



LEGUMINOSE
the way to a green transition

Report on opportunities for intercropping species mixtures

October 31, 2023

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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.

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

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

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List of abbreviations

Technical	D	Deliverable
	DPM	Dynamic Partnership Map
	EC	European Commission
	IP	Innovation Partnership
	LL	Living Lab
	SWOT	Strengths, Weaknesses, Opportunities and Threats
	WP	Work Package
Partners	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 Cientificas, Spain
	DSV	Deutsche Saatveredelung AG, Germany
	ECOLOGICA	ECOLOGICA For Environmental Consultants and Studies Co. L.L.C., United Arab Emirates
	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	Union 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
	PL	Poland
	CZ	Czech Republic
	UK	United Kingdom
	EG-AK	Egypt, Al-Kasr region
	EG-KE	Egypt, Kafr Elsheikh region



1 Introduction

1.1 Structure

This report is structured as follows:

- Chapter 2 presents the methodology that has been used by partners to acquire data based on workshops with key stakeholders identified using the DIP map involving Innovation Partnerships (IP) participants and methodology applied in the compilation of results in this report.
- Chapter 3 presents a synthesis of stakeholders' perspectives on intercropping species mixtures. The chapter is organised in three sections, each representing different considerations for intercropping across national partners.
- Chapter 4 summarises the main conclusions.

1.2 Purpose

Identify the knowledge gap between research and legume-cereal intercropping practices, to support subsequent research, experimental activities, and work dissemination. More specifically, the objectives of this task are to:

1. Assess the perceived barriers and opportunities for the adoption of intercropping as well as possible ways to overcome barriers, including with respect to policy, capacity building, and strengthening value chains.
2. Assess the strategies of crop selection and crop management as a basis for designing species mixtures.
3. Assess the correspondence between perceived barriers and opportunities for the adoption of intercropping and characteristics of farming systems and cropping choice.

2 Methodology

This report is written as a synthesis of the ten national reports that were prepared by LEGUMINOSE partners based on co-creating workshops in each country. In this chapter, we will first describe the approach and content of the workshops, secondly, we will describe the data that has been produced, and finally, we describe our approach to provide a useful comparison of the individual national reports.

2.1 Co-creation workshops

Several target groups were relevant to include for a useful workshop discussion about legume-cereal intercropping across the supply chain: Farmers (preferably future Living Lab (LL) participants) and members of the Innovation Partnership (IP). Since part of the discussion was to determine possible species mixtures for intercropping, partners were encouraged to ensure the participation of crop advisors and seed producers who have more detailed knowledge of relevant species for legume-cereal intercropping and how they may grow in combination.

Each partner country organised a meeting with farmers and members of IP in the summer or early autumn of 2023. AU developed guidelines and a suggested agenda for all of the workshops, which could be adjusted according to local conditions and opportunities (Annex A). The agenda included introducing the LEGUMINOSE project, field activities and



presentations from several important stakeholders (e.g., farmers with intercropping experience, seed producers, advisors) followed by a focus group discussion.

The purpose of conducting focus groups was to identify opportunities, strategies and enabling conditions for legume-cereal intercropping. To achieve these goals, a strengths, weaknesses, opportunities, and threats (SWOT) analysis was conducted. SWOT analyses provide a useful structure for discussions amongst stakeholders which has been applied to uncover new insights into complex food system dynamics and transition pathways (Blanco-Gutiérrez et al., 2020; Dergan et al., 2022). Strengths and weaknesses are defined as internal factors that are within the influence of farmers and value chain actors (e.g., level of collaborations, farming skills and accessible technology). Opportunities and threats are defined as external and structural factors that cannot be influenced by focus group actors (e.g., soil type, climate, market trends, legislation). After SWOT were identified for legume-cereal intercropping, they were prioritised (ranked) to support effective analysis and strategy development.

The focus groups then identified strategies by combining a key strength with a maximised opportunity and minimised threat. The same technique was used to identify risk mitigation strategies by combining a key weakness with an opportunity and threat. This exercise led to a set of four conditions for changing to an intercropping system based on the strategies identified.

2.2 Data

Focus groups are a method used to collect qualitative data in applied research. Data collected from focus groups are useful to support understanding of complex socio-environmental dynamics, like those of food systems and are commonly used in this context (Dorneich et al., 2023; Sonnino et al., 2019). Focus groups were conducted in each of the 9 countries and summarised into national reports using a common template (Annex B). The national reports are based on a total of 273 focus group participants, representing different perspectives on legume-cereal intercropping across the supply chain (Table 1).

The focus group sessions were designed to take approximately 45 minutes, and aimed to identify farmers' behaviour towards intercropping, and identify strategies for overcoming barriers and maximise opportunities, including considerations when designing suitable species mixtures. Focus group discussions were conducted in small groups with a targeted size of six to eight participants. Workshop participants were split into several groups if participants exceed $n=10$ to improve participation and the richness of the qualitative data collected. Facilitators aimed to create homogenous groups to support open conversation, often grouping based on occupation (farmer, researcher, supply chain representative) and farmer type (conventional, organic) (Krueger, 2015).



Table 1. The number and role of focus group participants within each of the participating countries. Partners identified who conducted the workshop in each country.

Country	Partner	Farmers	Researcher/ Scientist	Policymakers	NGO	Supply industry	Other	Total
Czech Republic	APR	9	7	2	2	8	1	29
Denmark	AU	3	7	3	2	3	0	18
Germany	LUH & DSV	34	3	0	0	2	2	41
Italy	UNIFI & CIA	10	4	2	1	0	11	28
Poland	IAPAS	13	9	0	0	1	5	28
Spain	UPA & CSIC	7	8	1	0	5	7	28
United Kingdom	SA	29	6	0	3	3	7	48
EG-AK	UNIFI & ECOLOGICA	8	3	0	0	0	0	11
EG-KE	UNIFI & ECOLOGICA	4	2	0	0	0	5	11
Pakistan	GCUF	11	15	1	0	1	14	42
Total		124	62	9	8	23	47	273

2.3 Data treatment

Focus groups were part of workshops that commonly took place as part of a farmers' field day. The total workshop length varied from 2 to 7 hours based on the objectives of each partner. In most cases, the focus groups were formed based on farm management type (e.g., conventional, organic) and position by organisation type (Table 1). In the European countries and Pakistan results were summarised collectively for each country. However, in Egypt where regional differences are great, the workshops were described separately for the two regions represented. The workshop on intercropping in Kafr Elsheikh (EG-KE), located in the heart of the Nile Delta, aimed to reinforce sustainable and prosperous farming in a region dominated by smallholder farmers. In the arid expanses of the Dakhla Oasis, the Intercropping Workshop at Al-Kasr (EG-AK) village, aimed to address the challenges and prospects facing agriculture, particularly focusing on the sustainable use of the region's significant, yet non-renewable groundwater resources.

Focus group summaries were collected from each partner country and summarised using a common template (Annex B). The purpose of conducting focus groups was to identify opportunities, strategies and conditions for legume-cereal intercropping. All individual inputs were added to a spreadsheet and then categorised into groups based on specific common themes. The themes were then placed into larger categories to enable more in-depth analysis and visualisation. The results of this analysis are described in the following section. For a more detailed overview of the country specific responses, see Appendices (C-E), which features national report summaries.



3 Results

This section outlines the outcome of the co-producing workshops assessing the behaviors of farmers toward intercropping and identifying strategies to overcome barriers. Results include an outline of the different perceptions of strengths, weaknesses, opportunities and threats of legume-cereal intercropping (section 3.1), followed by a summary of enabling factors and strategies (section 3.2). Subsequently, we analyse key considerations when selecting seed combinations for intercropping (section 3.3).

3.1 Important strengths, weaknesses, opportunities and threats of intercropping

Overall, many countries shared similar ideas about the strengths, weaknesses, opportunities and threats of intercropping in current production and supply chain contexts (Figure 1). The SWOT analysis also highlighted that many strengths and opportunities of intercropping were primarily environmental while weaknesses and threats were primarily knowledge and technology related, although the lack of markets and additional costs and complications were also widely noted (Figure 2).

3.1.1 Strengths

The most important strength of intercropping discussed in all ten focus groups was reduced fertiliser and pesticide (herbicide, insecticide) inputs together with a reduced need for alternative weed and pest controls for organic producers. Soil health was another central strength discussed in nine focus groups. Other aspects of environmental health also highlighted by most focus groups included: biological nitrogen fixation, biodiversity, plant health, carbon storage and soil erosion prevention. Yield stability and adaptability of intercropping across cropping system type and production scale was another notable strength highlighted in eight out of ten focus groups. Increased stability was considered a particularly valuable strength for farmers due to climate change and the increasing yield variability experienced by some farmers.

From an economic perspective, farm profitability and income diversification were an important strength of intercropping discussed in seven of the ten focus groups. In addition to reducing input costs, some focus groups expressed that increased yields were also a strength of intercropping (n=5). Notably, only two countries discussed technology related strengths, listing GPS and digital farm management technologies as conducive to supporting the integration of intercropping onto farm systems in Europe.

3.1.2 Weaknesses

The most important weaknesses for intercropping noted by the largest number of countries related to selling products profitably (n=8) and crop management challenges (n=8), followed by the perception of risk by farmers due to the lack of knowledge and experience with managing intercropping on their farms (n=6). Many economic concerns related to the lack of tested markets and pricing structures. Focus groups expressed the need to test economic viability before scaling up production via intercropping. The management concerns were threefold: Place-based (e.g., insufficient organic matter, limited water availability, high soil pH levels in alkaline calcareous soils); Management-based (e.g., seeding timing, synchronising harvest, appropriate equipment); and Market-based (e.g., consistent products to enable commercialization, lack of legumes in crop rotation due to low demand and prices). Each of these three categories of management challenges require different strategies to overcome and these strategies will be discussed in detail in the following two sections (2.2, 2.3). Of critical importance was the issue of not having region-specific approved crop varieties. Without these tested place-based seed combinations, several focus groups (n=3) expressed that there was



a possibility of weakness due to competition between species for water, light, and nutrients. Focus groups in four countries listed the lack of suitable seedstock as a key threat. Once specific seed combinations are optimised other management concerns regarding management and marketing can be addressed strategically.

▪ **3.1.3 Opportunities**

The most important opportunities for intercropping grains with legumes was to reduce fertiliser use (n=6), followed by governmental and policy support to increase intercropping adoption (n=5). Reducing farm system inputs was listed by all country focus groups as a strength and was also the most widely proposed opportunity. Reducing fertiliser use can reduce the environmental impact of crop production by decreasing the carbon emissions (e.g., mineral fertiliser synthesis & application) and reducing runoff into water bodies. Reducing inputs was also seen as an important way to reduce costs within farm systems. Many focus groups in Europe reported that although some governmental support is becoming available in both the UK and through EU CAP funds as a condition for SAPS in 2024, expanding on and refining environmental schemes through policy support and subsidies would be important to increase adoption and mitigate the risks for farmers.

From a food system perspective, opportunities to increase plant protein from legumes and potential value chains for human consumption are important. Building on opportunities for livestock feed and supply chain development in this context was discussed in four focus groups. These economic opportunities were reported together with more socially oriented opportunities such as improving stakeholder interactions and training for farmers (n=3).

▪ **3.1.4 Threats**

The most important threats identified were related to the lack of knowledge and technology (Figure 2). To mitigate threats to adoption of legume-cereal intercropping, lack of markets and prices (n=6), the risk of new weed, disease, and pest control issues (n=5) need to be addressed. Farmers' general risk perceptions (n=3) were also considered a threat due to the lack of experience and advice available concerning this new type of cropping system. For example, in the UK, facilitators observed that conventional farmer focus group comments were based around a monoculture mindset and the difficulty of changing that contrasted with the organic farmer focus group. In Spain, resistance to change was thought to stem from farmer's widespread short-term vision that favours monoculture as a means to mitigate low cereal grain productivity.

▪ **3.1.5 Crosscutting considerations**

Egypt and Pakistan faced several additional threats and weaknesses not considered critical to focus groups in the EU or the UK. For example, the EG-KE focus group identified land fragmentation as a threat and an obstacle for mechanised farming and efficient land use. The EG-AK focus group discussed limited agricultural land resources suitable for crop production in the region as a threat. The focus group in Pakistan identified incompatibility with genetically modified (GMO) crops as a threat and intensive management on depleted soils as a weakness. Another weakness unique to Pakistan was the relatively high pH of some soil that limits nodule formation and biological nitrogen fixation for legume species in these alkaline calcareous soils.

Community and farmer perceptions of intercropping are also important – as both an opportunity and a threat (Figure 2). Denmark and Egypt focus groups reported that an opportunity of intercropping is the transition to more climate-resilient agriculture. In Poland and the Czech Republic this was framed as a shift to regenerative agriculture, while the focus group in Spain identified the opportunity to commit to a more sustainable and diversified agriculture. All countries besides both regions of Egypt also reported resilience and adaptability as a strength



of intercropping. Yet, the Czech Republic, EG-AK, EG-KE and Pakistan focus groups reported that risks associated with climate change was an important threat to intercropping. The mixed perception of intercropping as a climate change mitigation strategy and a threat enhancing the risks of climate change is an important example of the uncertainty and the lack of consensus between key stakeholders. Providing evidence and consistent messaging is key to enabling public and policy support for intercropping. Shifting public perception in favour of intercropping was seen as an opportunity in Spain focus groups, and as a strength in Germany. Connecting producers with the benefits of environmentally friendly management practices like intercropping could, together with policy support, be an opportunity to foster appreciation for farmers and agriculture by society at large.



Strengths

- **Reduce fertilizers, pesticides & alternative weed/pest controls** (All)
- **Soil health** (CZ, DE, DK, ES, IT, PL, UK, EG-KE, Pakistan)
- **Biodiversity** (CZ, DE, DK, ES, PL, UK, EG-KE, Pakistan)
- **Resilience, yield stability & adaptability** (CZ, DE, DK, ES, IT, PL, UK, Pakistan)
- **Farm profitability & income diversification** (DK, ES, IT, UK, EG-AK, EG-KE, Pakistan)
- **Nitrogen fixation & carbon storage** (CZ, DK, ES, UK, EG-KE, Pakistan)
- **Increased yields** (DE, DK, UK, PL, Pakistan)
- **Erosion prevention** (CZ, IT, PL)
- **Plant health** (ES, PL)
- **More high-protein feed** (PL, UK)
- **Supportive technologies** (ES, PL)
- **Efficient use of water** (EG-AK, EG-KE)

Weaknesses

- **Inability to sell profitably** (CZ, DE, ES, IT, PL, UK, EG-KE, Pakistan)
- **Crop management challenges** (DE, DK, ES, IT, UK, EG-AK, EG-KE, Pakistan)
- **Farmers risk perception, lack knowledge & experience in management** (DK, ES, PL, UK, EG-KE, Pakistan)
- **Inadequate & costly equipment/technology** (CZ, DK, PL, UK, EG-KE, Pakistan)
- **Unknown timing of seeding & synchronizing harvest** (ES, PL, EG-KE, Pakistan)
- **Additional time & complication** (PL, UK, EG-AK, EG-KE, Pakistan)
- **Inconsistent product/poor implementation** (ES, UK, Pakistan)
- **Unavailable region-specific crop varieties, potential interspecies competition** (CZ, PL, Pakistan)
- **Deficient soil organic matter** (Pakistan, PL)
- **Additional costs for seed separation, labor & cultivation** (CZ, DK)

Opportunities

- **Reduce fertilizer use** (CZ, DE, IT, PL, UK, Pakistan)
- **New markets for a quality local product** (DE, DK, ES, PL, EG-KE)
- **Governmental support for intercropping** (CZ, ES, IT, PL, UK)
- **Increase plant protein** (DE, ES, IT, UK)
- **Quality livestock feeds** (CZ, DE, IT)
- **Regenerative agriculture & enhanced biodiversity** (ES, CZ, PL, Pakistan)
- **Soil health & fertility** (DK, PL, EG-KE)
- **Increase organic matter & carbon sequestration** (CZ, DK, PL)
- **Reduce plant diseases & herbicide resistant pests and plants** (CZ, DK, EG-AK)
- **Climate-resilient agriculture** (DK, EG-KE)
- **Stakeholder interaction, workshops & training** (DK, PL)
- **Promising research & group working on intercropping** (IT, Pakistan)
- **Innovative machinery & techniques for intercropping** (DK, ES)

Threats

- **Lack of markets and prices** (CZ, DK, IT, PL, UK, Pakistan)
- **New weed, disease, virus and pests control issues** (CZ, DE, IT, PL, Pakistan)
- **Unavailability of suitable plant species/seedstock** (CZ, ES, PL, Pakistan)
- **Difficulties with government regulations and policies** (CZ, DK, PL, UK)
- **Risk of climate change** (CZ, EG-AK, EG-KE, Pakistan)
- **Lack of equipment/technology** (ES, IT, PL)
- **New costs and complication** (DE, PL, UK)
- **Difficult to commercialize diversified crop markets** (ES, UK, EG-KE)
- **Farmer adoption low - difficulty changing mindset** (DK, ES, UK)
- **Limited water availability to support 2+ crops** (ES, PL, EG-AK, EG-KE)
- **Yield reduction** (DK, Pakistan)
- **New gaps in management knowledge** (DE, IT)
- **Lack of research for management in specific local conditions** (CZ, ES)

Figure 1. SWOT Analysis of key strengths, weaknesses, opportunities, and threats listed in order based on the number of countries identifying this theme, with specific countries listed in parentheses.



	Strengths	Weaknesses	Opportunities	Threats
Knowledge & Technology	Supportive technologies (n=2)	Crop management challenges (n=8) Inadequate and costly equipment/technology (n=6) Unknown timing of seeding and synchronizing harvest (n=5) Inconsistent product/poor implementation (n=3)	Innovative machinery & techniques (n=3) Promising research (n=2)	New weed, disease, virus & pest control issues (n=5) Unavailability of suitable seedstock (n=4) Lack of appropriate equipment/technology (n=3) New gaps in management knowledge (n=2) Lack of research for management in specific local conditions (n=2)
Environment	Reduce fertilizers, pesticides & alternative controls (n=10) Soil health (n=9) Biodiversity (n=8) Resilience, adaptability & yield stability (n=8) Nitrogen fixation & carbon storage (n=6) Erosion prevention (n=3) Plant health (n=2), Water efficiency (n=2)	Unavailable region-specific crop varieties, potential for interspecies competition (n=3) Deficient soil organic matter (n=2)	Reduce fertilizer use (n=6) Increase plant protein (n=4) Regenerative agriculture & biodiversity (n=4) Soil health & fertility (n=3) OM & C sequestration (n=3) Climate-resilient agriculture (n=3) Reduce plant diseases, pesticide resistant pests & plants (n=3)	Limited water availability to support 2+ crops (n=4) Risk of climate change (n=4)
Political			Governmental support for intercropping (n=5)	Government regulations and policies (n=4)
Social		Farmers risk perception & lack of management experience (n=6) Additional time and complication (n=4)	Stakeholder interaction, workshops and training (n=3)	Farmer low adoption (n=3)
Economic	Farm profitability and income diversification (n=6) Increased yields (n=5) More high-protein feed (n=2)	Inability to sell profitably (n=8) Additional costs for seed separation, labor and cultivation (n=2)	New markets for a quality local product (n=5) Quality livestock feeds (n=3) Reduce inputs costs (n=2)	Lack of markets & prices (n=6) New costs & complication (n=3) Commercializing new crop markets (n=3)

Figure 2. SWOT Analysis organised with themes listed based on their category (left column) and the number of countries listed in parentheses (n=).



3.2 Factors and strategies enabling intercropping

Legume-cereal intercropping was considered beneficial across all participating countries from an environmental or ecological perspective. Intercropping supports three key environmental factors: enhancing soil health, resilience and reducing inputs of nitrogen and pesticides. Reducing environmental impacts across farm and food system scales makes legume-cereal intercropping attractive for policymakers, researchers, and farmers alike. The wide-ranging environmental benefits are the basis for why expanding legume-cereal intercropping is desirable (Figure 3). However, to reach this desired state, it is critical to understand the barriers and factors enabling intercropping to identify strategies that effectively support this transition. This section first explores barriers, regional differences, and uncertainties; second, identifies enabling factors; and third, explains five key strategies that could be used to increase legume-cereal intercropping.

Although environmental impacts are reduced, important barriers make it challenging to increase adoption of legume-cereal intercropping. Some of the most important barriers are place-based differences such as low regional water availability (ES, EG-KE, EG-AK), climate change risks (CZ, EG-AK, EG-KE, Pakistan), and deficits in organic material (PL, Pakistan). Management-based barriers are also region-specific and created differentiated barriers depending on the current scale of production, equipment utilised and cultural norms. For example, in the United Kingdom cultural norms for conventional farmers who utilise well developed advice systems make changing to a new cropping system more difficult to accept than it is for organic farmers who are more accustomed to flexible and experimental approaches. The potential pairing of intercropping and organic production was noted by several focus groups, although several others expressed the importance of emphasising adaptability to increase adoption of intercropping practices on a broader range of different farming systems. Regional market-based differences also created regionally distinct intercropping market strategies. For example, legume-cereal intercropping has already been adopted in Spain for feed production and these markets are already operational, while expanding to food markets brings new uncertainties and challenges (e.g., marketable species and varieties, phytosanitary treatments, fertiliser types, additional harvest, and post-harvest work). Conversely, differentiated food and feed markets were of great interest in Poland where innovative functional food products (for people and animals) with higher levels of protein were considered an important strategy. Understanding barriers to intercropping in a specific regional context is important to enable the broader adoption of intercropping in Europe and beyond.

The interaction between intercropping and climate change risk is an important unknown for focus group participants. Intercropping was at once considered an opportunity by enhancing climate-resilient agriculture (CZ, DK, EG-KE) and a threat by enhancing climate change risks (CZ, EG-AK, EG-KE, Pakistan). Yield uncertainties were also common, focus groups in five countries listed yield increase as a strength (DE, DK, PL, UK, Pakistan), while Poland listed it as a weakness. Two countries (DK, Pakistan) listed potential future yield reduction as a threat, while the focus group in EG-KE included yield increase as an opportunity. Providing accessible evidence-based information to farmers and stakeholders is important to address uncertainties related to climate change risks and yield in the context of intercropping.

At the farm system level, key enabling factors for intercropping were identified as knowledge of best management practices (e.g., quality seed mixes), economic profitability, community-based advisory systems, and appropriate technology (e.g., farm equipment). Better community networks, training and communication across the supply chain could also support young people to become intercropping farmers, a current weakness highlighted by the focus group in Spain.



At the food system level, developing supply chains and supportive policies are key factors that will enable intercropping to expand (Figure 3).

There were five key strategies identified by the focus group participants (Figure 4). A summary of each country's strategies are also available (Annex D).

1. A new farmer lead advice system was a strategy identified by many European countries as well as Pakistan, where farmers exchange with one another and are also consulted by other stakeholders (e.g., researchers, policy makers). This strategy included three parts.
 - a. Connecting farmers to research and science-based information to on-farm management best practices, regionally test seed combinations and machinery developments to address farmer identified weaknesses and threats of intercropping systems.
 - b. Providing a platform and networking opportunities for farmers to exchange and share advice about intercropping. This could be accomplished by involving Rural Development Programs or associations to organise, advertise and connect experienced farmers with new or interested farmers.
 - c. Increasing education and awareness across the supply chain. Starting with farmers, creating accessible short online tutorials, demonstrations, and training opportunities. This needs to be partnered with public and policy awareness to enhance support across the supply chain.
2. Build networks and increase communication between policy makers, government organisations, researchers, industry leaders and farmers.
3. Reduce individual farmer risk by bolstering policy support and involve a diverse range of farmers by supporting adaptable intercropping schemes.
4. Increase demand for intercropped products developing high-protein products as both food and feed.
5. Create farm-scale regional economic models and commercialise supply chains for new products.



Legume-Cereal Intercropping

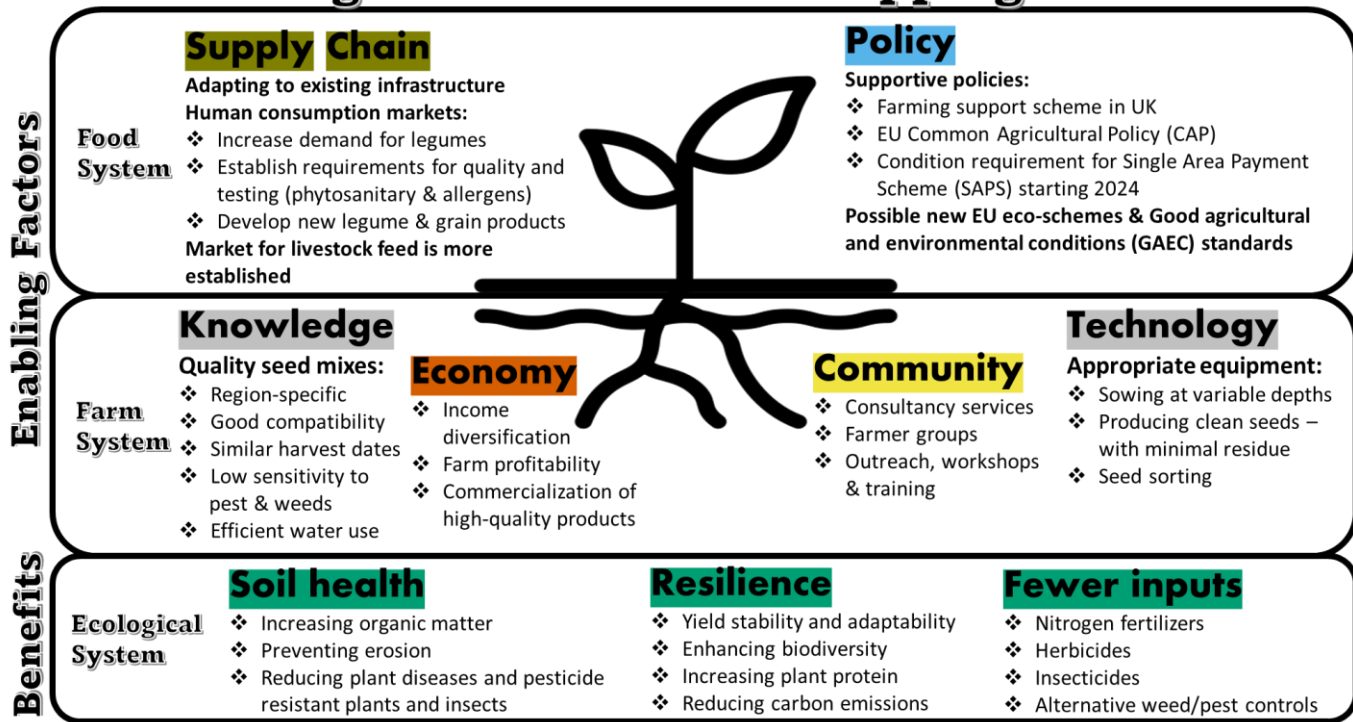


Figure 3. Enabling factors and benefits of legume-cereal intercropping.

Intercropping Strategies

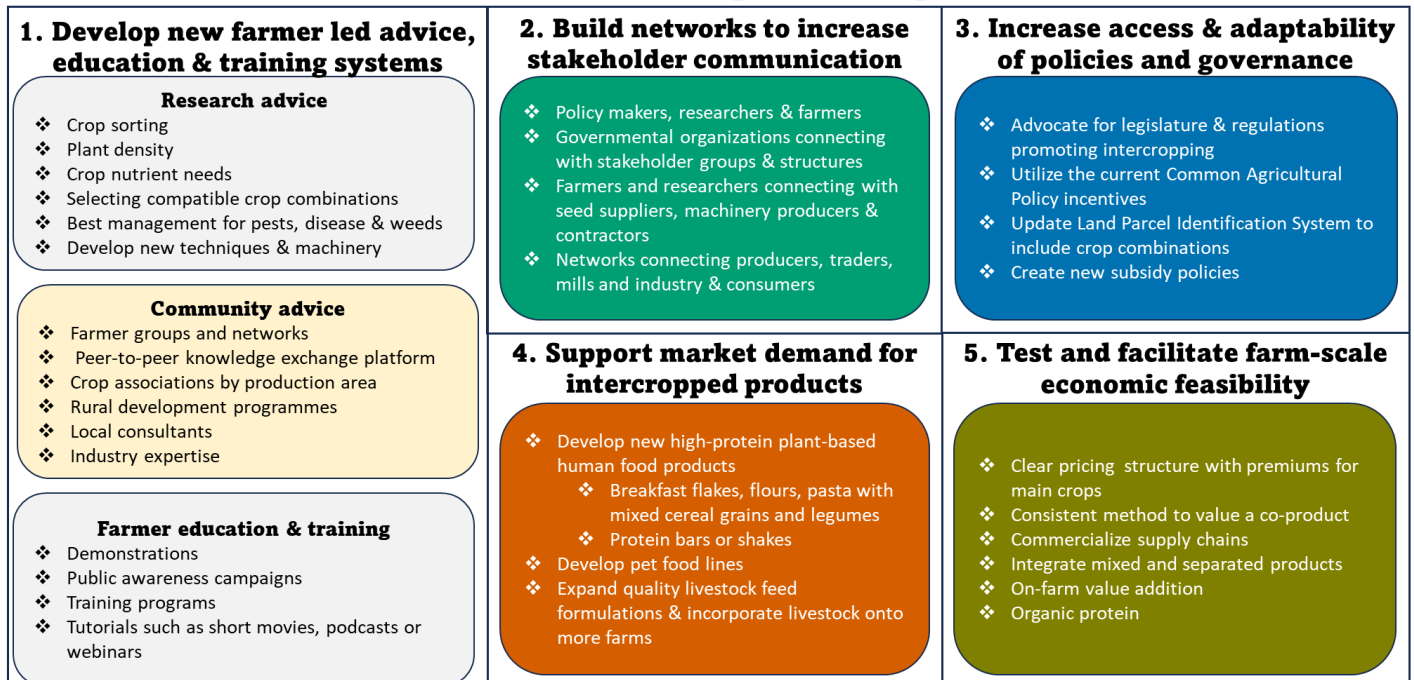


Figure 4. Strategies for legume-cereal intercropping.



3.3 Key considerations when selecting seeds for intercropping

Regionally specific seed mixes for legume-cereal intercropping optimised for environmental complementarity and profitability was a current gap emphasised by the focus groups in Europe, Egypt, and Pakistan. Identifying and testing seed combinations optimised for intercropping is the first step toward the effective expansion of intercropping (Figure 5). Developing high quality seed mixes may involve plant breeding to enhance positive intercropping characteristics in some cases. However, given the lack of tested regional intercrop seed mixes, starting with testing current varieties utilized by farmers could provide positive results sufficient for increasing adoption of intercropping. Focus group participants also identified four additional considerations for seed selection at the farm-scale related to new farm technology and management procedures, regional consultants to provide advice, supply chain development and new intercropped products for food and feed (Figure 5). Although crop advisors and seed producers were involved in focus groups, no specific seed combinations were identified or compared within the national focus group summaries. This notable lack of applied knowledge represents a critical gap that needs to be addressed before intercropping can be widely adopted.

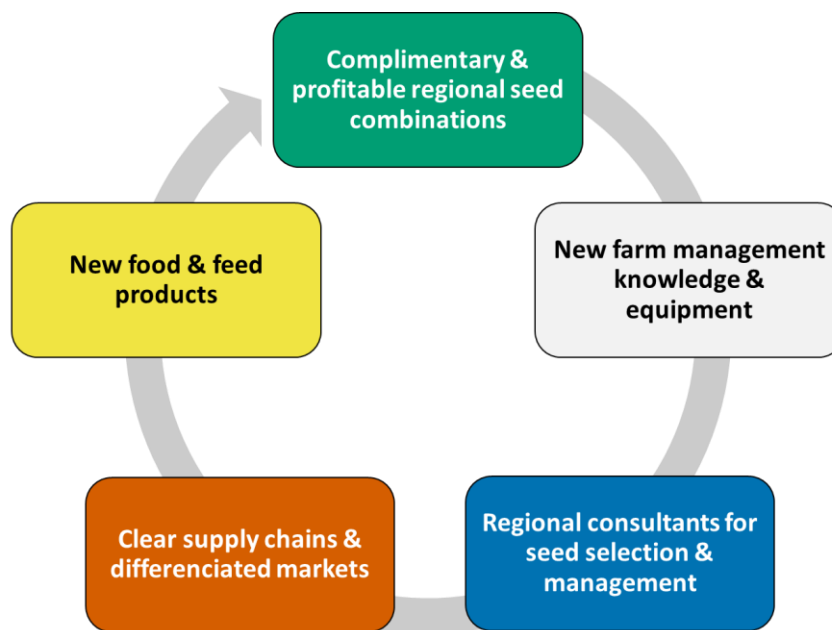


Figure 5. Considerations for species mixtures for legume-cereal intercropping.



Conclusions

Legume-cereal intercropping is a promising cropping system for improving soil health and cropping system resilience while reducing the input of nitrogen and pesticides alike. In addition to the environmental benefits, intercropping has the potential to be profitable and scalable, opening up the opportunity for more locally grown plant-based protein as both food and feed. Despite the great potential of intercropping, action needs to be taken across the food system to enable this shift in cropping systems. New farmer-led advice systems supported by research, community and governmental partners are critical to its success in European countries as well as Egypt and Pakistan. Knowledge and technical barriers regarding the seed selection and management of intercropping at the farm scale could be overcome by greater collaboration. Increasing collaboration and communication to create innovation across the supply chain and raise public awareness would also enable adoption of legume-cereal intercropping across a wide range of different farming systems and scales.

Ten focus groups from the nine countries involved in LEGUMINOSE identified strengths, weaknesses, opportunities and threats, as well as enabling factors and strategies for increasing legume-cereal intercropping in Europe and beyond. However, information related to specific intercrop seed mixtures was lacking. To support farmers, specific combinations of varieties need to be identified and tested on a regional basis to mitigate risk and support the largest range of environmental benefits possible. This could be accomplished by testing current legume-cereal varieties in intercropping systems to identify opportunities for future plant breeding that build up productivity and resilience. The LEGUMINOSE project is uniquely positioned to collect and distribute this technical information required by farmers, while also developing opportunities for innovative supply chains that support multiple objectives (environmental, economic, social, institutional) across scales. Outreach and engagement with farmers through living labs are a promising platform to deliver some of the knowledge and technology required to increase adoption of intercropping in Europe and other countries where monocropping remains the dominant cropping system.





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a) Workshop guidelines

Role of facilitators

We suggest that for each group, two people facilitate discussion, a moderator and a note taker.

1) The role of the moderator is to ensure that the discussion stays on track, keep time and facilitate the dialogue among partners. 2) The role of the note taker is to keep record of the discussion and to summarise key conclusions from the day. If you are short of staff or have many groups one person may fulfil both roles, but it is good to have two people there, as it can be difficult to remember discussions when also facilitating.

Introduction

1. A moderator presents the purpose of the exercise and the structure of the discussion.

Step 1: Identifying barriers (40 minutes)

2. It is great to work in groups of 6-8 people, so that participants have a good opportunity to share their reflections. Therefore, if more participants are attending the session please divide into two or more groups, and allow time towards the end for joint discussion of the findings. When dividing the group it can be useful to divide according to stakeholder category (that is farmers discuss with farmers, consultants etc.) and if you have several groups of farmers then it might be helpful for organic farmers and conventional farmers to be divided in separate groups, and also arable/mixed farmers.

3. Frame the discussion around a simple question, like “in your perspective what are the implications of changing to intercropping” and introduce the purpose of the exercise.

4. Allow participants 3-5 minute reflection time initially, for participants to gather their thoughts and write their reflections on a note or a post-it. One reflection pr. post it.

5. Always have a facilitator in the groups to moderate discussions, keep the time, to ensure that participants stay on the right track and understand the exercise.

6. Go through the SWOT one quadrant at a time, and allow individual participants time to share their reflections. Bring a whiteboard, a printout or a sheet from a flip-over with the four quadrants of the SWOT and ask participants to post their reflections when going through the quadrant.

7. Towards the end of the first session, moderator and/or participants should group statements that are similar, producing a consolidated set of categories and rank their 3 most important statements in each quadrant.

Step 2: (15 minutes)

8. Once you have identified and prioritised your SWOT results, you can use them to develop strategies. After all, the true value of this exercise is in using the results to avoid crop failure and to maximise a positive output.

9. Initially, look at the strengths you identified, and then come up with ways to use those strengths to maximise the opportunities (these are strength-opportunity strategies). Then, look at how those same strengths can be used to minimise the threats you identified (these are strength-threats strategies). Continuing this process, use the opportunities you identified to develop strategies that will minimise the weaknesses (weakness-opportunity strategies) or avoid the threats (weakness-threats strategies).

Step 3: (15 minutes)

10. Ask participants to summarise what their most important criteria for changing to an intercropping system, based on the 4 strategies for intercropping as outlined below:

		Intercrop market	
		Whole crop	Separated crops
Product use	Feed		
	Food		

Wrap up (15 minutes)

11. If several groups are used please take the time to briefly summarise the discussion of each group and allow participants to have a final say.



b) National workshop report template

Table 2 – Workshop report template

Background information about the workshop	
When was the workshop conducted?	(Month and year)
Who completed the reporting?	(Name and email)
Duration	
Please note the number of participants in each stakeholder category	
1) Farmers	
2) Researchers	
3) Policymakers	
4) NGO representatives	
5) Supply industry	
6) Other	
7) Total:	
Discussions in the workshop	
Most important strengths	(Please note and rank the most important categories)
Most important weaknesses	(Please note and rank the most important categories)
Most important threats	(Please note and rank the most important categories)
Most important opportunities	(Please note and rank the most important categories)
Please summarise the discussions regarding the content of the four SWOT elements	(please provide a short summary of discussions ~500 words)
Which strategies do stakeholders report with respect to mitigating weaknesses and threats?	(please provide a short summary of discussions ~500 words)
What are the most important considerations when selecting seeds for species mixtures?	(please provide a short summary of discussions ~500 words)



c) Strengths, weaknesses, opportunities, and threats

Table 3 - Summary of national discussions of strengths, weaknesses, opportunities, and threats

<p>Czech Rep.</p>	<p>Participants across groups agreed on the potential of intercropping in positive effect on soil quality (in terms of improvement of soil health and fertility), contribute to C sequestration and N fixation. Legumes used as an accompanying crop work over time by improving the nutrition for main (accompanied) crop and further fixed nutrients are stored in the soil and are available for next crop. Another important benefit is revitalization and increasing of biodiversity of both rhizosphere and overall soil microbiome. Increased crop diversity can contribute to effective integrated pest management: weed suppression during and shortly after emergence, legumes can serve as a visual, mechanical or chemical barrier which can lead to reduction of insecticide and herbicide consumption and number of applied sprays (cost savings; prevention of pest resistance). In terms of soil degradation is a widespread problem throughout the Czechia, the anti-erosion effect of intercropping (mainly in wide-row crops) is very important. Intercropping reduces evaporation and improve infiltration of the soil. More diverse or variable crop cover should lead to higher (a)biotic stress resistance or resilience in crops. Farmers emphasized the importance of the economic profitability as the most important consideration when deciding which crops to grow. It is important that there is a sufficient demand for products from intercropping (seeds, food, fodder). Very important thing is situation at spot market, it means “interest” in legumes and a willingness to buy them out at an acceptable price. This market demand is crucial factor for farmers and their production, harvest and also for their decisions in near future (next season). The other issue is the decline of livestock farms in a large part of the Czech Republic. Farms without livestock production are not able to use all biomass produced from intercropping on farm, and they must solve what to do with it (rentability). The intercropping method needs special machinery use (proper soil cultivation, sowing and harvest), this means higher input costs for farmers, very often without certain profit. There is a need to find out compatible varieties for intercropping because legume component in intercropping may suppress the cereal component and it can be true also in an opposite manner in some cases not all varieties of cereals and legumes are suitable for intercropping. The weakness can be the limited life span of varieties (8 year at maximum under the Czech conditions). From the point of view of farmers and supply industry there is a lack of cooperation and knowledge transfer between scientific and supply industry and farmer sectors.</p> <p>The biggest threat is that the Czech legislation is insufficiently prepared for intercropping. Everything is interconnected, the legislation and</p>
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	<p>subsidy policy does not contribute enough to the spread of legumes. E.g. the Land Parcel Identification System of Czechia (LPIS) is the only platform used for submitting subsidy applications of Czech farmers has only possibility to identify the cereal legume intercropping with either field pea or clover. This leads to the impossibility of proper reporting of pest control agents. Supply chain representatives highlighted insufficient quality and quantity of legumes seedstock from Czech farms (mainly field pea, fodder pea and beans) and large share of import of cheaper foreign production (seeds and extracted soyabean meal for fodder production). The common agreement was on non-transferability of some results of agricultural research due to the specific local conditions and uniqueness of the farms and also climate change.</p> <p>The biggest opportunities for spread of intercropping practice is limited availability of cheap and high quality of supplied organic material (manure, compost etc.) and high price of mineral fertilizers. Intercropping is a tool to slow down/reduce the resistance of pests to the active substances of pest control agents. There is an opportunity to support intercropping by suitable changes in subsidy policy. E.g. wide-row crops will be possible to grow only as intercropping/cover crops from 2024 (conditions for agricultural subsidies – SAPS), payment for carbon farming or implementation of principles of regenerative agriculture.</p>
Denmark	<p>The SWOT analysis conducted by the four stakeholder groups—Farmers, Value Chain Representatives, and International Intercropping Researchers—shed light on the multifaceted nature of intercropping practices.</p> <p>Intercropping boasts several noteworthy strengths that all stakeholder groups acknowledged. Foremost among these is its potential to drive sustainability in agriculture. By reducing nitrogen use, enhancing soil health, and sequestering carbon, intercropping aligns with the urgent need for eco-friendly farming practices. Furthermore, it fosters biodiversity, which benefits both the environment and crop resilience. The ability to improve nutrient and water use efficiency and the potential for increased yields were also identified as significant strengths. Additionally, intercropping can raise consumer awareness and acceptance, potentially creating a market demand for intercropped products.</p> <p>Crop management complexities, including crop sorting, plant density, and selecting compatible crop combinations, were a common concern among all groups. The limited knowledge and awareness of stakeholders about intercropping practices were recognized as hurdles to adoption. Technological barriers, such as the need for new machinery and difficulties in harvesting and sorting, were also cited as impediments. Perhaps most critically, there was a pervasive concern about farmer</p>



	<p>reluctance to embrace intercropping due to perceived risks and challenges, which could hamper widespread adoption.</p> <p>It aligns with the growing demand for sustainable agriculture by reducing the use of agrochemicals, improving soil quality, and decreasing plant diseases. The potential for innovation in intercropping machinery and techniques presents opportunities for developing new value chains, stakeholder interactions, and markets for intercropped products. Moreover, intercropping's role in climate resilience, through carbon sequestration and climate-adaptive farming practices, aligns with global efforts to combat climate change. Additionally, there are economic opportunities for farmers to brand Danish-produced protein and participate in the organic market.</p> <p>A key concern was the lack of policy and legislative support. Farmers and researchers feared that existing regulations might not favor intercropping and that legal obstacles could hinder its widespread adoption. Economic factors were also deemed a threat, as the availability of cheap agrochemicals and potential short-term yield reductions could dissuade farmers from engaging in intercropping. Additionally, there was a consistent apprehension about farmer reluctance to adopt intercropping systems, driven by low awareness, perceived risks, and challenges. Technical and knowledge gaps, including limited understanding of intercropping benefits and machinery limitations, were seen as obstacles to successful implementation.</p> <p>In summation, according to stakeholder groups, intercropping holds promise for sustainable agriculture, enhanced yields, and environmental benefits. However, it faces challenges related to awareness, education, technology, and policy support. To control its strengths and opportunities, stakeholders must proactively address these weaknesses and threats. Education and awareness campaigns, innovation in machinery, and policy support are essential steps in promoting the broader acceptance and adoption of intercropping practices. By doing so, stakeholders can contribute to more sustainable and resilient agricultural systems.</p>
Germany	<p>Farmers that are interested in intercropping see a chance to improve yield benefits in terms of quality, quantity. At the same time, they see a good chance to decrease the inputs of agrochemicals, which would save money and reduce environmental harm. The latter would be good to increase a positive awareness of farming practices in the society. Farmers experience the ongoing climate change and see a chance to make their farming practices more resilient with intercropping.</p> <p>Organic farmers are always interested to close the yield gap to conventional practices. If farmers have livestock they see a good chance for sustainable protein fodder production. In all discussions with pure arable farmer the biggest question was, how to sell mixed harvest. They</p>



	<p>need an establishment of a structure from trading companies to industry. If there is no such a structure, most farmers do not see that intercropping will establish on the long term.</p> <p>Conventional farmers see a strong problem with having the right agrochemicals at hand to manage the crop properly. On the other hand they have a willing to reduce the input of crop protectants that could help to increase their revenue and environmental benefits.</p>
Italy	<p>In general, workshop attendees have displayed a positive attitude toward the intercropping. Throughout the discussions, various strengths and opportunities regarding the integration of this technique at the farm level were highlighted. Both groups emphasized the benefits of intercropping for soil fertility, microbiology, and its role in preventing soil erosion through year-round cover. The presence of research groups and farms with extensive experience in intercropping adoption was recognized as a crucial factor in promoting the implementation of these practices at the farm level. However, it was noted that most farmers point to a lack of advisory services capable of providing guidance on intercropping adoption.</p> <p>A significant hurdle in the adoption of intercropping is the scarcity of products and machinery tailored to these systems. While crop diversification is acknowledged as a promising practice for enhancing the soil fertility, it still poses the challenges in finding markets and establishing suitable structures and facilities to manage the variety of crops.</p> <p>Another concern in arable production is the damage caused by wild fauna. Given the increased availability of fodder in intercropping systems, they may become more prone to this issue. The risk of harvest loss due to such damage could discourage the farmers from adopting these systems.</p>
Poland	<p>SWOT discussion was very effective giving us outputs in all four elements including: strengths, weaknesses, threats and opportunities in legume-cereal intercropping.</p> <p>Farmers emphasized that legume-cereal intercropping can be helpful in reduction of mineral (especially nitrogen) fertilizers use which can be important for reduction of money spend on fertilization on the farm. Moreover they expect that such kind of intercropping can increase of cereal crop and quality, especially in the context of proteins content. This can be helpful for production of better quality and high-protein feed. Under discussion it was underlined that environmental effects of such production are very relevant including: increase of biodiversity, reduction or prevention against erosion and general amelioration of environmental health. Moreover, intercropping practices can be an alternative for some agricultural management practices, supporting: reduction of weeds,</p>



enriching the soil with nutrients and organic matter, plant health improve. The other issues underlined in the discussion stressed that farms have technological facilities and GPS systems helping in strip cultivation, as well as digital farm manager including full documentation of agrotechnics which can be helpful in the cultivation of intercrops, especially in strip system.

Most important weaknesses of legume-cereal intercropping underlined during workshop included: doubts concerning plant growth due to possible competition between species for water, light and nutrients. Some people stressed that weeds can constitute one of the problems in such type of plant cultivation, especially on organic farms, e.g. in the case of winter rye with vetch, there are problems with weeding. There were also emphasised that many farmers don't have any experience in intercropping and they have doubts in the context of problems with sales/disposal and lack of certainty of yields, as well as with yield variability over the years depending on weather conditions (meteorology). One of the very often stressed weaknesses was pointed to agrotechnical problems including problems with sowing and harvesting, and especially harvest problems in intercropping concerning simultaneous ripening of plants. The other one included the sowing date and the technical possibility of sowing (sowing depth) and machines availability including the needs of their adaptation or purchase of new ones. Environmental and pedo-climatic factors including e.g., low organic matter content was also emphasized as one on possible weaknesses for legume-cereal intercropping.

Most important threats underlined by workshop participants in discussions included: the doubts with good price when selling, as well as no sale/transfer of mixtures possible, including with the problems that there are no entities purchasing mixtures. The other threats were connected with high price of seed material, availability of suitable plant species, including problems in selecting good plant protection products/herbicides. The other set of threats was connected with economic issues including: no financial support for such cultivation, expensive fertilizers, lower subsidies for farmers. The other threats group included not enough awareness about intercropping, no registration of protective equipment, lack of appropriate equipment and in general technological problems with intercropping. Farmers emphasised that intercropping is more complicated than pure sowing plant cultivation. Some of participants also underlined a limited water availability for plants (competition between plants for water).

During our workshop the most important opportunities were also discussed and it was emphasised: possibility to use agri-environmental financial resources (subsidies) – climate, supporting by ecoschemes - meeting GAEC standards (Good agricultural and environmental





	<p>conditions) which can help to obtain possible financial support for crops and especially to receive subsidies for organic farming. One of the most important environmental opportunities was the reducing the use of nitrogen fertilizers, the development of regenerative agriculture, enriching the soil with nutrients, improving soil quality and increasing the level of organic matter. Moreover the opportunity to support legume-cereal intercropping is to conduct training and workshops raising awareness of the importance of intercropping practices, and demonstration field days which will be helpful to develop the farms opening up to new trends. In discussion it was emphasized that there is large market for good quality product, innovative products, functional food products, new products for animals as well as increasing trend in popularity of vegetarian and vegan diets.</p>
Spain	<p>The use of cereal-legume intercropping for forage is quite widespread in Spain, because of the high livestock production. Regarding the use of intercropping products as grain, farmers have expressed great uncertainties about its possible extension for several reasons. The first reason is the lack of knowledge and information about its agronomic management; choice of species and varieties, phytosanitary treatments, fertilizers and harvest and post-harvest work. In addition, rainfall is almost zero in the summer months in Spain (June, July and August), and therefore growing crops during these months in areas without irrigation (most of the area of extensive herbaceous crops) is greatly limited. Farmers first highlight the need for a map of viable crop associations by production areas. The uncertainty regarding the possible commercialization of these products, which hardly meet the current needs of the industry, has also been highlighted. It would be necessary to work in the future on the characterization and homogenization of the final product(s), depending on the type of crop association.</p> <p>The use of associations with legumes can lead to savings in the use of nitrogen, in addition to an improvement in the structure and quality of agricultural soils. With the development of these new cropping systems, the sector would come closer to the demands of the new agricultural policies on diversification and global sustainability of the production system.</p> <p>In Spain, intercropping is viewed as an opportunity to increase protein production mainly for fodder rather than for human consumption, and to supply companies with local products, thus reducing imports. Intercropping for grain production is believed to be less viable than forage production. Intercropping can provide a niche market for the production of organic protein.</p>
United Kingdom	<p>The groups all highlighted the potential to reduce inputs through increasing soil health and diversity leading to increased resilience as</p>



	<p>major themes as strengths with the potential of increased yield/profitability and weed control (through rotational changes to spring cropping and different chemistry) as secondary considerations. Interestingly both conventional farming groups highlighted weed control, specifically due to chemical regulations as a weakness but the organic farmers, with more intercropping experience saw weed control as a strength of intercropping. The potential to increase grain protein was mentioned by the organic group and was of interest to the conventional farmers during post workshop conversations-showing value of experience and peer-to-peer conversations.</p> <p>All groups saw separation of products, marketing and storage as weaknesses with the supply chain group highlighting an inconsistent product and need for a testing (NIR) and pricing structure to allow trading, but it did have a good sustainability appeal to feed companies. Lack of knowledge, time and on farm equipment (drilling depth and combining issues specifically) were also noted. The conventional farmers were concerned about alignment of harvest dates, but it was less of a concern to organic farmers. Most groups saw threats related to time and labour particularly during harvest, but the conventional farmers again highlighted government regulations associated with agrochemicals and complication of rotations with more ‘break crops’ involved. There were concerns raised about possible contamination of food supply (for example gluten from wheat in intercropped pulses) and particularly where there were already milling wheat supply contracts. The supply chain group was less concerned as their experience showed that there were not issues but admittedly at low volumes-however they were concerned that the market may not be able to cope with bigger volumes. The biggest opportunities for farmers were generally that through new products, new products and new premiums there is the potential to bring a higher value economically and environmentally into their farm. The ability to increase protein production, either to earn a premium or as an additional product as well as reducing input prices is seen as the main opportunity.</p> <p>Overall summary, most conventional farmers comments were based around a monoculture mindset and the difficulty of changing, but doing things differently to their neighbours was also an issue. Lack of support had been mentioned as an issue by some during the workshop however the UK government announced that companion cropping would be supported through its farming support scheme after the meeting.</p>
Egypt-AK	<p>When it comes to the good sides, intercropping cereals and legumes together allows farmers to make the most out of their resources. By growing cereals and legumes together in the same field, they use water and nutrients more efficiently. This practice helps the crops support each other’s growth, leading to more production and helping farmers earn</p>



	<p>more money. Another positive aspect is the reduced need for nitrogen fertilizers. Legumes help in adding nitrogen to the soil, which is beneficial for cereal crops, leading to lower costs and a healthier environment. However, participants also highlighted several problems. Managing different crops together in the same field makes farming more complex. Another issue is weed management. It's harder to find suitable herbicides that work for both cereals and legumes. This makes it more difficult to manage weeds, leading to more labour requirements. Managing water and fertilization for different crops is also a challenge, needing more attention and expertise.</p> <p>Despite these issues, the group saw several opportunities with intercropping. This practice could increase the financial gains for farmers by effectively growing multiple crops together. It allows for synchronized growth, where each crop helps the other grow better. The local climate and conditions in Dakhla are also suitable for such intercropping systems.</p> <p>However, this doesn't come without its challenges. The biggest concern is water availability. With limited rainfall, reliance on finite groundwater is a serious issue. The scarcity of farming land and the different needs of each crop under intercropping systems also pose challenges. The effects of climate change on various crops further complicate the decision-making for farmers.</p> <p>In summary, the workshop was a platform for everyone to understand the various aspects of intercropping cereals and legumes in Dakhla. Participants agreed on the significant role of using water efficiently and the need for more research on suitable irrigation and fertilization methods. By addressing these issues and focusing on the sustainable practices of intercropping, a more profitable and environmentally friendly farming system can be achieved in the region.</p>
Egypt-KE	<p>The strengths emphasized the substantial advantages that intercropping brings to the table. Participants highlighted the enhanced resource utilization as a prime benefit, allowing for a more efficient and sustainable use of water and fertilizers, critical elements in the agricultural process. This efficiency not only contributes to environmental sustainability but also potentially reduces costs for farmers, fostering financial sustainability as well. Improved soil health was another significant strength discussed. Intercropping encourages biodiversity and enhances soil nutrients, leading to more robust crop yield and resilience against pests and diseases. Additionally, the diversification of income stands out as a tangible advantage for smallholder farmers, permitting them to broaden their revenue streams through diverse crop production, providing a buffer against market fluctuations affecting a single crop. However, the participants also acknowledged several weaknesses. Intercropping introduces additional complexity into crop management,</p>



	<p>necessitating enhanced knowledge and skills to effectively manage varied crops concurrently. This complexity can be a hurdle for smallholder farmers with limited access to modern agricultural technology, training, and market information, especially in regions like Kafr Elsheikh. The issue of resource accessibility is pivotal, accentuating the pressing need for substantial support systems to empower farmers to adopt intercropping practices effectively.</p> <p>The discussion on threats unveiled concerns of land fragmentation, which poses substantial obstacles for mechanized farming and efficient land use, exacerbating the challenges for smallholders to adapt to innovative agricultural practices. The restricted access to diversified crop markets is another significant barrier, underscoring the importance of robust market linkages and support systems for farmers adopting intercropping. Environmental concerns, particularly the impacts of climate change and water scarcity issues, loom large as threats to the sustainability of intercropping practices, making it imperative to develop climate-resilient agricultural strategies.</p> <p>Despite these challenges, participants explored several opportunities. Intercropping holds the promise of soil and crop enhancement, contributing to boosted fertility and yields. It opens avenues for transitioning to organic farming pathways, reducing reliance on chemicals, and potentially gaining access to profitable organic market segments. Intercropping stands as a promising technique for advancing climate-resilient agriculture, introducing farmers to more adaptable and resilient farming practices.</p> <p>In summation, the participants expressed both hope and concerns, thoughtfully considering the multi-dimensional impacts of intercropping. The collective consensus underscored the indispensable role of robust governmental support, continuous training programs, and the promotion of organic farming. These elements are vital for overcoming the identified challenges and capitalizing on the available opportunities. The workshop solidified the commitment to pursue intercropping as a viable and sustainable agricultural strategy, recognizing its potential to contribute significantly to the agricultural landscape in Egypt, enhancing both environmental sustainability and economic viability for smallholder farmers.</p>
Pakistan	<p>All workshop participants actively participated and responded to the possibilities of legume-cereal intercropping in Pakistan and summarized that the legume-cereal intercropping offers multiple benefits to involved stakeholders by improving crop yields and soil health, conserving soil biodiversity, reducing chemical fertilizer inputs, rationalizing farm resources and leading to better farm economics. This increased productivity stems from enhanced soil fertility, as different plant species complement each other's nutrient requirements. Consequently, it boosts</p>



overall crop production and could contribute to local and regional food security. Farmers can also benefit from higher profitability by cultivating appropriate approved varieties simultaneously and diversifying income sources. Intercropping provides high climate resiliency because varied crops can adapt to changing weather patterns and reduce the risk of total crop failure. Moreover, it improves soil health by reducing erosion and promoting nutrient cycling and recycling. This, in turn, encourages soil biodiversity conservation and improves soil functions in agroecosystems. It helps in insect and pest control management by disrupting their habitat and reducing the risk of infestations, thus promoting eco-friendly and sustainable agriculture.

The participants viewed that legume-cereal intercropping, while beneficial with multiple benefits, face various weaknesses and threats. High soil pH levels in alkaline calcareous soils in Pakistan can hinder crop growth, especially for legumes, which prefer slightly acidic conditions. The deficiency of soil organic matter in soils can limit nutrient cycling and also influence nitrogen fixation process. Variability and lack of availability of intercropping varieties can also affect their compatibility and yield potential. The unavailability of appropriate technology and machinery was considered an important barrier which makes intercropping challenging, and farmers' knowledge gaps due to lack of proper training and knowledge may hinder its successful implementation. Limited sustainability can arise due to resource-intensive management in already nutrient-depleted low fertility status soils in Pakistan. Sowing methods and the unavailability of farm-machinery are among the major challenges for local farmers whereas the plant protection measures can also become significant issue. Managing weeds and insects in intercropped fields can be complex and challenging, potentially resulting in lower crop yields. Irrigation issues, such as water distribution and scheduling, may affect crop productivity. Moreover, variations in growing periods among intercropped species can disrupt harvest planning, affecting overall productivity. Marketing and harvesting problems can also deter farmers from adopting this practice. Addressing these weaknesses and threats is crucial to maximize the benefits of legume and cereal intercropping.





d) Strategies

Table 4 - Summary of national strategies

<p>Czech Rep.</p>	<p>All groups highlighted the need for stimulation of demand for mixed/separated products from intercropping.</p> <p>The change in legislation and subsidy policy is needed in terms of identification of intercropping as a method of crop cultivation and erosion control measure for wide-row crops growing. At least the update of the list of crops (crop combinations) in LPIS will lead to possibility to identify intercropped crops (cereal/oilseed rape/wide-row crops and all legumes etc.) and report correctly about the pest control agents. There is a need for more intensive communication between policy makers (Central Institute for Supervising and Testing in Agriculture, The State Agricultural Intervention Fund and Ministry of Agriculture) with farmers and researchers.</p> <p>Good agricultural practices demonstration of intercropping, more networking opportunities between farmers already adopted intercropping and those just starting and more effective knowledge transfer would convince farmers to adopt intercropping method in usual farming practice.</p>
<p>Denmark</p>	<p>Crop Management: Strategies include investing in research and development to address challenges in crop sorting, plant density, and selecting compatible crop combinations. This involves developing new techniques and machinery to make intercropping more manageable for farmers.</p> <p>Education and Awareness: Stakeholders emphasize the need to educate farmers and other stakeholders about the benefits and techniques of intercropping. This can be achieved through public awareness campaigns, training programs, and knowledge sharing.</p> <p>Technological Innovation: To overcome technological barriers, stakeholders hope to see innovation and development in machinery that simplifies intercropping tasks such as harvesting and sorting. These innovations aim to make intercropping more accessible and efficient.</p> <p>Economic Incentives: Strategies include exploring new markets and branding opportunities for intercropped products to improve profitability for farmers. Encouraging consumer acceptance and willingness to pay for intercropped produce can also help address economic concerns.</p> <p>Policy Support: Stakeholders aim to engage in advocacy efforts to influence policy and legislative changes that support intercropping. This involves addressing legal obstacles and advocating for regulations that promote intercropping.</p> <p>Economic Diversification: To counteract economic threats, stakeholders propose diversifying income sources for farmers through innovative value chains and market development. This can help reduce dependency on agrochemicals and mitigate yield fluctuations.</p>



	<p>Research and Development: Researchers plan to continue studying intercropping benefits and practices, providing evidence to respond to farmer reluctance and low awareness on intercropping in general. Demonstrating the advantages of intercropping through research can encourage adoption.</p> <p>Knowledge Sharing: Stakeholders aim to foster knowledge sharing and collaboration among all parties involved in intercropping, from farmers to researchers and value chain representatives. This can help bridge the gap in understanding and address various challenges.</p> <p>Summary: Stakeholders emphasize the importance of education, innovation, policy support, and collaboration to promote a sustainable adoption of intercropping practices.</p>
Germany	<p>Technical issues could be overcome quite quickly by working together with seed suppliers, machinery producers or contractors. Seed suppliers could sell proper crop combinations that are tested to be high yielding and resilient.</p> <p>Establishment of a chain to sell intercropping products must be established. The network should connect producers, traders, mills and industry and consumers. Governmental organizations should help to connect the stakeholder groups and structures.</p> <p>The piling up of rotational diseases could be overcome by resistant crop combinations or a wider crop rotation.</p> <p>A platform for exchange between farmers could help to solve problems with intercrop management. Farmers like to learn from the experience of colleagues about challenges, mistakes and success. Tutorials such as short movies, podcasts or webinars could help to overcome hesitations.</p>
Italy	<p>Intercropping is a versatile technique that can be implemented using various agronomic approaches and machinery, making it adaptable to diverse farm realities. Emphasizing this adaptability could help to overcome many barriers linked to its adoption. Conducting more on-farm experiments and sharing the results with fellow farmers, consultants, and industry experts can effectively promote this positive aspect across different regions. These experiments serve not only to showcase the benefits but also to address any concerns and hesitations related to intercropping.</p> <p>In the face of evolving resistance and the diminishing efficacy of herbicides, weed management has become a critical limitation in field crops, especially in organic farming. Intercropping, in this context, presents a viable solution/tool and could be possibilities in increase of its adoption by farms, struggling with weed management challenges. Utilizing incentives provided by the current Common Agricultural Policy (CAP) could serve to offset potential reductions in production during the early years of intercropping adoption. These incentives could also act as compensatory measures for wildlife-induced damages. Furthermore, Rural Development Programs could be tailored to</p>



	<p>establish a network of producers, facilitating the seamless placement of intercropped products within the market.</p>
<p>Poland</p>	<p>To mitigate weaknesses and threats stakeholders proposed to focus on increase in the share of farms with animal production which will help to increase demand for intercropped grains. The other strategy presented in discussion was to looking for new markets for selling yield crops.</p> <p>Moreover to increase farmers/advisors/citizens awareness on intercropping stakeholders proposed a strategy to organize more trainings, workshops and courses on intercropping importance for the development of new, future, sustainable agriculture with high quality crops production.</p> <p>Based on the discussion, a strategy was proposed that included the possibility of expanding the farm's activities by processing crops and their processing divided into fractions or in entirety, providing new sales opportunities for the produced products. The other strategy included processing of produced mixture crops residues for biofertilizers in order to increase water retention and nutrients availability improvement.</p> <p>One of the most important strategy for intercropping development is the collaboration with the other farms to spread and sell innovative products and support the other branches.</p> <p>The other strategy include the development of new agrotechnical industry such as machinery by production agricultural equipment suitable for intercrops sowing and harvesting – farmers can be advisors (they know the best what they need) of such companies having additional money from that activity. This strategy can help to mitigate weaknesses and threats of intercropping, as well as will help to grow agromachinery industry by offering new solutions and machines to farmers.</p> <p>Very important strategy to overcome barriers is education and marketing, therefore besides of demonstration events, short movies on e.g., you tube channel with instruction how to provide intercropping will be very useful for development this trend of production within farmers. One of the most important indicator of agricultural production for farmers is economic effect. Therefore developing of innovation can give farmers real economic effect.</p> <p>The other strategy is to develop of functional food products with higher level of proteins, for special group of people, but also for animals – product innovations.</p> <p>People carry about their animals and also more often they try to support diets of pupils, therefore development of veggie products for animals is growing branch, by offering such products as: protein shake for cats, vegan dish for dogs. It is worth to add that plant-based protein products, represented by “plant meat”, are gaining more and more popularity as an alternative to animal proteins.</p> <p>Innovative functional food products can include e.g., flour with increased protein content obtained by grinding a mixed crop of cereal</p>



	<p>grains and legumes. Moreover such flour can be used for functional pasta production, as well as the other products covering all links in the value chain.</p> <p>Farmers can include to own farm processing of yield and sell to value chain innovative functional food such as: protein breakfast flakes from cereals and legumes, protein bars or shakes, mixture of powder proteins, products for special groups of people e.g., sportsmen, people with some diseases or for older people or for children with balanced content of proteins and vitamins and other nutrients. This strategy can also include to sell yield to the other Partners who will produce such products. During discussion it was underlined that these kind of products are sought after by consumers and the branch of development of these products has great potential, especially in the era of increased popularity of vegan and vegetarian diets.</p>
Spain	<p>The stakeholders report that it is important to carefully analyze the selection of species. For this purpose, funds for specific research on cereal and legume associations is needed. Likewise, scientific research must provide information on the nutrient needs of these associations, both in terms of quantity and time of application.</p> <p>The products obtained from intercropping must have harmonized characterization criteria that allow them to be released to the market both as human and animal food.</p> <p>Production should focus mainly on forage, so that intercropping may have a better implementation in Spain.</p> <p>The stakeholders finally highlight the need of extensive economic studies that consider conventional rotations and the introduction of associations to reduce uncertainties.</p>
United Kingdom	<p>All groups highlighted that knowledge and advice was an important area that was lacking. Most attendees felt that there was a lack of knowledge in the farming and advice community for farmers to feel supported in making these changes. Specifically, questions relating to crop agronomy (pests, disease and weeds) although the organic experience was that these are not issues anyway. More farm centered work, peer-to-peer knowledge sharing (such as the farm-walk following the workshop) and better communication with experienced intercroppers. A big discussion in the organic group was around the potential uplift in protein in milling wheat, demonstrated experimentally and anecdotally, but disputed by a researcher on the day as 'not possible'-highlighting a knowledge exchange and information gap that needs to be filled.</p> <p>Allowing more off-label chemical use would be seen as a positive for conventional growers who seemed to be more risk averse, particularly for fungicides and those in high grass weed areas specifically.</p> <p>The management of the combined product was also highlighted, separation was an issue, but the supply chain needs to have a consistent method to value a co-product/biproduct in order to have a premium for the high-quality main crop/s. Farmers were broadly happy</p>



	<p>to produce the crop and could see the need to separate to have a market, but the pricing structure needs to be obvious.</p> <p>Many conventional farmers have been used to a structured system, drilling dates, drilling depths, fertiliser timings, harvest dates based around a one-size fits all advice system which is not independent, or government funded in the UK. Organic farmers have tended to be more innovative and more flexible in their approach. One farmers comment during the workshop was that we need to overcome the perception that intercropping is too complicated.</p>
Egypt-AK	<p>To address the numerous challenges in the intercropping of cereals and legumes, several mitigating strategies were brought to light during the workshop discussions. Understanding the constraints related to water, the introduction and training on innovative, water-efficient irrigation methods were emphasized. These techniques will not only conserve the valuable water resources of the region but will also contribute to the optimized growth of intercropped cereals and legumes. Efficient irrigation systems, such as drip and sprinkler irrigation, could minimize water wastage and ensure that crops receive adequate water for healthy growth.</p> <p>Another critical area identified was the need for enhanced weed management solutions. Participants discussed the development and widespread dissemination of effective and sustainable weed management strategies. This effort involves researching and identifying herbicides that are suitable for use in intercropping systems involving both cereals and legumes, ensuring the elimination of weeds without negatively impacting the crops. Training programs could ensure farmers understand the safe and effective use of these herbicides, minimizing both economic and environmental impacts.</p> <p>The importance of comprehensive training initiatives on intercropping methodologies, complex irrigation, and fertilization systems was also highlighted. Ensuring that farmers have a deep understanding of the unique needs and interactions of intercropped cereals and legumes, as well as effective irrigation and fertilization techniques, will contribute to improved crop yields, financial viability, and overall sustainability of farming practices in the Dakhla region.</p>
Egypt-KE	<p>In light of the prevalent practice of intercropping cereal-legume in the Nile Delta region of Egypt, the participants explored numerous strategies to enhance the efficiency and sustainability of this approach. Emphasis was placed on comprehensive training initiatives, ensuring farmers have the in-depth knowledge necessary for maximizing the potential of intercropping. With the understanding that legume crops, such as beans, lentils, and peas, naturally nourish the soil by adding nitrogen, training programs aim to deepen farmers' understanding of these natural benefits, helping them minimize the use of artificial fertilizers, and thereby contributing to environmental sustainability.</p> <p>Strengthened government support was also identified as a crucial element. By supporting infrastructural and financial backing,</p>



	<p>governmental bodies can assist in reducing the risk of crop failure, a notable benefit of intercropping. Support in the form of subsidies or access to low-cost resources can further encourage farmers in the Nile Delta region to continue and expand their intercropping practices.</p> <p>The promotion of organic farming, aligned with the natural advantages of intercropping, was highlighted. Campaigns to increase awareness of the reduced need for pesticides and herbicides in intercropping systems, thanks to the diverse environment that discourages pests, can help farmers transition more fully to organic farming methods. This transition not only contributes to environmental health but also taps into the growing market demand for organic produce, potentially increasing farmers' incomes.</p> <p>Lastly, the discussion on climate adaptive strategies emphasized the potential reduction in water use associated with intercropping, crucial in Egypt's arid climate. By educating farmers on the best practices for maximizing water efficiency in intercropping systems, long-term agricultural sustainability in the Nile Delta region is further promoted.</p>
<p>Pakistan</p>	<p>Various stakeholders participating in the workshop hailed the Stakeholder Workshop organization and also admitted the significance of the LEGUMINSOE project within the European and beyond European context. They viewed the legume-cereal intercropping as a win-win situation if propagated and adopted appropriately and effectively. Establishing of Living Labs in Pakistan was considered as a promising opportunity because it provides “seeing is believing” approach by involving farmers and other relevant stakeholders inclusively to demonstrate the benefits and challenges of adopting legume-cereal intercropping. The participants, particularly, the farmers emphasized the need of better research, development and training opportunities that involve the local research and academic organizations to address the weaknesses and threats of legume-cereal intercropping systems.</p>



e) Species mixtures for intercropping

Table 5 -National report summaries on species mixtures for intercropping

Czech Rep.	<p>The most important is compatibility (suitability for growing in mixture) of varieties in order to avoid competition and support the suitable composition (do not suppress; serve as a support for a partner crop - procumbent; height etc.).</p> <p>Variety requirements used in mixture (intercropping) should differ from variety requirements planted in monoculture. It is necessary to identify the specific traits and attributes for be accompanying/accompanied crop in intercropping. There is a need for change in variety registration and testing (Central Institute for Supervising and Testing in Agriculture) those varieties used in intercropping.</p> <p>Appropriate choice of variety can have insecticidal effects, serve as a visual, mechanical and chemical barrier and lead to the reduction of insecticide application.</p> <p>The choice of species for mixture is closely dependent on the available machinery in relation to the seed size, sowing depth and row width. Equally important is the harvest date (maturity at the same time).</p>
Denmark	<p>During the workshop, there was limited in-depth discussion regarding the selection of seeds for species mixtures. However, the discussions indirectly touched upon this topic by emphasizing the importance of addressing technological prerequisites beforehand. To effectively choose seeds and species mixtures, farmers must initially acquire knowledge on crop management and yield handling. This includes proficiency in sorting and cleaning crops, as well as the harvest and sorting of yields. Additionally, it involves understanding which retailers and agricultural supply companies would be interested in purchasing specific mixtures and at what price points. As a result, considerations regarding the selection of seeds and mixtures are heavily contingent on the evolution of the intercropping value chain in the years ahead.</p>
Germany	<p>There should be a good availability of seed. Since the different seeds have to be deposited partly at different depths, the technology for this should be available; otherwise, one would have to find a middle way. Again and again a similar harvesting date of the mixture was mentioned. The harvestability of the mixture also seems to be very important. The grains should be harvested as pure as possible and with little plant residue. For the farmers who feed the harvest, this is not quite as problematic, as the harvest is still ground.</p>
Italy	<p>One of the most significant factors influencing the adoption of intercropping practices is the availability of technical resources for cultivating the associated species. This factor remains a critical</p>



	<p>consideration regardless of the production's intended use or the harvesting method.</p> <p>Regarding the individual harvest of intercropped crops, if the end goal is livestock feed, that destination is established. However, when considering combined grains for human consumption, uncertainty arises. Currently, there is a notable lack of widely available products in the market made from blended legume and cereal flours. Addressing this gap calls for the development of new and innovative products in this domain.</p> <p>Furthermore, a fundamental aspect in promoting intercropping adoption is the establishment of dedicated consultancy services for companies. These consultancies can provide valuable guidance, assisting companies in making informed choices and selecting the most suitable species to blend, further encouraging the successful integration of intercropping practices.</p>
Poland	<p>The most important consideration during the choice of plant species included: profitability/profitability, ease of harvesting, machine availability, selection of similar harvest dates seeds, feed needs.</p> <p>The most important considerations when selecting seeds for species mixtures, taking under consideration feed needs, underlined in discussions included: species that can be used as feed for pig and as green fodder for cattle, as well as for silages production. Moreover they emphasized the needs of species which support production of new products with nutritional value for production of high-proteins products.</p> <p>Moreover, it was stressed that there is the needs to adapt plants to the existing infrastructure, which reduces costs compared to only adapting or changing the infrastructure on the farm to selected plants.</p> <p>Few farmers emphasized that very important in plants selection is their usefulness for new products development including functional food and new trends e.g., new seed species recommended by seeds advisors. They also underlined that selection of seeds should be made by the needs: e.g., to select such plant species that will be useful for production of animal feed taking under account the particular species of animal and its nutritional requirements. However, it was also underlined to select new species of plants that will give an opportunity to produce new kind of animal feeds.</p> <p>Selection of seed species important for production of new functional products for human taking under consideration different needs e.g., for sportsmen, old people, young people etc.</p> <p>Undoubtedly one of the most important consideration was also costs of seeds, taking into account especially reducing costs in the scale of farm.</p> <p>Some people stressed that very important is to select plant species based on their composition in order to obtain products with better quality comparing to traditional ones.</p>



	<p>Very important issue during selection of plant seeds was also obtaining a higher seed yield and better crop quality.</p> <p>During the workshop it was underlined that very important is also purpose of the crop - whether it will be harvested together or separately. It was underlined that when crops will be harvested together very important is the content of proteins. As an example it was presented the mixture of rye and vetch, produced for haylage in order to obtain feed for ruminants with an increased protein content. Another example was organic production, in which plants should be selected in such a way that they enable obtaining valuable functional food products, e.g. flour and high-protein pasta, which is a product innovation. A mixture of wheat and soy can be used for this purpose. Selection of plants suitable for the production of vegan and vegetarian food with increased protein content - there is now an increase in interest in this type of products.</p> <p>In the case of plants harvested separately, a good example is the use of oats and yellow lupine, the crops of which, after sorting, can be sold both as feed, but also as seeds for the main crop and intercrops, as well as for further processing into food products, e.g., oatmeal from organic farming and lupine for high-protein functional food products.</p>
Spain	<p>Production cycle of the different species and varieties involved in the intercropping.</p> <p>Water requirements of crops.</p> <p>Adaptation of the intercropping system to water availability, with a special consideration of the summer dry season in Spain.</p> <p>Competition with weeds and sensitivity to pests and diseases.</p> <p>Proportion of cereal in the mixture much lower than that of legumes.</p> <p>Size of the seeds of the species.</p>
United Kingdom	<p>Similar maturity dates allowing planning of harvest.</p> <p>Seed/grain size differences to allow easy combine settings and separation-colour sorting can be used for similar sized seeds but it is slow.</p> <p>Potential premium market for one or 2 both as premium crops plus a use for the out of spec grains, broken pulses etc.as animal feed-so no taint or toxin risks as animal feed is base market.</p> <p>The need for an understanding of whether there was a big enough market for pulse or potential value in livestock feed.</p>
Egypt-AK	<p>The workshop discussions also led to an examination of seed selection considerations vital for the success of intercropping in the region. Participants emphasized the importance of crop compatibility. It is essential to select crop pairs that complement each other for enhanced mutual growth, maximizing the benefits of intercropping. This involves considering the nutrient, water, and space requirements of each crop to ensure they do not compete but support each other's growth.</p>



	<p>Water efficiency was another crucial factor. Given the limited groundwater resources in Dakhla, priority should be given to crops with lower water requirements. This strategy will help to conserve water and ensure the sustainability of farming practices in the region. Properly selecting crops that have lower water requirements but can thrive in the local conditions is a vital step in enhancing the efficiency and sustainability of intercropping practices.</p> <p>Furthermore, the importance of climate resistance in seed selection was noted. Choosing crops that are resilient to the local climatic conditions of the Dakhla Oasis is vital. This involves selecting seeds that are resistant to potential temperature extremes, capable of thriving in arid conditions, and resilient to potential pest and disease challenges associated with the local environment. Proper seed selection, prioritizing climate resistance, will contribute to the robustness and yield of intercropped cereals and legumes in the region.</p>
Egypt-KE	<p>With the practice of intercropping cereal-legume crops in the Nile Delta region, the workshop underscored the significance of strategic seed selection. Emphasis on crop compatibility, ensuring that chosen cereal-legume pairs complement each other's growth, is fundamental for maximizing yield and soil health benefits. Opting for crops with diverse root systems allows for efficient utilization of soil nutrients and water, further contributing to increased yield and reduced water use, key benefits of intercropping.</p> <p>Climate and disease resistance were highlighted as crucial factors in seed selection. Choosing seeds resilient to the local climate and potential diseases safeguards the intercropped system from environmental vulnerabilities, enhancing the overall reliability and productivity of the intercropping practice in the Nile Delta region.</p> <p>Additionally, conducting a robust market demand assessment for chosen crops ensures the economic viability of the intercropping systems. By aligning their crop choices with market trends, farmers in the Nile Delta region can ensure consistent demand for their produce, further strengthening the economic sustainability of their intercropping practices. This alignment guarantees that the many benefits of intercropping, from increased yields and reduced resource use to enhanced soil health and biodiversity, translate to tangible economic gains for the farmers, solidifying the role of intercropping as a sustainable agricultural practice in the region.</p>
Pakistan	<p>The workshop participants highlighted the issues relating to availability of quality seeds for cereal-legume intercropping. They emphasised the need to provide disease-resistant and regional-adaptable seeds of both cereal and legume cultivars. In particular, the farmers were very critical of appropriate good quality seeds for adopting the cereal-legume intercropping. They admitted that climate change was the major factor affecting their crops and viewed the available crop varieties more susceptible to insects, pests and</p>



diseases. In summary, availability of quality seeds was considered indispensable for adopting cereal-legume intercropping in Pakistan.