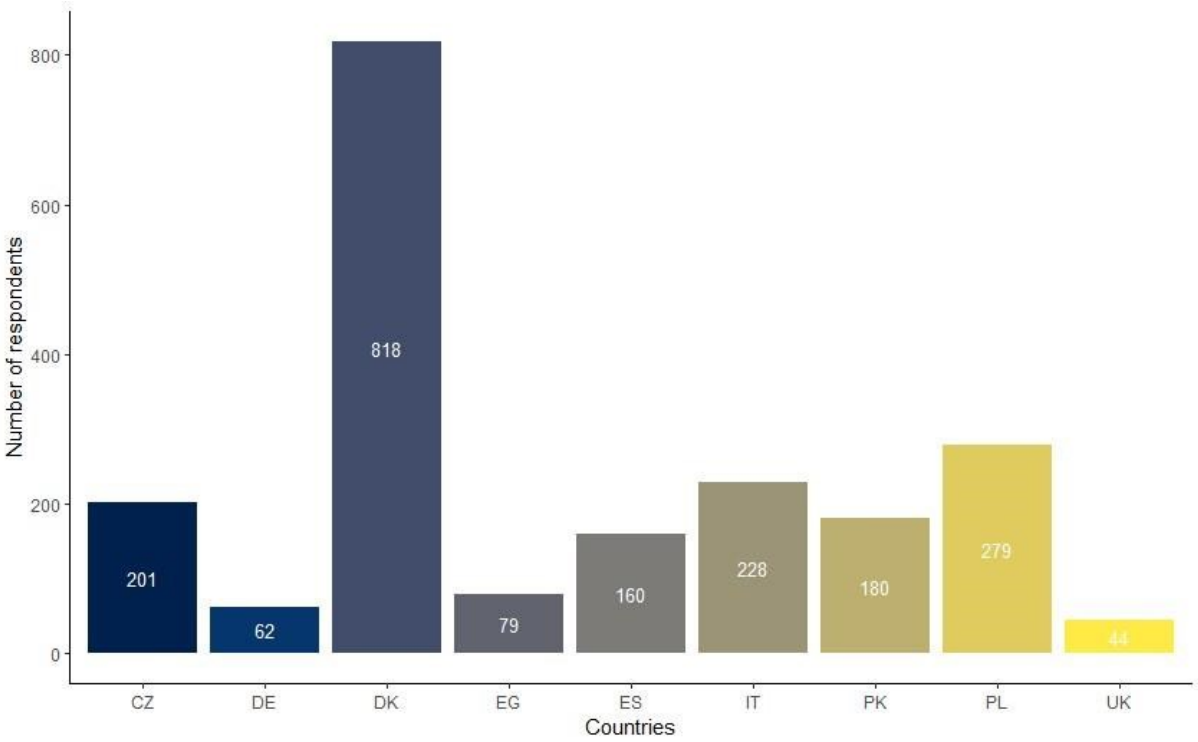

Figure 1 - The total survey participation by country with number of responses for each national survey listed in white.

2.3 Data treatment

The survey data was wrangled and analysed in R with *tidyverse* and *ggplot2* packages. Due to the uneven number of responses by country, results are presented as percentages to enable cross country comparison within the figures presented. In addition, weighted averages are presented in the text, as otherwise the largest dataset from Denmark would have the strongest influence in the interpretation of results.

All Likert scale questions were asked on a 1 – 5 scale with an additional "I don't know" option. To enable effective interpretation, "I don't know" responses were omitted from the visualisations. When respondents selected two numbers on the Likert scale or indicated two values for a response throughout the survey an average was taken. Some of the national surveys omitted questions or specific factors either in error or knowingly based on irrelevance in the country's specific context. In either case, these show up as missing values in the figures (e.g., white boxes in the heatmaps).

Barriers and Opportunities questions were interpreted in two ways, resulting in two groups of responses. For barriers in Group one, respondents (n= 166, 8.1%) listed the top three most important factors from a list leaving the other factors blank. In Group 2 (n= 1885, 13.9%) each factor was rated as most, second most and third most important. These two groups were processed together, however, additional processing was necessary for the Barriers and Opportunities questions for the United Kingdom dataset (n= 44) as each of the factors were ranked (from 1 most important to 8 least important), so a subset of the top three were selected. Similarly, a portion of the Egypt dataset was also ranked and a subset of the top three were taken for these responses as well.

With respect to the qualitative data provided in the open questions, each national partner synthesised the replies to open questions and prepared a national report based on a set of predefined questions, to provide context and enable comparisons across national contexts where inputs were provided in local languages. This ensured that we could represent perspectives of individual stakeholders or specific national concerns and reflections. Importantly, when we analysed national datasets, input from each country was presented

separately without a regional aggregation to avoid blurring differences in representation as well as other national and regional characteristics.

For the analysis of the qualitative elements, the text which summarised discussions across partner countries was initially coded, and subsequently organised into categories, identifying common themes, shared experiences and patterns. Following, Corbin (1998) and Silverman (2011), initially the text provided by partners was examined line by line. After coding of the entire text, similar codes were grouped into higher order categories that are broader and encompass the content of several codes thus reducing the overall amount of concepts for the analysis.

2.4 Survey demographics

The most common age groups for producers surveyed were the two oldest 41-60 years old (n= 981), followed by greater than 60 years old (n= 575) (Figure 2). The smallest was the less than 25 age group (n= 80) and 26-40 years old was the second smallest (n= 383). The gender most producers identified with was as a man at 90.1% (n=1848), followed by as a woman at 9.0% (n=184), only twelve respondents identified as another option or chose not to disclose (Figure 3). The majority of respondents (62.6%, n= 1284) work full time on the farm, 33% work part time on the farm, and 3.3% selected other or chose not to disclose their occupational status (Figure 4).

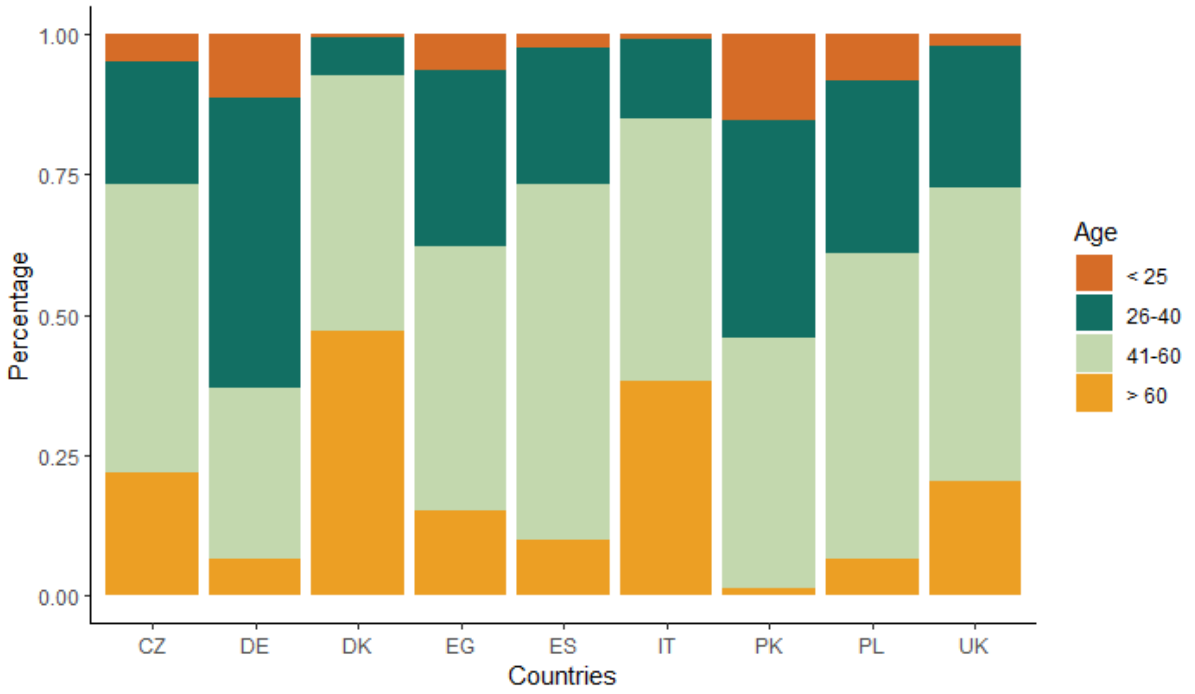

Figure 2 – Percentage of reported age category (< 25, 26-40, 41-60, > 60) of survey respondents by country.

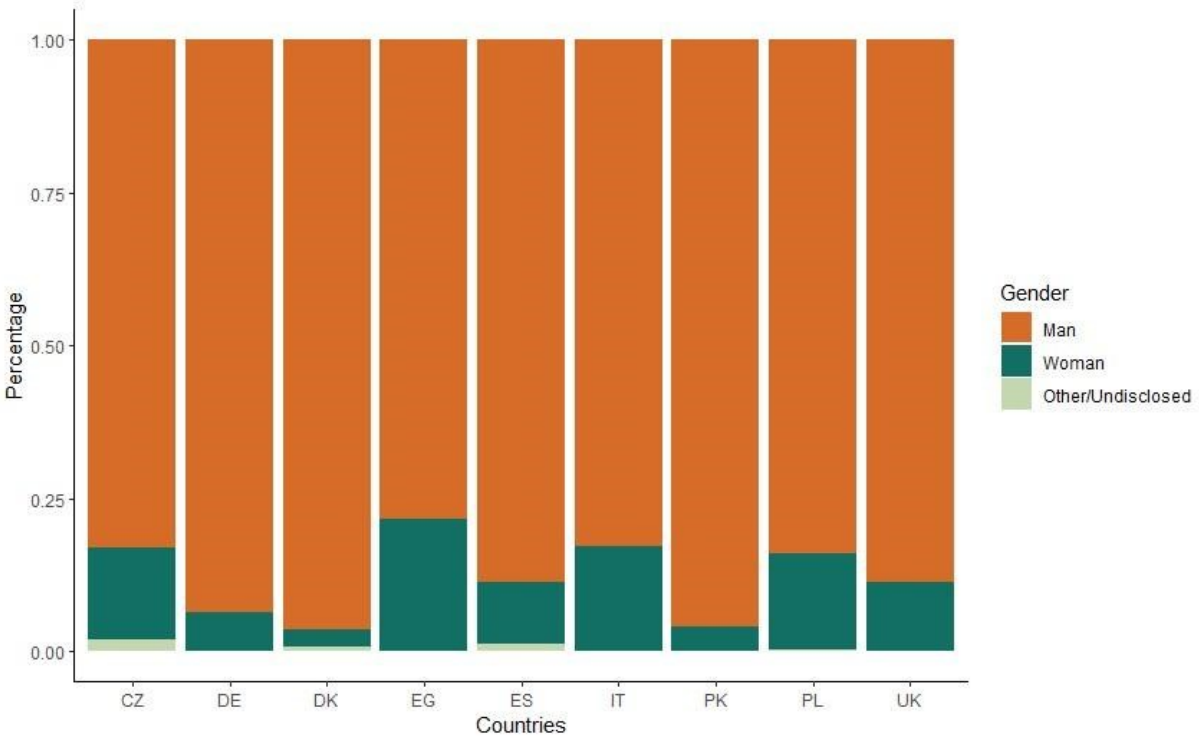

Figure 3 – Percentage of reported gender (man, woman, other/undisclosed) of survey respondents by country.

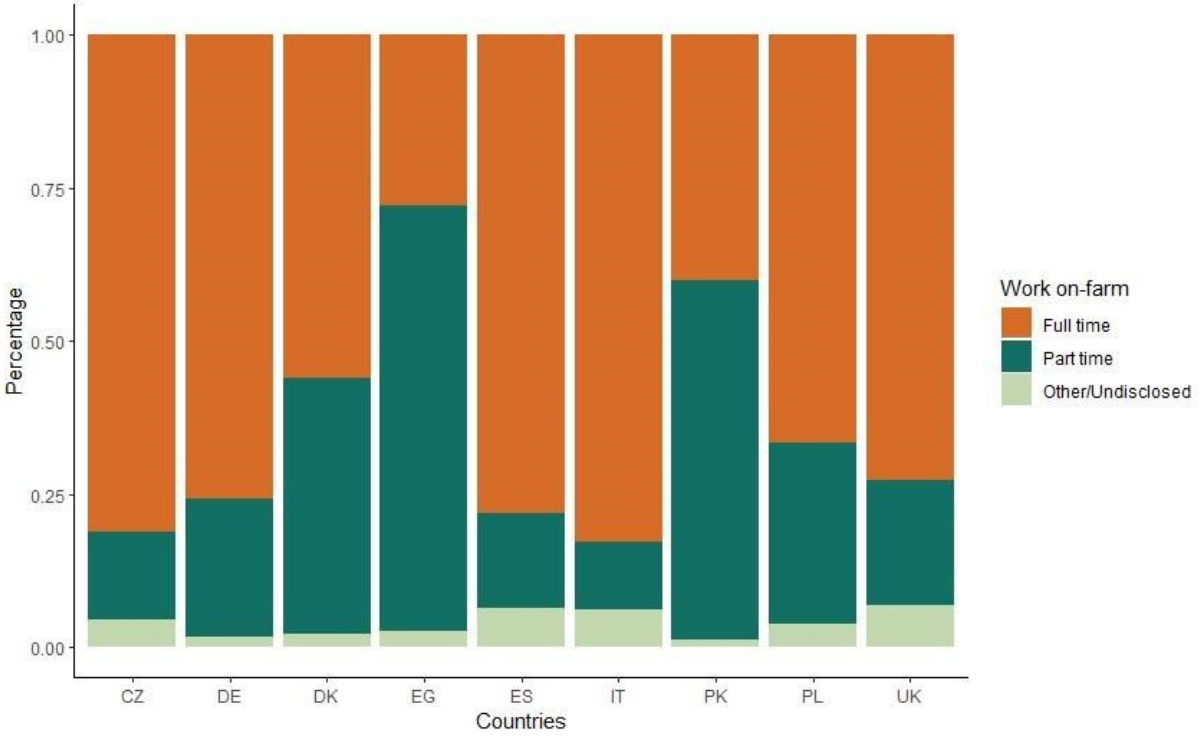

Figure 4 – Reported on-farm work category (full time, part time, other/undisclosed) of survey respondents by country.

3 Results

This section outlines the outcome of a survey gathering farmer reflections regarding crop choice, crop management as well as the opportunities and barriers for legume-cereal intercropping. The results section begins with an overview of farm system characteristics (section 3.1) including farm system resources and challenges. Subsequently, the cropping system characteristics are presented (section 3.2). Crop choice, crop management and crop market channel and crop choice information sources are outlined (section 3.3), followed by experience and likelihood of adopting intercropping (section 3.4). Finally, we identify barriers and opportunities toward intercropping (section 3.5).

3.1 Farm system characteristics

The majority of respondents operate a conventional farm system (83.9%, n= 1720), while 12.2% operate an organic farm system (n= 250) (Figure 5). Most of those that chose other (n=73) specified that they have both organic and conventional fields. Several conventional farmers also specified that they use regenerative principles on their farms (these were included in the conventional category). The biggest categories for total arable land size were the smallest with less than 50 ha (n= 945), followed by the largest with greater than 200 ha (n= 424) (Figure 6). An additional 195 farmers reported a size of 101-150 ha and 117 reported a size of 151-200 ha. Soil type based on soil texture varied significantly across countries; however, the two most common soil types were sandy loam (n= 698), followed by sandy soil (n= 599) (Figure 7). The most common livestock animal kept was cattle including both dairy and beef (38.9%, n= 797), although the majority of respondents did not keep livestock (53.7%, n= 1101) (Figure 8).

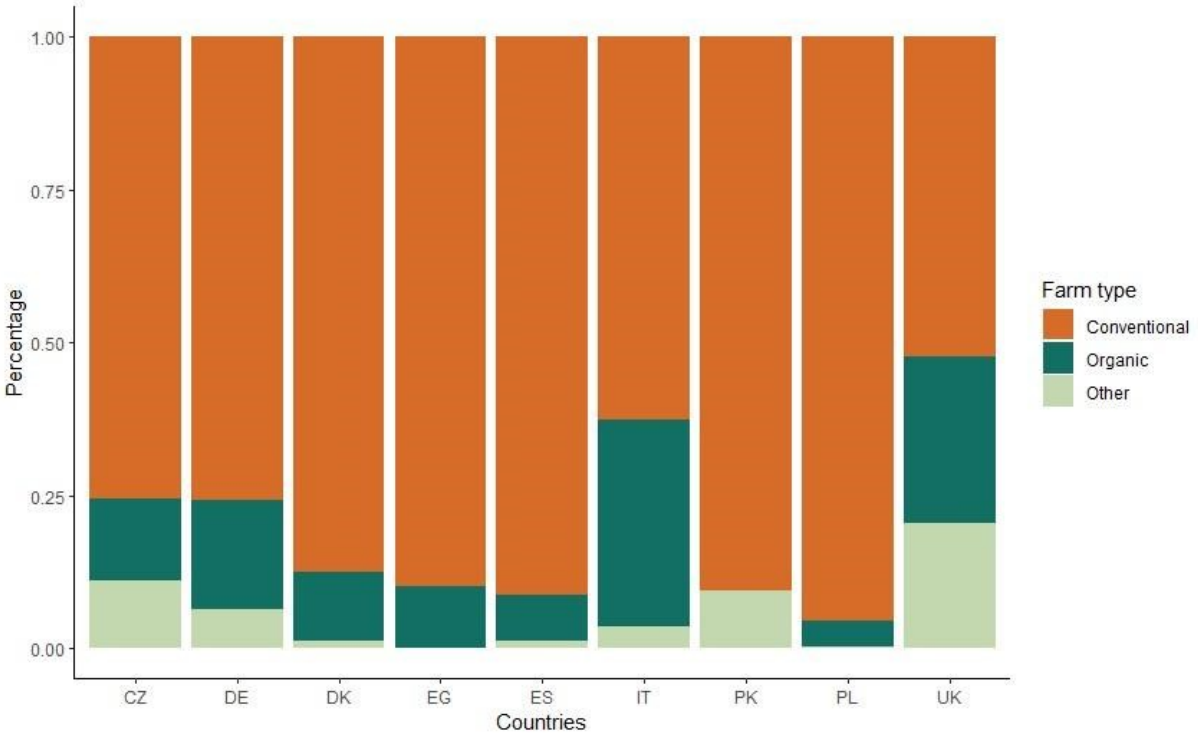

Figure 5 – Percentage of farm types (conventional, organic, other) of survey respondents by country.

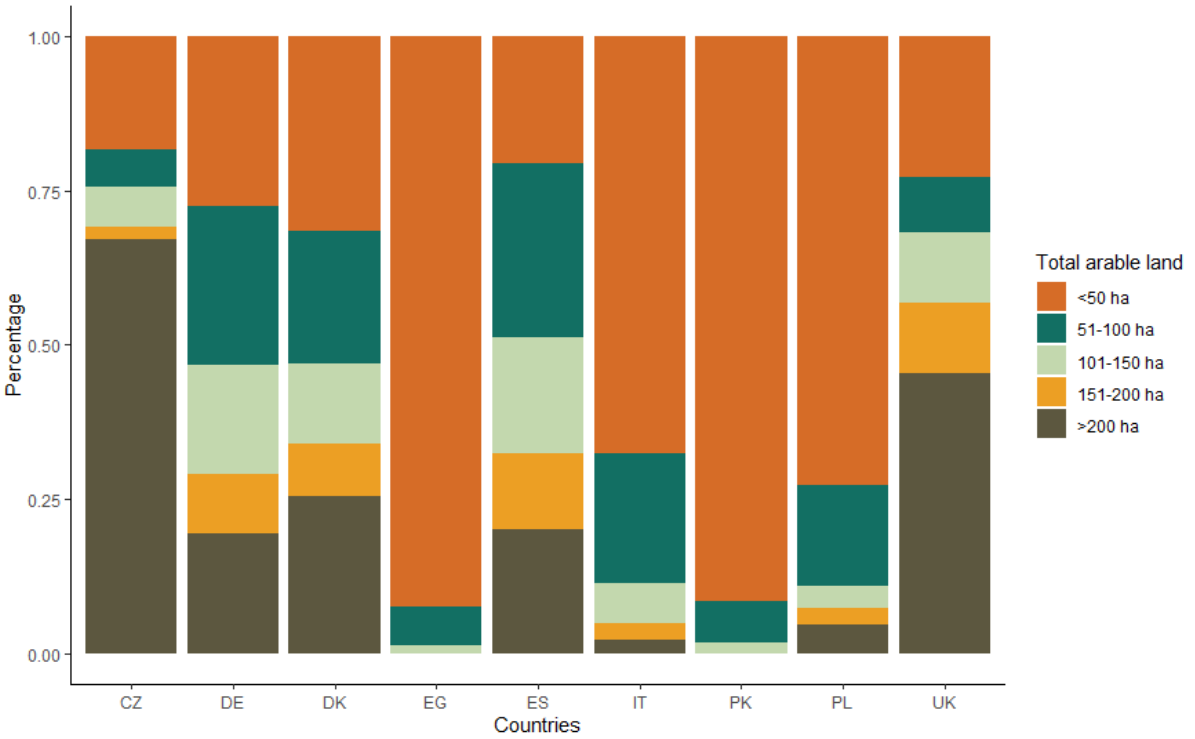

Figure 6 – Percentage of total arable land categories (>50 ha, 51-100 ha, 101-150 ha, 151-200 ha, and >200 ha) of survey respondents by country.

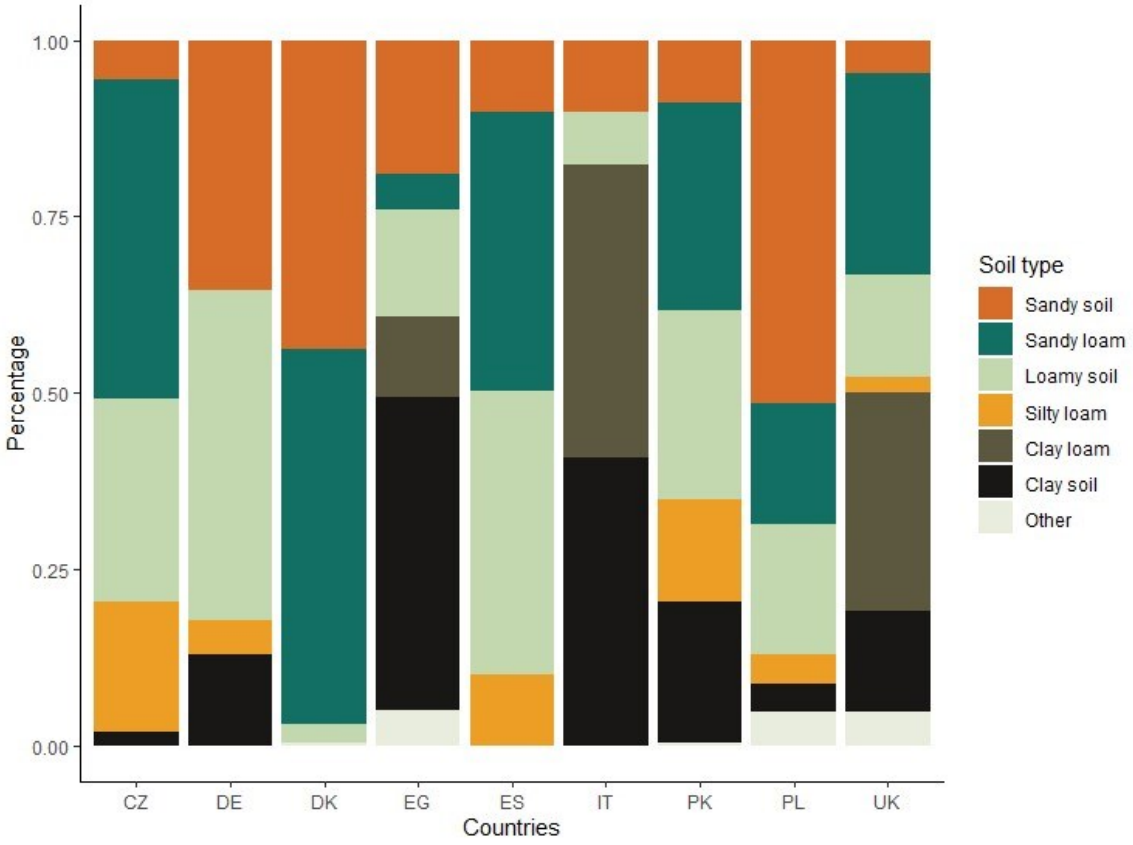

Figure 7 – Percentage of soil type categories (sandy, sandy loam, loamy, silty loam, clay loam, clay, and other) of survey respondents by country.

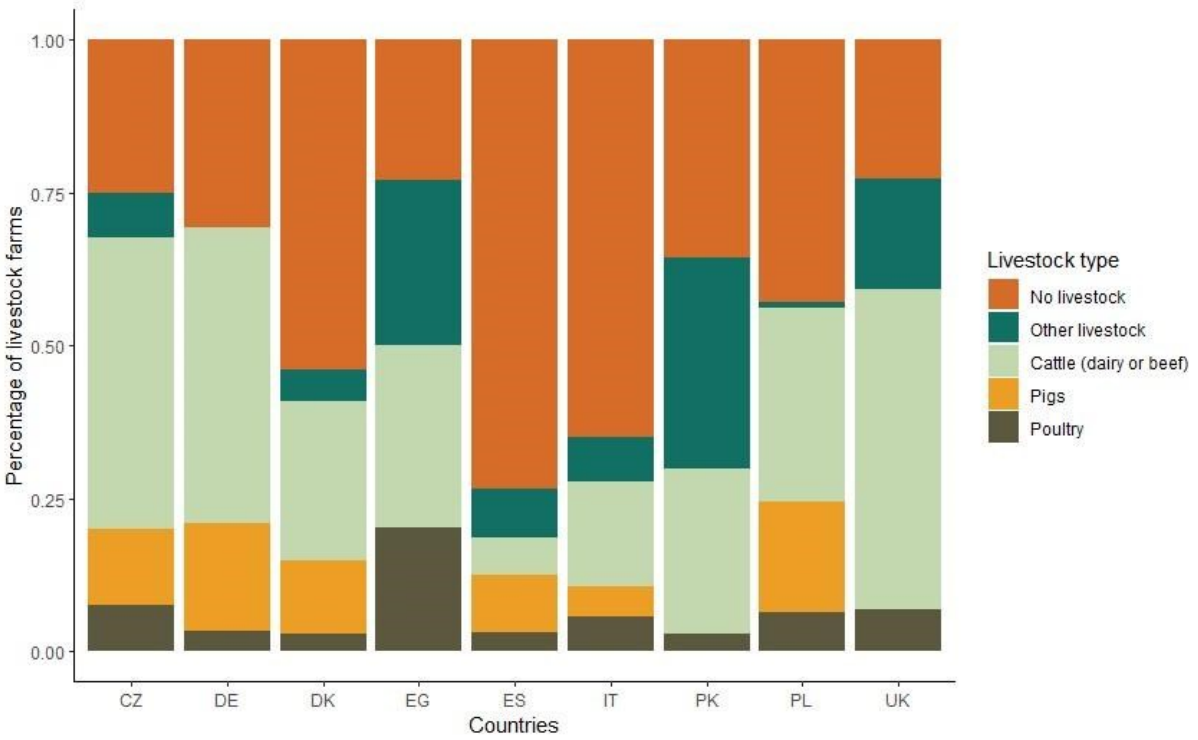

Figure 8 – Percentage of livestock categories (poultry, pigs, cattle - dairy or beef, other livestock, no livestock) kept on farm systems of survey respondents by country.

Farmers were asked to rate the challenges they faced from a list of options on a five-point Likert scale from not at all up to a very high extent. The top three most important factors based on the weighted average by country were 1) Drought (3.57), 2) Weeds (3.32), and 3) Low soil fertility (2.70) (Figure 9). The least important factors were Salinization (2.05), Erosion (2.24) and Flooding fields (2.54). Figure 9 highlights the variability across the countries assessed, for example, drought is important across all countries, but this challenge is particularly critical to respondents in Czech Republic, Germany, and Spain. Similarly, low carbon is critical to respondents in Egypt and weed control is considered particularly challenging in Pakistan and Poland.

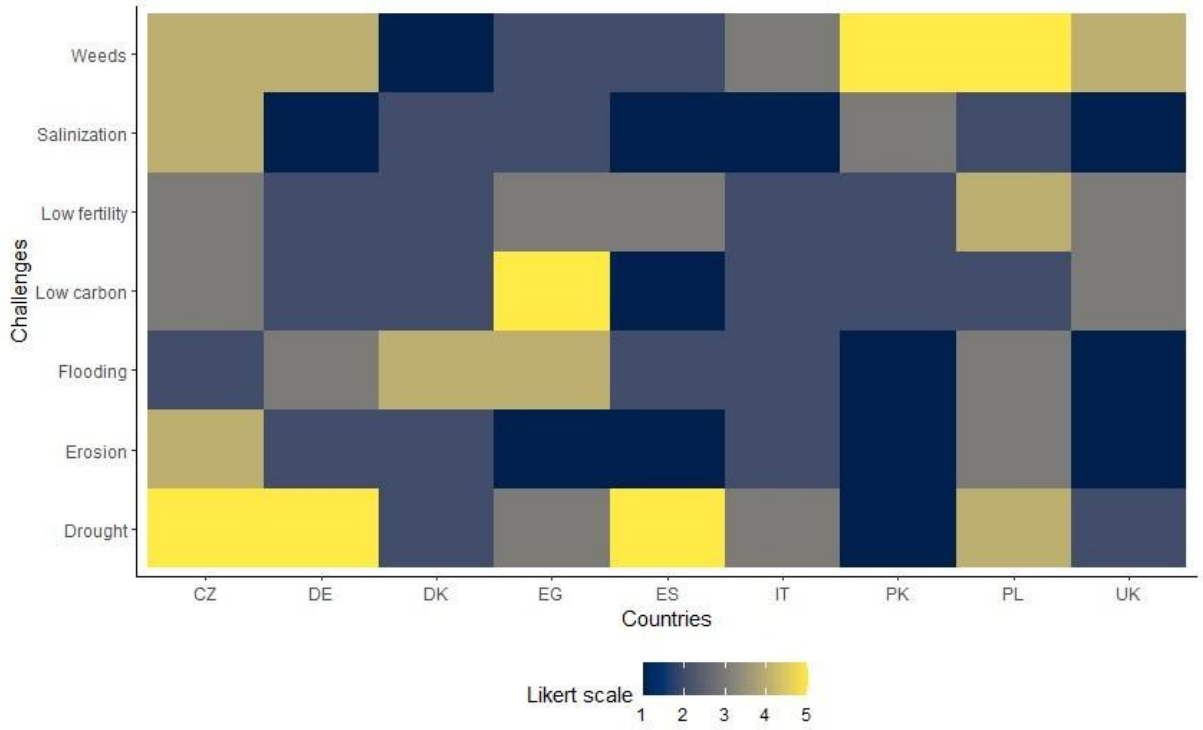

Figure 9 – Average Likert scale ratings for challenges experienced by respondents listed by country (1: Not at all, 2: To a small extent, 3: Neutral, 4: To some extent, 5: To a very high extent).

3.2 Crop system characteristics

The survey asked about the number of crops grown and respondents reported growing by country weighted average 5.34 different crops (Figure 10). The highest average number of crops reported by country was in the Czech Republic (7.09), and the lowest was in Egypt (2.03). The missing value in Figure 10 is due to this question not being asked in the Denmark survey. The percentage of grain grown by country weighted average was 57.5%, while legumes made up just 11.5% of total crop production (Figure 11). Spain (65.6%) and Denmark (63.8%) grew the highest percentage of grain while Egypt grew the highest percentage of legumes (41.3%).

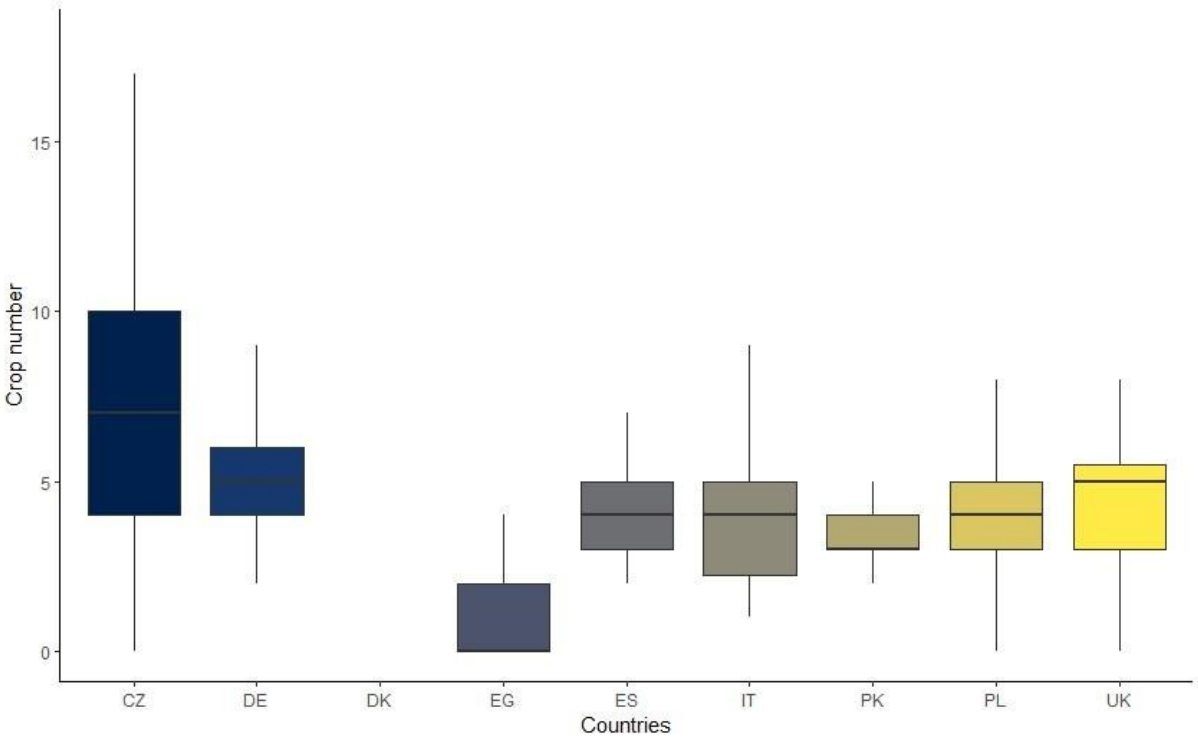

Figure 10 – A box plot with outliers hidden of the number of crops grown on each farm system by country.

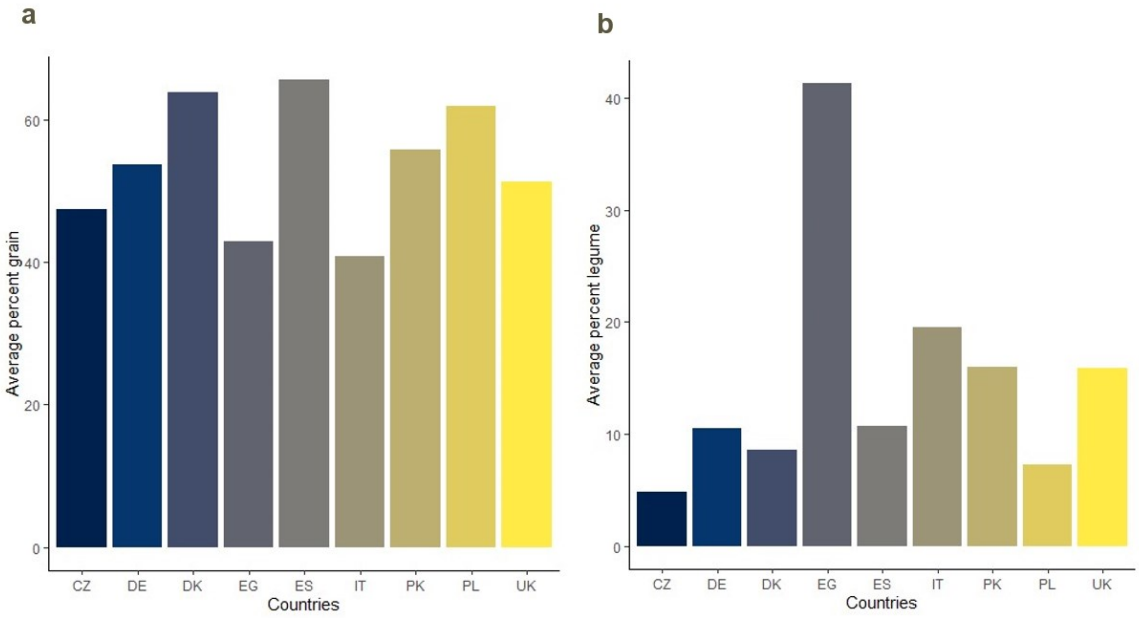

Figure 11 – a) Average percentage of grain crops grown by country and b) Average percentage of legume crops grown by country. The y-axes are scaled differently to enable cross country comparison.

The use of irrigation varied considerably by country (Figure 12). In Egypt and Pakistan, most respondents always use irrigation. The majority of respondents in the Czech Republic, Poland and the United Kingdom do not use irrigation because it is not relevant in the region. While the remaining countries (Germany, Denmark, Spain and Italy), primarily do not use irrigation, although it would be great for their crops. Two fertiliser types made up 74.5% of those reported: mineral fertilizers (n= 750), livestock manure (n= 579) and a mix of both (n= 199) (Figure 13). Aside from the manure types mentioned as categories in the closed questions, respondents also indicate that various forms of green manure, digestate and compost are utilised across the surveyed countries. The countries with the largest proportion of only mineral fertiliser use

were Denmark (49.4%) and Spain (53.8%). The category Mix (n= 245) included both mineral fertilizer together with legumes and/or organic fertilizers and this category was most prevalent in Egypt, the Czech Republic and Poland. Legumes and organic fertilizers (n= 88), and other fertilizers (n= 87) were the smallest categories.

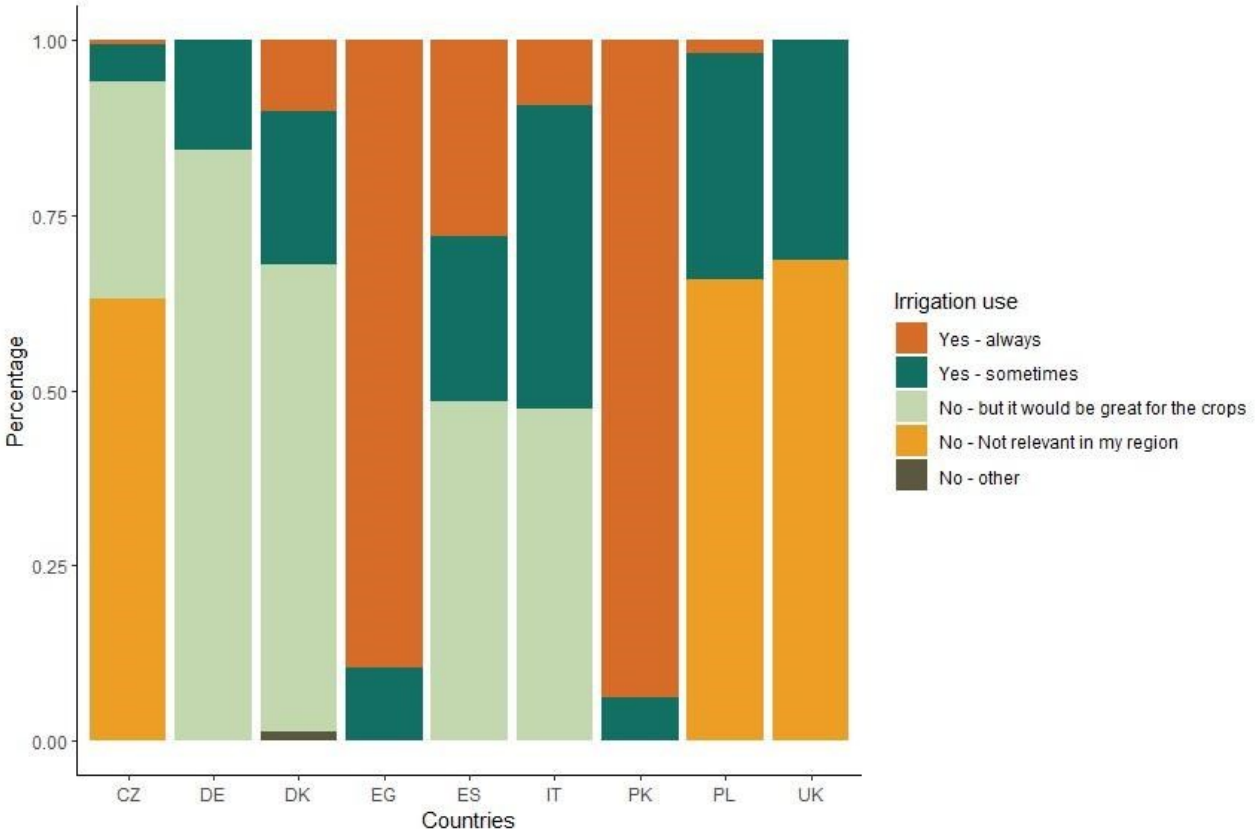

Figure 12 – Percentage of farmers using irrigation by country.

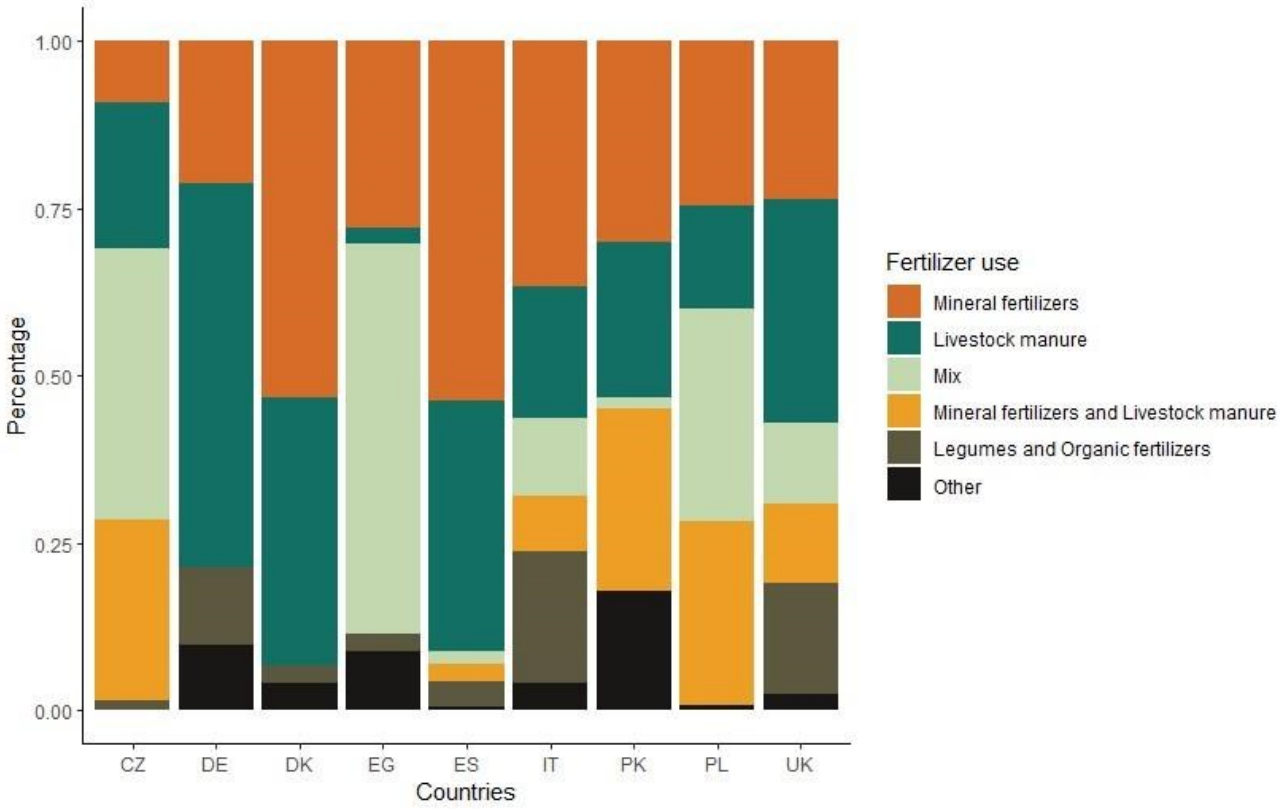

Figure 13 – Percentage of respondents by fertiliser type and by country.

Access to resources are important to understanding opportunities to change production practices. The resources with the greatest proportion of on farm access were seed drills (n= 1574) and weed management equipment (n= 1408) (Figure 14). The resources that respondents most commonly accessed through external partners were seed varieties (n=1183) and advisors (n= 1090). Many respondents did not have access to grain cleaning (n= 947), grain drying (n= 823) and credit to borrow money (n= 718).

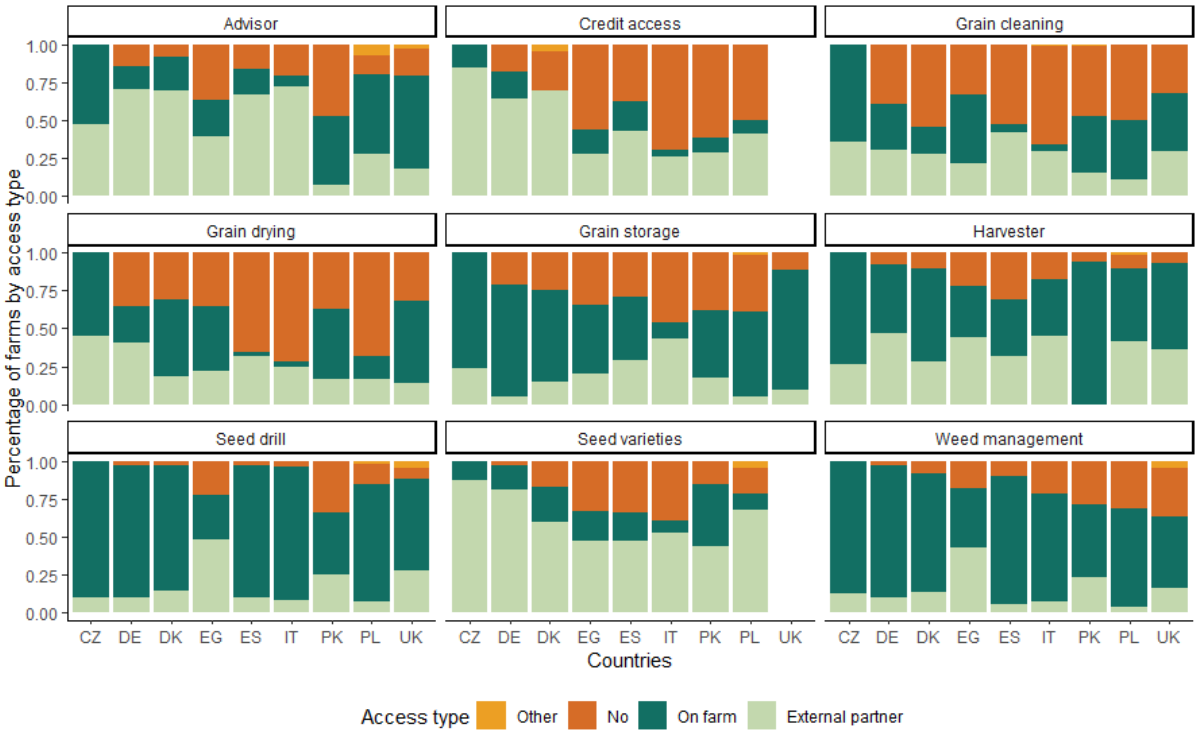

Figure 14 – Percentage of farmers with access to resources by access type (no, on farm, external partner, both, other) by country.

3.3 Crop choice, management, and markets

Crop choice considerations are important to supporting legume-cereal intercropping, and these considerations varied by country (Figure 15). The top three statements that influenced crop choice to the largest extent based on the weighted average by country were 1) It is very important that my crops are resistant to diseases (4.30), 2) I select crops based on past experience (4.26), and 3) I prefer varieties with a high yield (4.14). The statements respondents agreed with least in relation to crop choice were 1) The crops are selected for me (1.87), 2) My current cropping system is not sustainable (2.54) and 3). I select crops in collaboration with my advisor (2.91). The individual countries rated crop choice statements very differently. For example, Pakistan rated 8 out of 11 statements as important to a very high extent on average while Spain rated the same number of factors as not at all important.

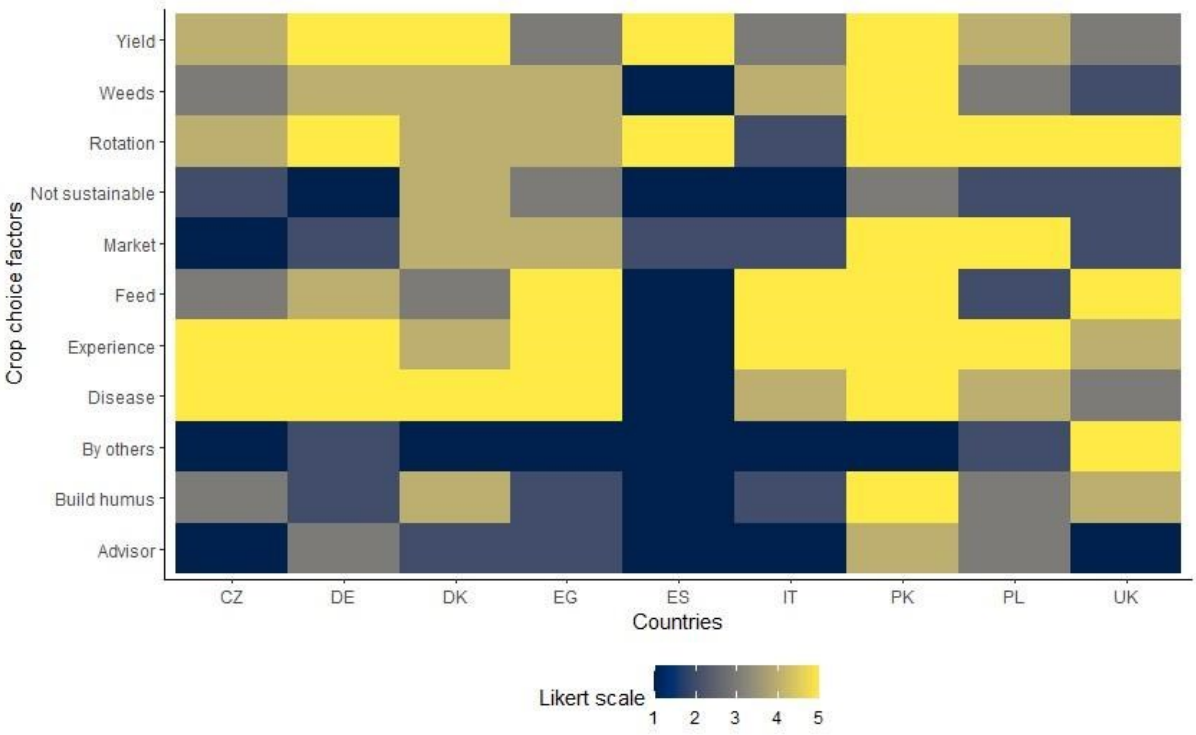

Figure 15 – Average Likert scale ratings for factors impacting crop choice of respondents by country (1: Not at all, 2: To a small extent, 3: Neutral, 4: To some extent, 5: To a very high extent).

Various crop management practices were used within each country surveyed (Figure 16). Of the four practices listed, the most common crop management practice used by farmers was mechanical weeding (n= 718). Integrated pest management was the least common practice (n= 532). Few farmer respondents did not use at least one of the practices listed (n= 349). By country, Pakistan had the greatest proportion of farmers using conservation agriculture (67.8%) while Italy had the greatest proportion of mechanical weeding (61.4%).

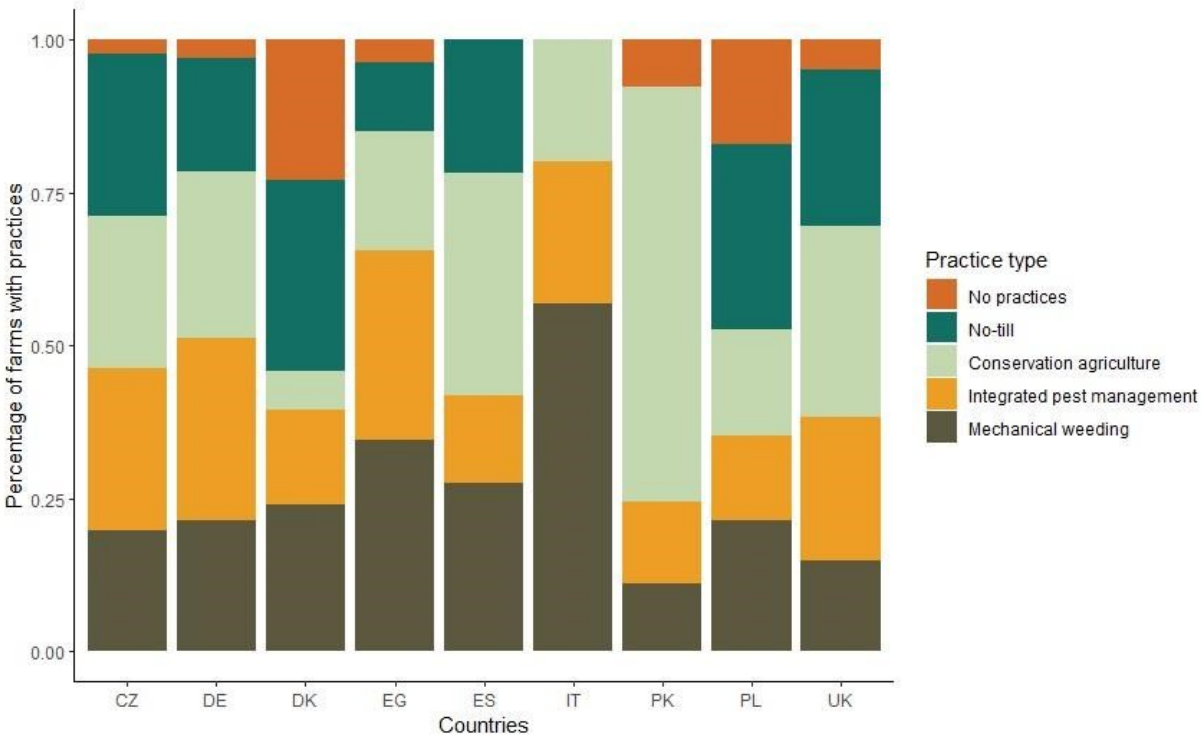

Figure 16 – Percentage of farmers with crop management *practices (no practice, no-till, conservation agriculture, integrated pest management, mechanical weeding) by country.*

The top three statements that influenced crop management to the largest extent based on the weighted average by country were 1) Having clean fields is important to me (4.27), together with I find it is very important to continuously monitor crops for pests or disease (4.27), and 3) Weed and pest management is planned during the growing season (3.99) (Figure 17). The statements respondents agreed with least in relation to crop choice were 1) My fields are managed by external contractors (1.72), 2) I use decision support tools to adjust my disease and pest management in the growing season (2.62) and 3). Following a fixed spraying schedule is important to me (2.87).

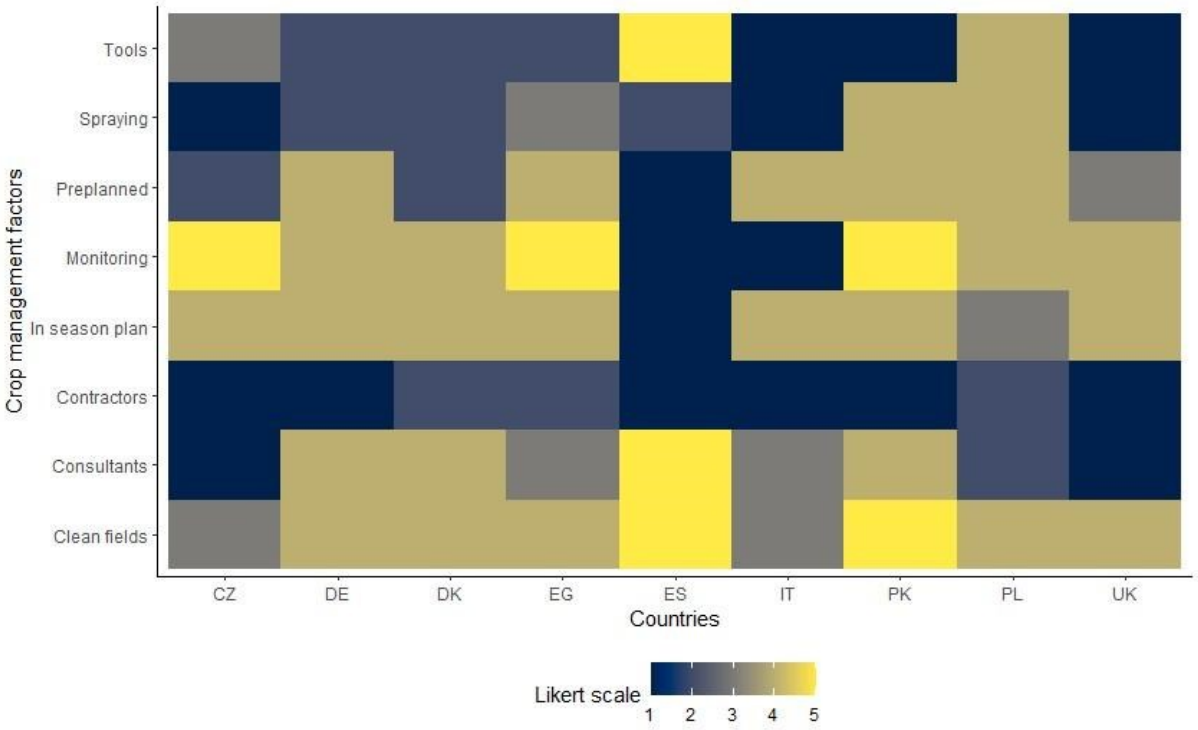

Figure 17 – Average Likert scale ratings for crop management factors of respondents by country (1: Not at all, 2: To a small extent, 3: Neutral, 4: To some extent, 5: To a very high extent).

Information sources used to inform crop choice varied in importance, and many were considered unimportant (Figure 18). By country weighted average the most important information sources were 1) Crop advisors (3.41), 2) Other farmers (3.21), and 3) Farmer associations (3.08). The least important information sources were 1) Social media (2.11), 2) Decision support tools (2.44) and 3) print media (2.67). In Egypt, processors were an important source of information and in both Pakistan and Poland seed providers were important. Farmer associations were important in Spain and Poland and also highly regarded information from other farmers. Responses in Italy and the United Kingdom both had average ratings of three (neutral) or less for all information sources listed.

Aside from these general approaches to communication, an open question revealed that various forms of peer-to-peer discussion groups are instrumental in sharing experiences and insights, disseminating information and advocating for sustainable farming practices, such as “The Farming Forum” in the United Kingdom, and “ERFA” groups in Denmark. The specific configuration of such groups are, however, highly contextual and driven by various national or regional organisations. Further, demonstrations from field trials, either for first hand dissemination, or virtually (e.g., Facebook or YouTube) are also an important source of knowledge for farmers.

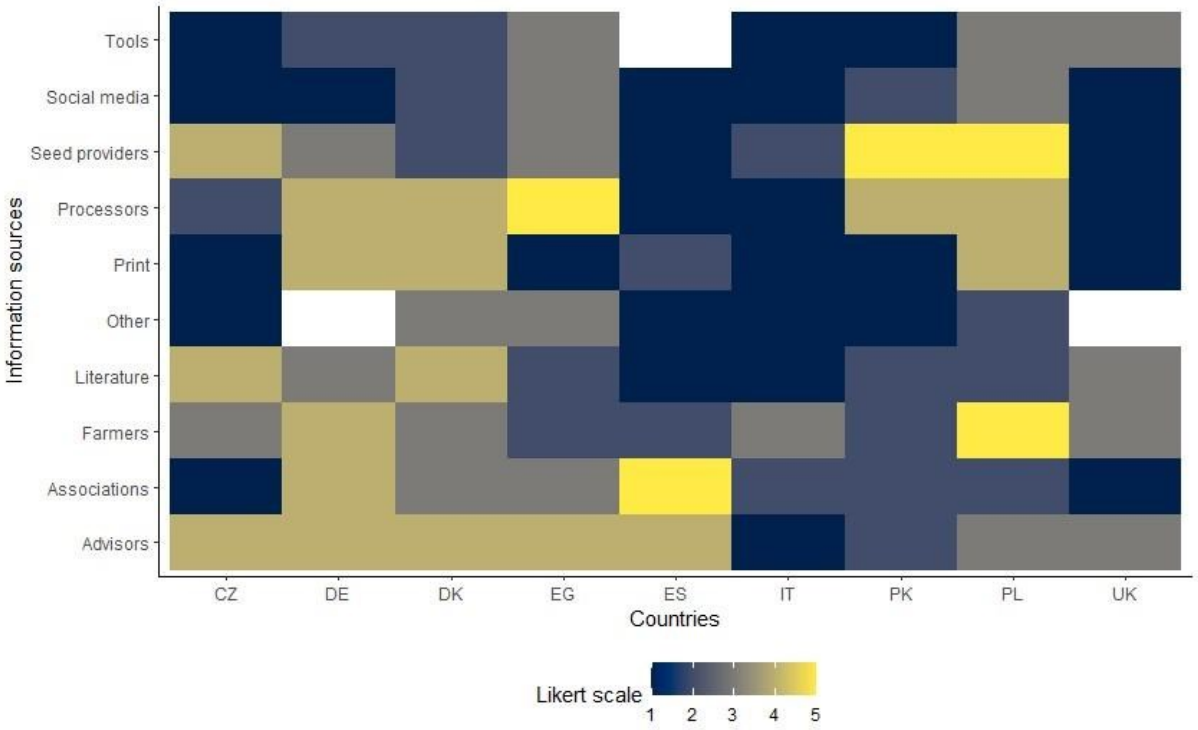

Figure 18 – Average Likert scale ratings for information sources supporting crop choices of respondents by country (1: Not important at all, 2: Slightly important, 3: Neutral, 4: Important, 5: Very important).

Regarding markets for cereal crops and grain legumes, amid country variability, use on farms included the highest percentage of grain legumes (46.5%) while the highest percentage of cereal crops were sold to processors (85.7%) (Figure 19). Many respondents did not grow grain legumes (n= 642), while few did not grow cereal crops (n= 92). Selling on the spot, contracting before and selling to a farmer all had relatively similar proportions by country with Spain, Egypt, Italy and the United Kingdom having the largest percent of grain legumes sold in these categories, while the other countries primarily used these market types to sell cereal crops. Spain was an outlier based on our survey results with the greatest proportion of grain legumes sold on contract before and to other farmers reported as compared to the other countries in this study, although these markets remain a small proportion of the total across all market types.

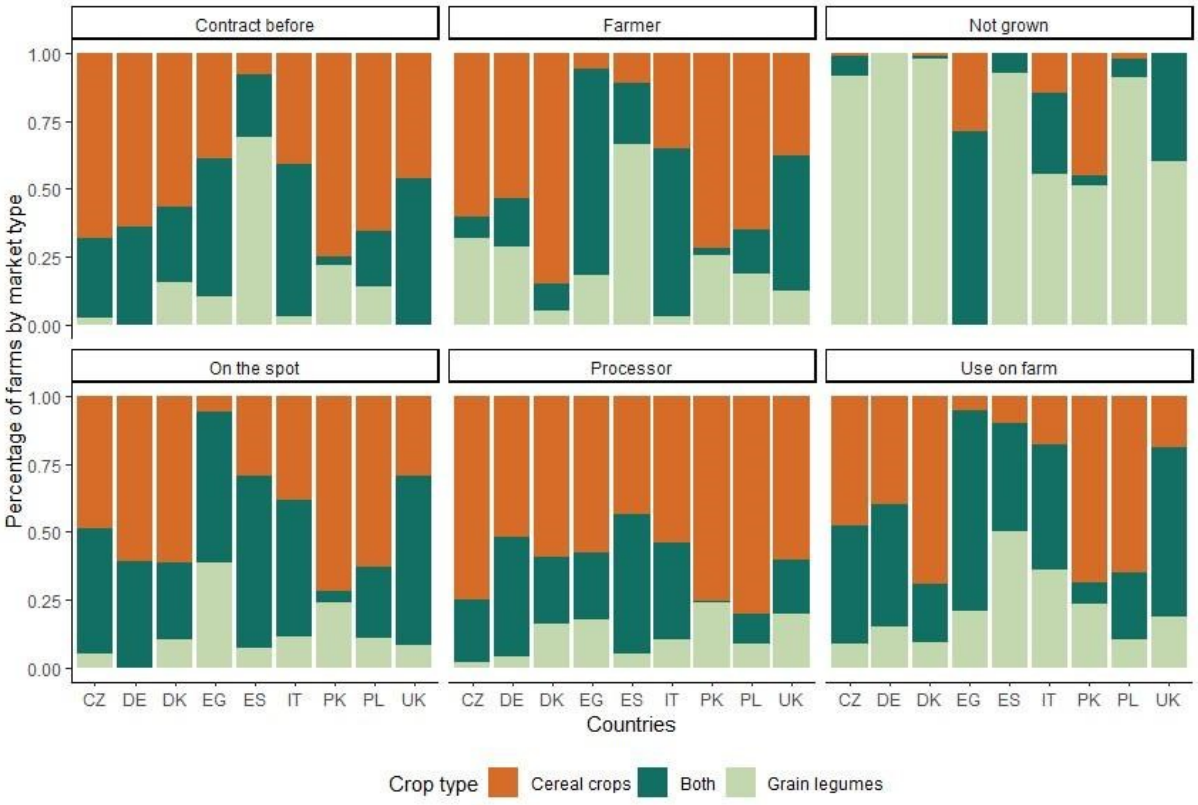

Figure 19 – Percentage of farmers market use by crop type (Cereal crops, Grain legumes, Both) by country.

3.4 Intercropping experience and likelihood for adoption

Approximately 16.8% of farmers had experience with intercropping. 11.2% have tried intercropping while 5.6% have often incorporated intercropping into their farm system (Figure 20). The United Kingdom had the highest proportion of respondents with experience in intercropping. Conversely, no respondent in Egypt had heard of intercropping before. Across all countries a total of 14.9% had never heard of intercropping. Overall, the largest category of respondents had heard of intercropping 36.1% a little, while 10.4% had heard of intercropping a lot.

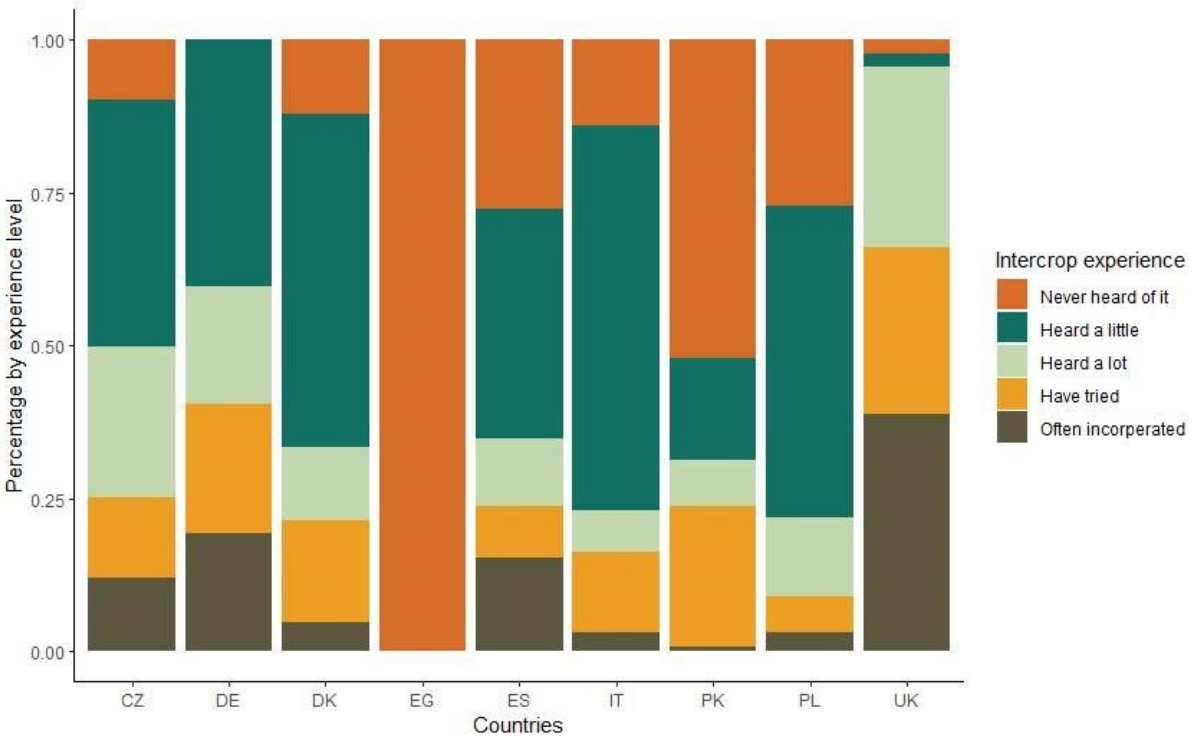

Figure 20 – Percentage of farmer intercropping experience type by country.

The largest group of survey respondents across countries were neutral about their likelihood of adopting intercropping in their fields in the future (26.5%) (Figure 21). Overall, 12.1% respondents expressed a high likelihood of intercrop adoption and 15.7% expressed that it was likely. The countries with the highest proportion of farmers responding they were likely and very likely to adopt intercropping were the United Kingdom, Egypt, Germany, and Pakistan. Approximately one third of respondents expressed that it was unlikely or highly unlikely that they would adopt intercropping in their fields in the future (34.7%). Italy, Poland and Denmark had the highest proportion of unlikely to highly unlikely responses.

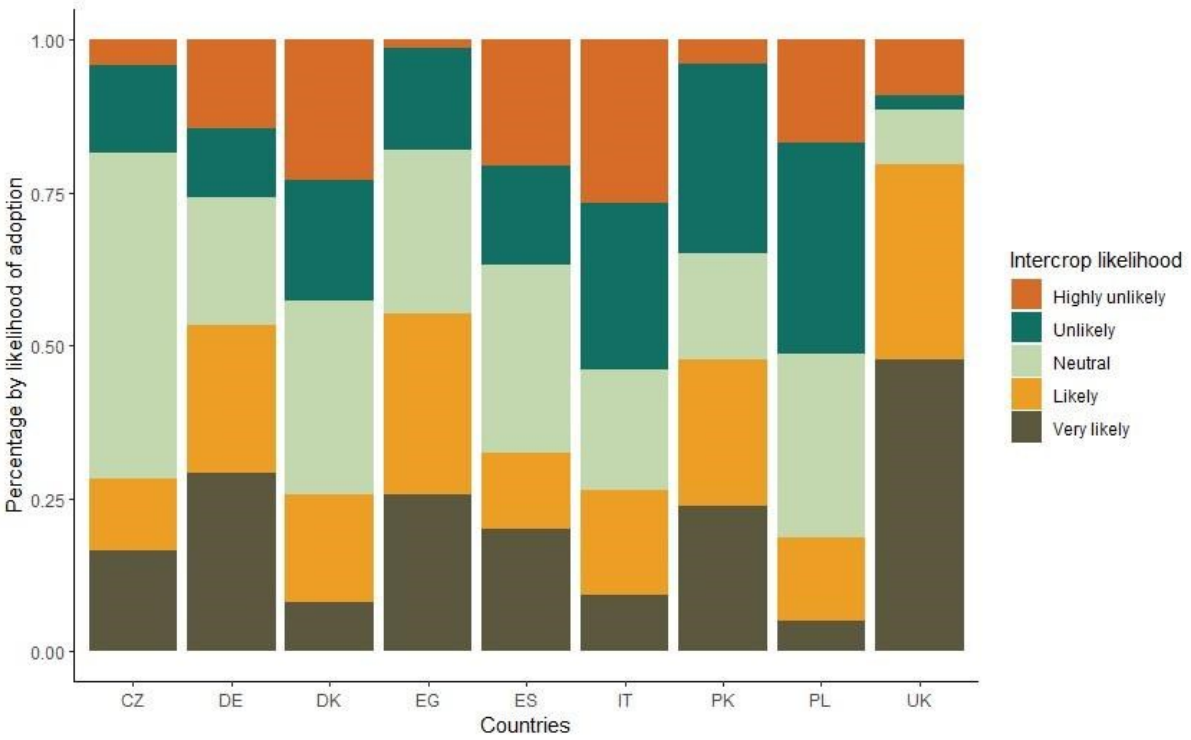

Figure 21– Percentage of farmers intercropping likelihood type by country

3.5 Barriers and opportunities towards intercropping

The factors that would most strengthen farmers' ability to adopt intercropping by country weighted average were 1) Markets (3.81), 2) Subsidies (3.65), and 3) Machinery (3.50) (Figure 22). The least important factors were 1) Decision support tools (2.90), 2) Advice (3.33) and 3) Field demonstrations (3.37). In contrast to the rest of the countries surveyed, for Germany field trials, for Italy field demonstrations and for Spain both decision support tools and advice were considered important enabling factors. In the United Kingdom none of the factors listed were considered important to strengthening farmer adoption of intercropping.

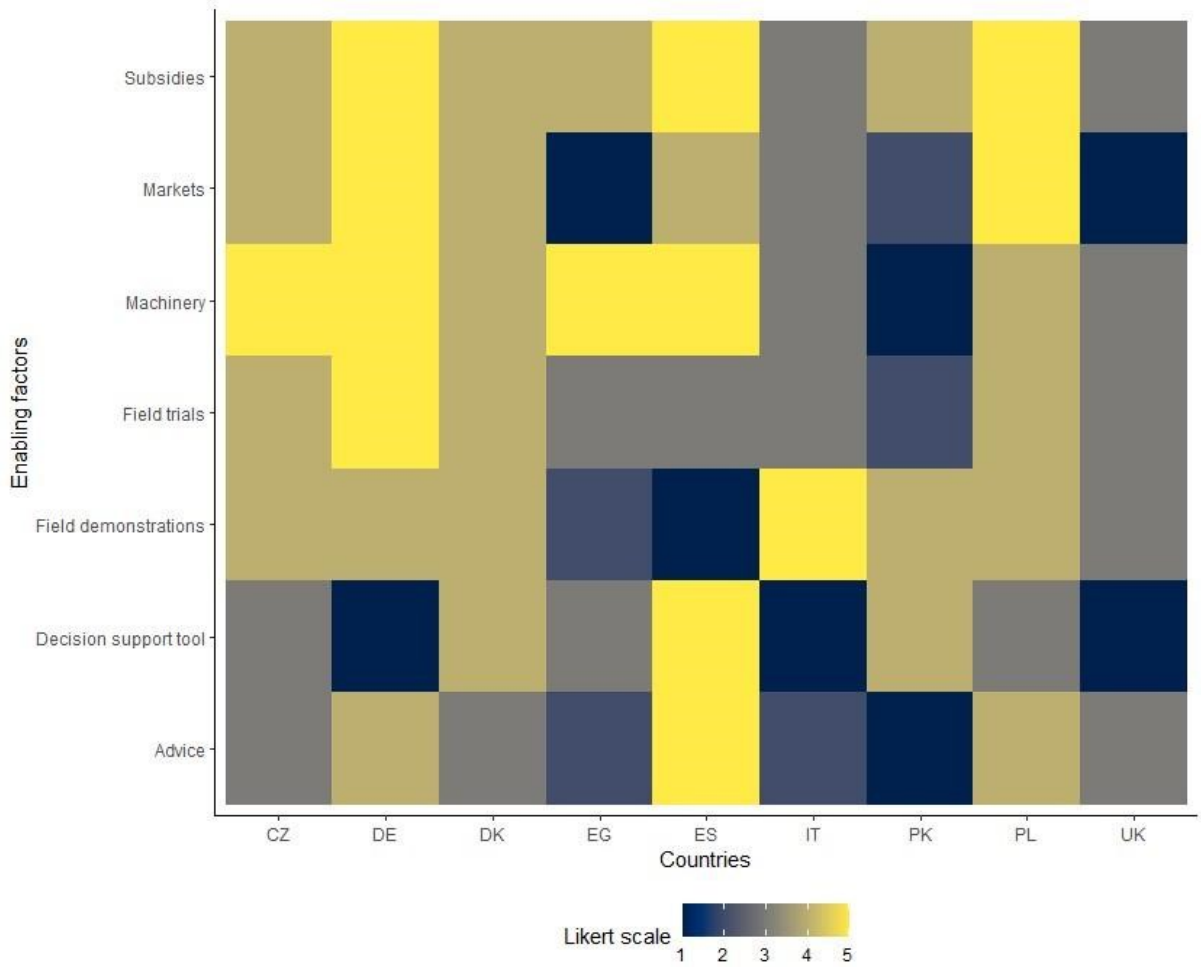

Figure 22– Average Likert scale ratings for enabling factors by country (1: Not at all, 2: To a small extent, 3: Neutral, 4: To some extent, 5: To a very high extent).

A host of barriers typically prevent farmers from intercropping, and their importance varied by country (Figure 23). The most important barriers to intercropping based on the highest percentage of overall importance ratings by country were 1) Subsidy schemes do not provide support for intercropping (63.7%), 2) I do not have access to machinery to implement intercropping at my farm (62.6%), and 3) I do not have sufficient skills to grow multiple species in a field (61.0%). The least important barriers were 1) Advisors are unable to support me with relevant knowledge (45.1%), 2) For me it is difficult to use a mix of cereal and grain legumes as feedstock (50.9%), and 3) Yield of intercropping is uncertain (54.7%) (Table 1).

Aside from the barriers mentioned, a number of general aspects were brought up in an open question asking respondents to clarify and broaden our understanding of concerns that prevent them from adopting intercropping. Some of the aspects mentioned here include 1) technological aspects (a lack of suitable equipment for separating crops, difficulty in finding appropriate herbicides due to regulatory issues), 2) Knowledge and capability (uncertainty about suitable crop varieties for intercropping, the need for more data and research, a lack of knowledge, advice, and support in the industry), 3) Marketing issues (cost-related concerns, vested investments in particular cropping systems and potential income loss), 4) Agronomic aspects (challenges related to weed control and the effects of drought and diverse irrigation needs of different crops (in arid regions), identifying proper combine settings. Although some of these barriers are structural (market conditions) and difficult to address, others are of a more practical nature (e.g. suitable species and combine settings) and can be addressed through targeted testing and advisory programs as well as knowledge exchange among peers. Further,

a number of respondents also pointed out that lock-ins are important, including a high entrance barrier for experimenting with intercropping in the form of machinery investments in combination with difficult market access. This indicates the importance in advancing intercropping using systemic solutions that address multiple barriers simultaneously. However, importantly, a number of respondents also reply that they lack knowledge and capability, which prevents them from properly assessing the barriers to intercropping.

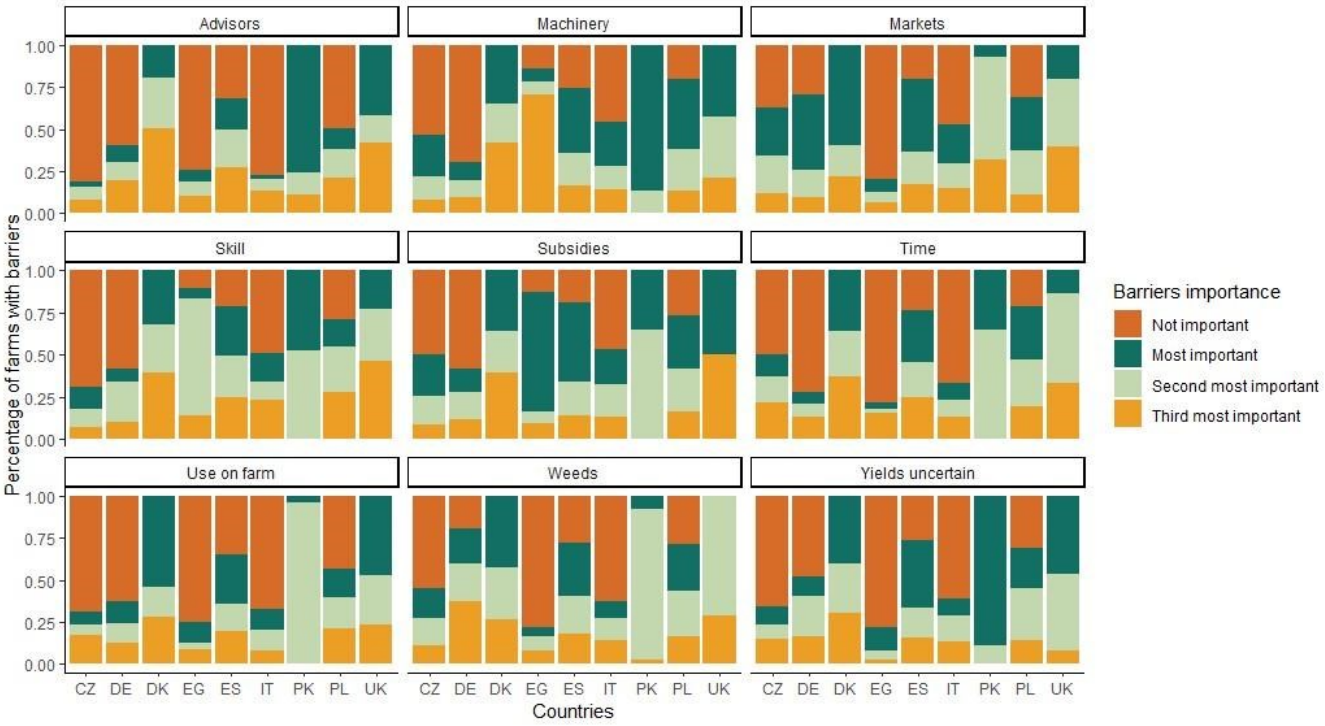

Figure 23– Percentage of farmer barriers importance ratings (Not important, Most important, Second most important, Third most important) by country.

Table 1 – Average percent ratings of barriers to intercropping by country based on level of importance (Most important, second most important, third most important, overall importance). The scale of green indicates relatively higher values (from dark to light) while the scale of red indicates relatively lower values (from dark to light), white cells are values that fall in between.

	Most important	Second	Third	Overall importance
Advisors	16.7%	11.6%	16.8%	**45.1%**
Machinery	29.3%	13.8%	19.5%	**62.6%**
Markets	24.6%	19.8%	13.3%	**57.6%**
Skill	17.5%	26.5%	17.0%	**61.0%**
Subsidies	29.0%	22.8%	11.9%	**63.7%**
Time	18.2%	19.9%	17.9%	**56.0%**
Use on farm	15.5%	21.3%	14.1%	**50.9%**
Weeds	17.6%	26.7%	15.0%	**59.2%**
Yields uncertain	27.1%	15.8%	11.8%	**54.7%**

Intercropping could produce a host of opportunities for benefits that farmers rated based on their importance (Figure 24). The most important opportunities for supporting intercropping based on the highest percentage of overall importance ratings by country were 1) Reducing fertiliser applications (75.3%), 2) Yield stability (68.1%), and 3) Improving soil structure

(68.0%). The least important opportunities for benefiting were 1) Improving climate footprint of products (45.0%), 2) Reducing tillage (50.9%), and 3) Crop diversity (56.7%) (Table 2).

Aside from the opportunities highlighted in Table 2, a number of general aspects were brought up in an open question that clarify and broaden our understanding of the most important opportunities for advancing intercropping. Aside from the practical barriers, respondents across the countries surveyed were quite positive towards the idea of increasing the amount of legumes and intercropping in their crop rotations as it would improve resilience and minimise the need for external inputs. In several countries, respondents indicate that a range of factors can be collectively combined to serve as a lever for intercropping, most importantly demonstrations of how to implement intercropping in practice, as well as the effects on yield stability, and pests. Further, access to new technology or modernization of existing technology to enable field management and market access for intercropping products are another important aspect.

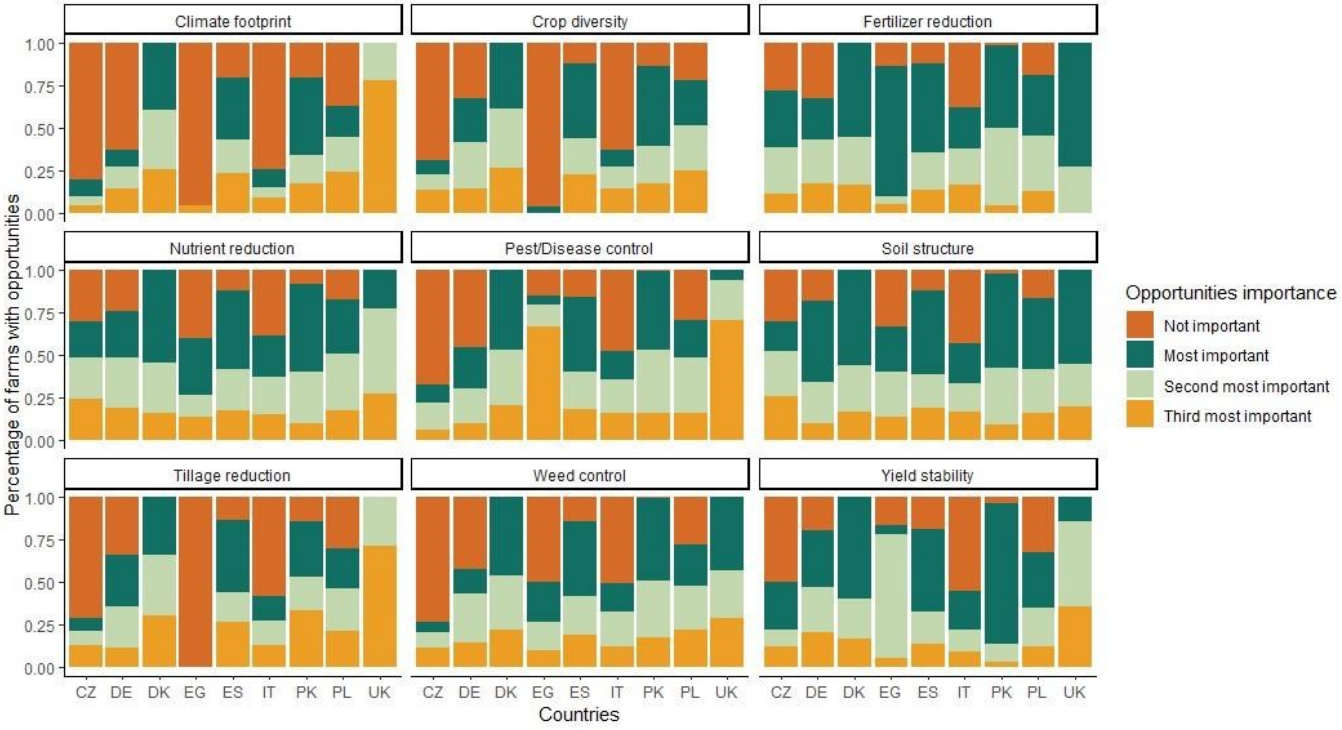

Figure 24– Percentage of farmer opportunity importance ratings (Not important, Most important, Second most important, Third most important) by country.

Table 2 – Average percent ratings of opportunities for intercropping by country based on level of importance (Most important, second most important, third most important, overall importance). The scale of green indicates relatively higher values (from dark to light) while the scale of red indicates relatively lower values (from dark to light), white cells are values that fall in between.

	Most important	Second	Third	Overall importance
Climate footprint	20.0%	12.3%	12.7%	**45.0%**
Crop diversity	21.6%	18.8%	16.3%	**56.7%**
Fertiliser reduction	40.8%	23.1%	11.4%	**75.3%**
Nutrient reduction	28.2%	22.8%	14.3%	**65.3%**
Pest/Disease control	23.0%	21.1%	19.4%	**63.4%**
Soil structure	33.6%	21.1%	13.3%	**68.0%**
Tillage reduction	22.7%	17.6%	18.2%	**58.6%**
Weed control	22.3%	19.6%	13.3%	**55.2%**
Yield stability	34.8%	22.8%	10.4%	**68.1%**

4 Conclusion

4.1 Approaches toward increasing intercropping adoption

The most important barriers to intercropping across all countries were the lack of subsidy support, the lack of appropriate machinery and the lack of sufficient skills. It is thus important to address and support effective governance, farm technology and farmer capacity building to enable the adoption of intercropping. The most important benefits were fertiliser reduction, yield stability and soil structure improvements. Focusing communication with farmers and facilitating knowledge exchange among farmers on these benefits could provide more opportunities to increase intercrop adoption compared to messaging with a focus on the climate footprint, reduced tillage and crop diversity concerns.

Most of the farmers surveyed in this study use no-till, conservation agriculture, integrated pest management or mechanical weeding practice, although the proportions in each group varied by country (Figure 16). Thus, targeting farmers and integrating intercropping messages into conversations within other production paradigms (e.g., conservation agriculture) could enhance adoption and provide opportunities for effective intercropping business planning as these groups appear to be most interested in adopting such alternative modes of production. In addition, it could be useful to target specific information channels to support intercropping (Figure 18). Our findings also suggest that crop advisors, other farmers and farmer associations were the most important sources of information for survey respondents overall, but their inability to provide information was not considered an important barrier to farmers. Targeting the information campaigns based on responses in each country could provide the best support for farmers in the transition to intercropping.

Crop choice decision-making was most influenced by characteristics of the varieties (disease resistance, high yielding) together with past experiences of the farmers (Figure 15). Based on our findings, it is important to support initiatives where farmers are able to gain experience with intercropping as an opportunity to support adoption. Likewise, key crop management considerations of planning weed and pest management in season and continuously monitoring crops for pests and disease are well aligned with intercropping practices and could provide an opportunity for farmers to see the benefits of intercropping firsthand (Figure 17). However, an equally important crop management consideration was the importance of having clean fields. This clean field aesthetic could act as a barrier to intercrop adoption as it will significantly change the appearance of fields. Developing a more complete understanding of how farmers

conceptualise clean fields could help to build better communication to address this potential barrier.

4.2 Developing effective intercropping business plans

The relative low percentage of farmers with intercropping experience (16.8%) could be harnessed as an important opportunity for increased adoption through initiatives such as living labs, as farmers' own experience was found to be a key consideration when selecting crops. There were likewise relatively few farmers who had not heard of intercropping (14.9%) and most of these respondents were in Egypt and Pakistan. This presents an opportunity to expand outreach regarding intercropping in Egypt and Pakistan and an opportunity to enhance familiarity in Europe through messaging addressing key crop choice concerns (e.g., disease, yield, weeds) while providing support and education for intercrop management (e.g., monitoring, planning in-season).

Based on the enabling factors to support intercropping explored in this survey, effective business plans will need to develop clear marketing strategies with effective subsidy support and machinery to best enable farmer adoption. Resource access is critical and the widespread lack of access to grain cleaning and drying equipment could be compounded by lack of credit access, which together act as barriers to farmer adoption of intercropping. Market access is another critical factor, and this study highlights the general lack of legume production and potential market barriers as more grain legumes were sold to farmers and used on farm as compared to marketing to processors, contracting before, or on the spot (Figure 19). Effective business plans that acknowledge and provide solutions to address lacking appropriate technology and market structures for intercropping would best support intercrop adoption.

Approximately one quarter of farmers were neutral regarding their likelihood of adopting intercropping on their fields in the future. The rest of respondents were split between very likely and likely (28.6%) and unlikely and highly unlikely (34.7%) with high variability between countries. Future research assessing what country and individual farmer characteristics impact attitudes toward the likelihood of adopting intercropping could elucidate effective business models and pathways toward intercrop adoption.

5 References

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Appendix A: Survey questions

1. You and your farm

Initially we would like to know a bit about you and your farm.

1. How much arable land is on your farm? (owned and leased combined)
   - <50 ha
   - 51-100 ha
   - 100-150 ha
   - 151-200 ha
   - > 200 ha
2. Farm type
   - Conventional
   - Organic
   - Other
3. Do you employ any of the following practices on your farm? (tick more boxes if needed)
   - No-till
   - Conservation Agriculture
   - Integrated Pest Management
   - Mechanical weeding
4. Do you work with farming full time?
   - Full time
   - Part time
   - Other/I do not wish to disclose
5. How old are you?
   - <25 years
   - 26-40 years
   - 40-60 years
   - >60 years
6. Gender
   - Man
   - Woman
   - Other/I do not wish to disclose
7. Which soil type is dominant on your farm?
   - Sandy soil
   - Sandy loam
   - Loamy soil
   - Silty loam
   - Clay soil
   - Organic soil
8. Do you have livestock on your farm?
   - No
   - Yes – Cows (dairy or beef)
   - Yes – Pigs
   - Yes - Poultry
   - Yes – Other, please specify:_____
9. How much of your arable land is used for growing grain crops?
   - _____ % of your total arable land
10. How much of your arable land is used for growing grain legume crops?

- _____ % of your total arable land

11. How many different harvestable crops did you grow on your fields in the last growing season?
    - _____

	On farm	External partner	No
Farm advisory service			
Grain storage facilities			
Drying facilities			
Grain cleaning facilities			
Harvester			
Machinery for weed management			
Sowing machine			
Wide selection of seeds			
Access to credit			

12. On a scale from 1-5 do you experience any of the following challenges in your fields?

	1: Not at all	2: To a small extent	3: Neutral	4: To some extent	5: To a very high extent	I don´t know
Drought						
Erosion						
Low carbon content in the soil						
Low soil fertility						
Salinization						
Flooding of fields						
Weeds						
Other important challenges:_____						

2. Crop choice

The following section contains a set of questions regarding the background for your choice of crops.

13. On a scale from 1-5 to how important are the following information sources for your choice of crops?

	1: Not important at all	2: Slightly important	3: Neutral	4: Important	5: Very important	I don´t know
Social media						
Printed media						
Other farmers						
Farmer associations						
Advisory service						
Scientific literature						
Seed providers						
Processing companies						
Decision support tools/ Farm information systems						
Other						

14. Other platforms used and other reflections regarding media for communication?
    - _____

15. Which of the following statements most accurately describe your decision making regarding the timing of your crop choice? (please select the most relevant option)
    - I plan which crops to grow on most my fields years in advance
    - I plan which crops to grow on some of my fields years in advance
    - I plan which crops to grow on most my fields months in advance
    - I plan which crops to grow on some of my fields months in advance
    - Other, please detail

16. On a scale from 1-5 to which extent do you agree with the following statements regarding your crop choice?

	1: Not at all	2: To a small extent	3: Neutral	4: To some extent	5: To a very high extent	I don´t know/ not applicable
I pay close attention to market signals before deciding which crops to grow?						
I select crops in collaboration with my advisor?						
It is very important that my crops are resistant to diseases?						
I prefer varieties that are strong in competition with weeds						
I select crops based on past experience						
I follow a fixed crop rotation plan						
I prefer varieties with a high yield						
I select crops that contribute to building humus in the soil						
I select crops I can use on my farm for feed						
The crops are selected for me						
My current cropping system is not sustainable						

3. Crop management

The following section contains a set of questions regarding how you manage your crops in the growing season.

17. What is the most important source of fertilization for your crops
    - I only use mineral fertilizers
    - Livestock manure
    - Legumes
    - Other source of nutrients (please specify): _____
18. Do you irrigate your crops?
    - Yes – always
    - Yes – sometimes
    - No – but it would be great for the crops
    - No - Not relevant in my region

19. To which extent do you agree with the following statements regarding crop management on a scale from 1-5?

	1: Not at all	2: To a small extent	3: Neutral	4: To some extent	5: To a very high extent	I don´t know
Following a fixed spraying schedule is important to me						
My fields are managed by external contractors						
I find it is very important to continuously monitor crops for pests or disease						
Having clean fields is important to me						
Weed and pest management is something I plan before the beginning of the growing season						
I use decision support tools to adjust my disease and pest management in the growing season						
Consultants are important in my deciding how I should manage pests and disease in my fields						
Weed and pest management is planned during the growing season						

20. What do you typically do with your cereal and grain legume crops? (please select relevant options)

	Grain legumes	Cereal crops
Sell - On contract before harvest		
Sell - On the spot market		
Sell - Directly to another farmer		
Sell - Directly to processor/mill		
Use on farm		
I don't grow the crop		
Other		

4. Intercropping

The following section contains a set of questions specifically addressing your perceptions of legume-cereal intercropping.

Legume-cereal intercropping is an agricultural technique where legume crops (such as beans or peas) are planted alongside cereal crops (such as wheat or barley) in the same field. The crop can either be sold as a mixed crop, separated or used as livestock feed.

21. Which statement most accurately describes your level of experience with respect to intercropping? (Please select the most relevant option)
    - I have never heard of intercropping before
    - I have heard a little about intercropping before
    - I have heard a lot about intercropping
    - I have tried intercropping
    - Intercropping is often a part of my crop rotation
    - I don't know

22. On a scale from 1-5 how likely is it that you would have intercropping on your fields in the future?

	1: Highly unlikely	2: Unlikely	3: Neutral	4: Likely	5: Very likely	I don´t know/not applicable

23. On a scale from 1-5, how familiar are you with the following intercropping systems?

	1: Unfa miliar	2: Some what unfamil iar	3: Neutral	4: Some what familiar	5: Very familiar	I don´t know
Cereal and pea mixtures						
Cereal and forage legumes						
Cereal and grain legume crops						
Oilseed and grain legume crop						
Other combinations, please elaborate						
Not familiar with intercropping at all						

24. A number of barriers typically prevent farmers from intercropping. Which of the following barriers are the three most important for you?

	1: Most important	2: Second most important	3: Third most important	I don't know
I do not have access to machinery to implement intercropping at my farm				
Subsidy schemes do not provide support for intercropping				
I do not have sufficient skills to grow multiple species at a field				
Advisors are unable to support me with relevant knowledge				
For me it is difficult to sell a mix of cereal and grain legumes				
For me it is difficult to use a mix of cereal and grain legumes as feedstock				
It is very difficult to control weeds or pest in an intercropping field				
I do not have the resources (time/labour) to experiment with intercropping				
Yield of intercropping is uncertain				
Other concerns, prevent me from adopting intercropping: _____				

25. Why do you consider these to be the biggest barriers?
    - _____

26. On a scale from 1-5 to which extent would the following elements strengthen your ability to adopt intercropping?

	1: Not at all	2: To a small extent	3: Neutral	4: To some extent	5: To a very high extent	I don´t know
Field demonstrations						
Documentation of results of field trials						
Access to subsidies						
Better opportunities to sell mixed crops						
Access to machinery to separate mixed crops						
Access to advice						
Access to online decision support tool						
Other, please elaborate						

27. What is the most important element, and why?
    - _____

28. Intercropping may also potentially provide a range of benefits. Which of the following benefits are the three most important for you?

	1: Most important	2: Second most important	3: Third most important	I don't know
Yield stability				
Reducing fertiliser applications				
Provision of nutrients for crops in subsequent growing seasons				
Pest and disease control				
Improving soil structure				
Weed control				
Crop diversity				
Reducing tillage				
Improving climate footprint of products				

29. Why do you consider this to be the biggest benefits?

    - _____