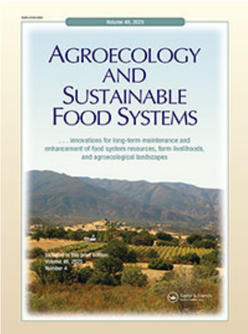


Taylor & Francis
Taylor & Francis Group

Agroecology and Sustainable Food Systems

ISSN: 2168-3565 (Print) 2168-3573 (Online) Journal homepage: www.tandfonline.com/journals/wjsa21

Food system strategies to increase grain legume-cereal intercropping in Europe

Tiffanie F. Stone, Jerry Alford, Petra Hanáková Bečvářová, Mohammad A. M. Eisa, Ahmed H. El-Naggar, María José Carpio Espinosa, Magdalena Frąc, Jorge Álvaro-Fuentes, Juan C. García-Gil, Kasper Krabbe, Juliana Trindade Martins, Shamina Imran Pathan, César Plaza, Jim Rasmussen, Cosimo Righini & Martin Hvarregaard Thorsøe

To cite this article: Tiffanie F. Stone, Jerry Alford, Petra Hanáková Bečvářová, Mohammad A. M. Eisa, Ahmed H. El-Naggar, María José Carpio Espinosa, Magdalena Frąc, Jorge Álvaro-Fuentes, Juan C. García-Gil, Kasper Krabbe, Juliana Trindade Martins, Shamina Imran Pathan, César Plaza, Jim Rasmussen, Cosimo Righini & Martin Hvarregaard Thorsøe (2025) Food system strategies to increase grain legume-cereal intercropping in Europe, Agroecology and Sustainable Food Systems, 49:4, 518-542, DOI: 10.1080/21683565.2024.2427783

To link to this article: https://doi.org/10.1080/21683565.2024.2427783

AGROECOLOGY AND SUSTAINABLE FOOD SYSTEMS
2025, VOL. 49, NO. 4, 518–542
https://doi.org/10.1080/21683565.2024.2427783

Food system strategies to increase grain legume-cereal intercropping in Europe

Tiffanie F. Stone[a], Jerry Alford[b], Petra Hanáková Bečvářová[c], Mohammad A. M. Eisa[d], Ahmed H. El-Naggar[e], María José Carpio Espinosa[f], Magdalena Frąc[g], Jorge Álvaro-Fuentes[h], Juan C. García-Gil[f], Kasper Krabbe[a], Juliana Trindade Martins[a], Shamina Imran Pathan[i], César Plaza[f], Jim Rasmussen[a], Cosimo Righini[j], and Martin Hvarregaard Thorsøe[a]

[a]Department of Agroecology, Aarhus University: Aarhus Universitet institution, Foulum, Denmark; [b]Soil Association, Bristol, UK; [c]Department of Plant Protection, Agritec Plant Research s.r.o, Šumperk, Czech Republic; [d]Department of Agricultural Botany Faculty of Agriculture, Ain Shams University, Cairo, Egypt; [e]Sustainable Natural Resources Management, International Center for Biosaline Agriculture, Dubai, United Arab Emirates; [f]Department of Soil, Plant, and Environmental Quality, Instituto de Ciencias Agrarias, Madrid, Spain; [g]Institute of Agrophysics, Polish Academy of Sciences, Lublin, Poland; [h]Soil and Water Department, Estacion Experimental de Aula Dei, Spanish National Research Council, Estación Experimental de Aula Dei, Zaragoza, Spain; [i]Department of Agriculture, Food, Environment and Forestry, University of Florence, Firenze, Italy; [j]CIA Agricoltori Italiani, Firenze, Toscana, Italy

ABSTRACT

Intercropping has garnered renewed attention in Europe as an agroecological practice to enhance environmental sustainability. Interest in plant-based proteins by increasing human consumption of legumes is gaining traction. Legume-cereal intercropping for dual seed production could offer environmental and economic advantages. However, barriers hinder widespread adoption by farmers. This study analyzes the results of seven focus groups with 220 diverse stakeholders. Barriers, enabling factors, and strategies for the adoption of grain legume-cereal intercropping were assessed to determine food system transition strategies. The five strategies for intercropping support related to farm, food, advice, governance, and network systems. Farmer-led, institutionally supported, and research-informed advice systems, effective governance, and increased networking would enable strategic pathways for regional food and feed production through intercropping.

KEYWORDS

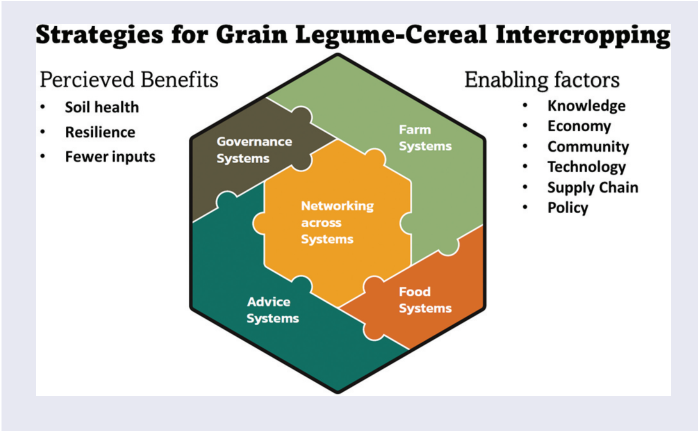
Sustainable cropping systems; focus groups; SWOT analysis; intercropping

SUSTAINABLE DEVELOPMENT GOALS

SDG 2: Zero hunger

CONTACT Tiffanie F. Stone tstone@agro.au.dk; Martin Hvarregaard Thorsøe martinh.thorsoe@agro.au.dk Department of Agroecology, Aarhus University: Aarhus Universitet Institution, Blichers Alle 20, Tjele, Foulum 8830, Denmark

Supplemental data for this article can be accessed online at https://doi.org/10.1080/21683565.2024.2427783.



1. Introduction

A growing body of literature supports the environmental and agronomic benefits of grain legume-cereal intercropping as a promising practice for sustainable production (Brooker et al. 2015).

Studies and reviews have consistently found overall yield per area increases, fertilizer and pesticide input reductions, and a diverse range of soil health benefits by implementing this agroecological practice (Brooker et al. 2015; Curtright and Tiemann 2021; Glaze-Corcoran et al. 2020; Jensen et al. 2020; Księżak, Staniak, and Stalenga 2023). Legume-cereal intercropping also increases resilience to biotic and abiotic stressors, increasing yield stability, which is critical to farm and food system sustainability under ongoing climate change conditions (Jensen et al. 2020). Legume-cereal intercropping studies have noted economic, environmental, and social benefits across diverse geographical contexts globally (Kwabiah 2005; Mthembu, Everson, and Everson 2018). Some of the additional positive impacts include increased biological productivity and nutrient use efficiency (Brahimi et al. 2022; Ghosh et al. 2007), as well as pest and weed suppression (Flores-Sanchez et al. 2013; Helenius 1991; Mthembu, Everson, and Everson 2018). Intercropping also supports the provision of ecosystem services by harnessing diversification of cropping systems with legumes to sequester carbon and reduce agrochemical and fossil fuel usage (Bedoussac et al. 2015; Ditzler et al. 2021; Justes et al. 2021). Studies in Europe found that intercropping can improve economic performance at the farm system scale while reducing environmental impacts (Bedoussac et al. 2015; Pelzer et al. 2012). However, the lack of markets for grain legumes remains a critical barrier in Europe (Ditzler et al. 2021). Barriers to intercropping for grain production can also include operational barriers on the farm (e.g., sorting grains) and often more importantly, supply chain barriers (e.g., lack of processing facilities, food safety requirements) that can further limit potential economic advantages (Aare, Lund, and Hauggaard-Nielsen 2021; Himanen et al. 2016).

Intercropping is a practice that can be implemented in a variety of ways and these differences in implementation have important implications for crop management on-farm and across the supply chain. Legume-cereal companion species can be seeded by casual spread of seeds, alternating furrow and alternating strips. They can also be grown together from sowing to harvest or with partially mismatched growing cycle, for example, legume species can be killed before cereal shoot elongation to transfer nitrogen to the cereal, which is the species sold to market (Guiducci et al. 2018). Intercropping can also support a range of purposes, for feed, green manure, or food. The main limitations to adoption of intercrops occur when crops are sown together and grains of the two species are harvested at once. However, in the context of the green transition, increasing the production of plant-based protein through the practice of legume-cereal intercropping could enable the production of benefits from a holistic food system perspective.

Despite the potential for environmental and economic benefits of intercropping supported by studies in the European context, grain legume-cereal intercropping has not been widely adopted in Europe, particularly in large-scale industrialized cropping systems (Bybee-Finley and Ryan 2018). Legumes have low fertilizer requirements, a relatively high protein content and could potentially increase protein self-sufficiency and environmental impact reductions in support of the European Union's "Green Deal" (Ferreira, Pinto, and Vasconcelos 2021). Enhancing grain legume production in the European Union (EU) has become a political objective both in rotated monocultures and through legume-cereal intercropping (Ferreira, Pinto, and Vasconcelos 2021). The EU's Common Agricultural Policy (CAP) regulations currently include legumes as part of the greening restriction, for the provision of Ecological Focus Areas (EFA), to encourage adaptation by farmers (Bonke, Michels, and Musshoff 2021). Yet even as monocrops legumes are not widely adopted, they are grown on an estimated two percent of arable land in the EU (Ditzler et al. 2021). The registration of legume-cereal intercrops is not available in some EU countries which makes it difficult to estimate the current production area. To increase the adoption of grain legume-cereal intercropping, it is important to understand the complex social, technical, and political barriers to adoption in Europe (Mamine and Farès 2020). Identifying the strategies for increased adoption are also important to support enabling environments for intercropping and could provide a framework to enable other green transitions. It is particularly important to understand the considerations and perceptions of supply chain stakeholders from field to fork to uncover barriers and tradeoffs, enabling the design of mutually beneficial strategies across scales (Haysom et al. 2019).

Figure 1. Workshops to conduct focus groups which often included field visits were conducted in nine countries. The ten focus groups used a shared template to provide a synthesis of barriers and opportunities, defining strategies for grain cereal-legume intercropping. Photographs taken by Dr. Agata Gryta and Prof. Magdalena Frąc, used with permission.

This study uses focus groups and a food systems perspective to address the following objectives:

1) identify barriers, enabling factors, and strategies related to the adoption of grain legume-cereal intercropping for food production in Europe, highlighting regional differences and similarities across focus groups, and 2) determine strategies and possible pathways toward sustainable food system transitions in Europe (Figure 1).

Focus groups are a preferred method for enabling a more rich understanding of complex socio-ecological issues in a variety of food system contexts. Himanen et al. (2016) engaged Finnish farmers in workshops to identify how opportunities and challenges impact the wider adoption of intercropping as a climate change adaptation. Dorneich et al. (2023) used focus groups to understand farmer and consumer perspectives on diversifying local food systems in the Midwest United States. Sonnino, Tegoni, and De Cunto (2019) used focus groups to identify challenges to food system change from a global perspective at the city scale; this focus group data was later triangulated with data from a semi-structured questionnaire. Grinberga-Zalite and Zvirbule (2022) also used a mixed method approach combining discourse analysis, case studies, and focus groups to understand challenges to waste minimization challenges in EU food production enterprises. Strengths, weaknesses, opportunities, and threats (SWOT) analyses have also been combined with focus groups to develop a deeper understanding of barriers and effective strategies for future research and policy development from a food system perspective (Blanco-Gutiérrez, Varela-Ortega, and Manners 2020; Dergan et al. 2022).

2. Methods

This study reports on findings from a collection of focus groups conducted in the framework of the LEGUMINOSE (Legume-cereal intercropping for sustainable agriculture across Europe) project. In this study, we used a food system perspective, an interdisciplinary approach aimed at understanding socio-economic and biophysical drivers while acknowledging the systemic nature of sustainability. The food system perspective is a useful framework for understanding interactions across complex human-nature systems to inform research and policy (Allen and Prosperi 2016). This framework also supports the integration of diverse perspectives and flexible pathways toward sustainable solutions (Haysom et al. 2019). We place particular emphasis in this paper on the barriers and strategies related to legume-cereal intercropping for dual grain production within the food system in Europe.

2.1 Focus group design

Focus groups were conducted to identify opportunities, enabling conditions and strategies for legume-cereal intercropping. Focus groups collect qualitative data useful in applied research to describe complex socio-environmental dynamics across contexts (Dorneich et al. 2023; Holzer, Carmon, and Orenstein 2018; Sonnino, Tegoni, and De Cunto 2019). SWOT analyses were conducted with participants in the focus groups to provide a useful structure for stakeholder discussions in this study. SWOT analyses have been applied in other studies to uncover new insights into complex food system dynamics and transition pathways (Dergan et al. 2022). Strengths and weaknesses are defined as internal factors that are influenced by farmers and value chain actors (e.g., level of collaboration, 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 by participants for grain legume-cereal intercropping in the context of food system integration within each focus group, they were prioritized to support effective analysis and strategy development by the group. The focus group participants then identified strategies by combining key strengths with maximized opportunities and minimized threats. 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 enabling conditions and strategies developed by each focus group to support increased adoption of grain legume-cereal intercropping. The focus groups were summarized by researchers who facilitated the focus groups in each country. These summaries were collected for further qualitative analysis and coding by T.F.S and M.H.T.

2.2 Focus group implementation

Focus groups were conducted in seven European countries, the Czech Republic, Denmark, Germany, Italy, Poland, Spain, and the United Kingdom (Figure 2). This wide range of different climatic and cropping conditions provides a useful overview of opportunities, barriers, and strategies to support grain legume-cereal intercropping across the food system in the European context. Based on the study objectives, several target groups were relevant to be included. The first were groups of farmers, particularly those interested in or experienced in intercropping. Groups of researchers, policy-makers, and participants across the supply chain were also included to strengthen the food system perspective. Partners were also encouraged to ensure the participation of crop advisors and seed producers who have more detailed knowledge of relevant species for grain legume-cereal intercropping and how they may grow in combination.

Focus groups were part of workshops (e.g., a farmer field day) organized by partners in the summer or early autumn of 2023. Guidelines and a focus group agenda were developed and distributed to all partners to enable comparison while supporting adjustments based on local conditions and opportunities (Supplementary Material). The workshop length varied from 2 to 7 hours; the common agenda included introducing the research project, field activities, and

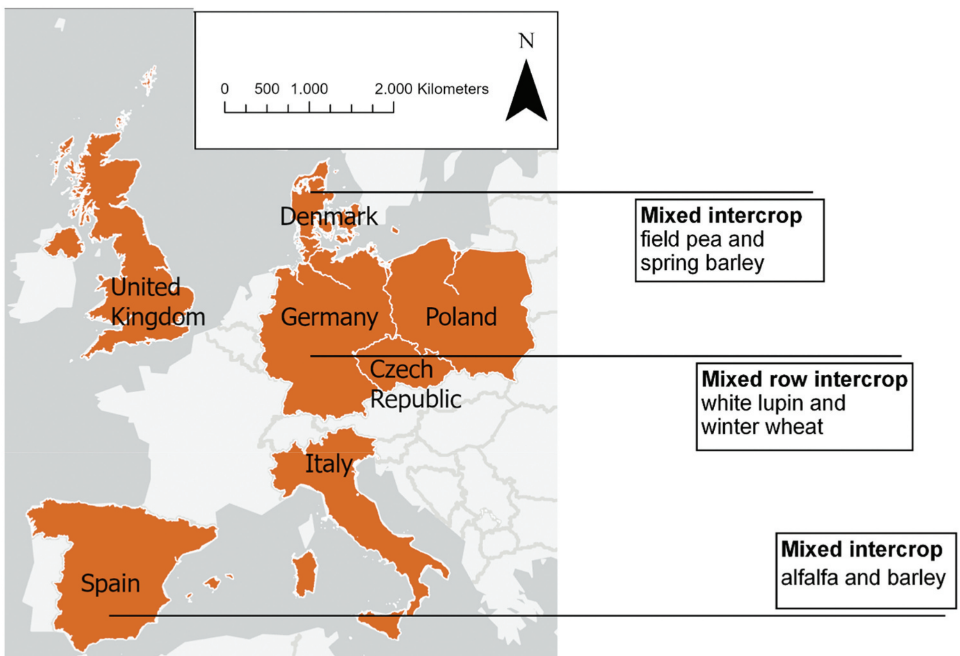


Figure 2. Map of participant countries highlighted in orange with legume-cereal intercrop examples from long-term research trials on the right for three countries (Denmark, Germany, Spain).

presentations from several important stakeholders (e.g., farmers with intercropping experience, seed producers, advisors) followed by a focus group discussion. The focus group sessions were designed to take approximately 45 minutes, and discussions were conducted in small groups with a targeted size of six to eight participants. Workshop participants were split into several groups if there were more than ten participants 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 & Casey, 2015).

2.3 Focus group analysis

Focus groups were conducted in seven countries and summarized in seven reports using a common template to support analysis across groups (Supplementary Material). As understanding intercropping from a food system perspective is a critical aim of this study, it was essential to involve a broad range of stakeholders from across the value chain. Two hundred twenty participants representing different perspectives on grain legume-cereal intercropping were included to enable a more comprehensive list of food system strategies useful for applied research and policy development (Table 1). Although the number of responses by country ranged from 18 (Denmark) to 48 (United Kingdom), this quantitative variation in participant number did not impact the number of codes or the relative weight of that country's qualitative responses reported in this study.

This qualitative analysis was conducted using an inductive coding method. All individual focus group text summaries were examined line by line, splitting an individual concept or perception into a single code (Corbin 1998; Silverman 2011). Each code was added to a spreadsheet and used to code the remaining text summaries; new codes were simultaneously identified when a new concept was uncovered. After coding all the focus group text summaries, codes were grouped based on specific themes. Themes were

Table 1. The categories and number of focus group participants within each participating country.

Country	Farmers	Researchers/ Scientists	Policymakers	Non-governmental organizations	Supply industry stakeholders	Other	Total
Czech Republic	9	7	2	2	8	1	29
Denmark	3	7	3	2	3	0	18
Germany	34	3	0	0	2	2	41
Italy	10	4	2	1	0	11	28
Poland	13	9	0	0	1	5	28
Spain	7	8	1	0	5	7	28
United Kingdom	29	6	0	3	3	7	48
Total	**105**	**44**	**8**	**8**	**22**	**33**	**220**

developed to organize strengths ($n = 12$), weaknesses ($n = 18$), opportunities ($n = 16$), threats ($n = 17$), intercropping species selection ($n = 12$), and strategies ($n = 17$). The themes, once established, were placed into larger categories to enable more in-depth analysis and visualization based on conceptual groupings. Five categories were included in SWOT analyses: Knowledge and Technology, Environment, Political, Social, and Economic. These categories were further synthesized for explanation by ecological, farm, and food systems. The strategies were similarly synthesized into five themes by system type: farm system, food system, advice system, governance system, and networking across systems, as described in section 3.3.

3. Results

Overall, many countries shared similar ideas about the strengths, weaknesses, opportunities, and threats of intercropping in current production and supply chain contexts (Table 2). SWOT analyses 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.

3.1. Strengths, weaknesses, opportunities, and threats of grain legume-cereal intercrop adoption

3.1.1. Strengths

The most important strength of intercropping critical in all ten focus groups was reduced fertilizer and pesticide (herbicide, insecticide) inputs and reduced need for alternative weed and pest controls for organic producers. Reducing these inputs is important for farmers due to high costs, regulations restricting their use, and sometimes both. Intercropping was seen as a win–win to sustain yields while reducing inputs. Soil health was another central strength discussed in nine of ten focus groups. As land stewards, farmers were concerned about reducing erosion and improving their soil's physical properties and microbiome to sustain production on their fields into the future. Other aspects of environmental health highlighted by most focus groups included improvements in biological nitrogen fixation, biodiversity, plant health, and soil carbon storage. Yield stability and adaptability of intercropping across cropping system types and production scales were notable strengths highlighted in eight out of ten focus groups. Increased yield stability was considered a particularly valuable strength for farmers due to climate change, which impacts water availability and increases the yield variability experienced by some farmers.

Table 2. SWOT analyses of grain legume-cereal intercropping across the food system organized with themes listed based on their category and the number of countries listed in parentheses (*n*=).

	Strengths	Weaknesses	Opportunities	Threats
Knowledge & Technology	Supportive technologies (n=2)	Crop management challenges (n=5) Inadequate and costly equipment/technology (n=4) Unknown timing of seeding and synchronizing harvest (n=3) Inconsistent product/poor implementation (n=2)	Innovative machinery & techniques (n=2)	New weed, disease, virus & pest control issues (n=4) Unavailability of suitable seedstock (n=3) 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=7) Soil health (n=7) Biodiversity (n=6) Resilience, adaptability & yield stability (n=6) Nitrogen fixation & carbon storage (n=4) Erosion prevention (n=3) Plant health (n=2)	Unavailable region-specific crop varieties with potential for interspecies competition (n=2)	Reduce fertilizer use (n=5) Increase plant protein (n=4) Regenerative agriculture & biodiversity (n=3) Soil health & fertility (n=2) OM & C sequestration (n=3) Climate-resilient agriculture (n=2) Reduce plant diseases, pesticide resistant pests & plants (n=2)	Limited water availability to support 2+ crops (n=2)
Political			Governmental support for intercropping (n=5)	Government regulations and policies (n=4)
Social		Farmers risk perception & lack of management experience (n=4) Additional time and complication (n=2)	Stakeholder interaction, workshops and training (n=2)	Farmer low adoption (n=3)
Economic	Farm profitability and income diversification (n=4) Increased yields (n=4) More high-protein feed (n=2)	Inability to sell profitably (n=6) Additional costs for seed separation, labor and cultivation (n=2)	New markets for a quality local product (n=4) Quality livestock feeds (n=3) Reduce inputs costs (n=1)	Lack of markets & prices (n=5) New costs & complication (n=3) Commercializing new crop markets (n=2)

From an economic perspective, seven of the ten focus groups discussed increased farm profitability (e.g., increased land equivalents ratios, reduced input costs) and the potential for income diversification (e.g., cereal as nurse crop for new niche legume crop) as an important strength of intercropping for dual grain production. In addition to reducing input costs, some focus groups expressed that increased yields were also a strength of intercropping ($n = 4$). 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 ($n = 6$) and crop management challenges ($n = 5$), followed by the perception of risk by farmers due to the lack of knowledge and experience with managing intercropping on their farms ($n = 4$) and inadequate equipment ($n = 4$). Many economic concerns are related to the lack of tested markets and pricing structures for mixed legume-cereal grains or for separating the grains for sale within food grade and feed grade markets. Focus groups expressed the need to test economic viability before scaling up production via intercropping. The management challenges were threefold: Place-based (e.g., areas with low organic matter and water availability may require different intercrops and practices); Farm management-based (e.g., seeding timing, synchronizing 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 management challenges requires different strategies to overcome (section 3.3). Of critical importance was the issue of not having region-specific approved crop varieties. Without these tested place-based seed combinations, several focus groups ($n = 2$) expressed concern for 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 optimized, concerns regarding management and marketing can be addressed strategically.

3.1.3. Opportunities

The most important opportunities for intercropping cereals with grain legumes were to reduce fertilizer use ($n = 5$) and governmental and policy support to increase intercropping adoption ($n = 5$). Reducing farm system inputs was listed by focus groups in all countries as a strength and was also the most widely proposed opportunity. Reducing fertilizer use can reduce the environmental impact of crop production by decreasing carbon emissions (e.g., mineral fertilizer 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 the UK and through EU CAP funds as a condition for SAPS in 2024, it is still important to expand and improve environmental schemes through policy support and subsidies to increase adoption and mitigate the risks for farmers.

From a food system perspective, opportunities to increase plant protein by incorporating more grain legume while reducing production inputs and other environmental impacts were highlighted. Building on opportunities for livestock feed and to develop value chains for human consumption of plant-based proteins 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 ($n = 2$).

3.1.4. Threats

The most important threats were related to the lack of knowledge and technology (Table 2). To mitigate threats to adopting grain legume-cereal intercropping, lack of markets and prices ($n = 5$), the risk of new weed, disease, and pest control issues ($n = 4$) must be addressed. Farmers' low adoption ($n = 3$) and general risk perceptions were also considered a threat due to the lack of experience and advice about re-introducing this type of cropping system. For example, in the UK, facilitators observed that conventional farmer focus group comments were based around a monoculture mind-set and the difficulty of changing that contrasted with the organic farmer focus group. In Spain, resistance to change was thought to stem from farmers' widespread focus on a short-term vision that favors monoculture to mitigate low cereal grain productivity.

3.1.5. Crosscutting considerations

Community and farmer perceptions of intercropping are also important – as both an opportunity and a threat (Table 2). The focus group in Denmark reported that an opportunity for 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 also reported resilience and adaptability as strengths of intercropping. Yet, the Czech Republic focus group reported that the risks associated with climate change were 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 lack of consensus among key stakeholders. Providing evidence and consistent messaging is key to enabling public and policy support for intercropping. Shifting public perception in favor of intercropping was seen as an opportunity in Spain's focus groups and as a strength in Germany's focus groups. 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.

3.2. Barrier and factors enabling grain legume-cereal intercropping

From an environmental or ecological perspective, grain legume-cereal intercropping was considered beneficial across all participating countries. Intercropping supports three key environmental factors: enhancing soil health, increasing resilience, and reducing inputs of nitrogen and pesticides. Reducing environmental impacts across farm and food system scales makes grain legume-cereal intercropping attractive for policymakers, researchers, and farmers alike. The wide-ranging environmental benefits provide the basis for why expanding grain 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 grain legume-cereal intercropping.

Although environmental impacts are reduced, important barriers make it challenging to increase adoption of grain legume-cereal intercropping. Some of the most important barriers are place-based differences, such as regional water availability (ES), climate change risks (CZ), and deficits in organic material (PL). Management-based barriers are also region-specific and create differentiated barriers depending on the current scale of production, equipment utilized and cultural norms. For example, in the United Kingdom, conventional farmers with well-developed advice systems found it more difficult to adapt to new cropping systems compared to organic farmers who are more accustomed to flexible and experimental approaches. Several focus groups noted the potential pairing of intercropping and organic production, although several others expressed the importance of emphasizing adaptability to increase adoption of intercropping practices on a broader range of different farming systems. This highlights the importance of considering regional and cultural factors when introducing intercropping strategies.

Regional market-based differences also created regionally distinct intercropping market strategies. The cost of separating mixed cereal-legume grains is high and availability is limited, especially to produce food-grade single grain products. Thus, alternatives like selling mixed grains for food and feed or finding lower cost alternatives for separating grains were important. In Spain, these barriers led to legume-cereal intercropping being adopted for forage production. Intercrop forage markets are already operational, while expanding to food markets brings new uncertainties and challenges (e.g., marketable species and varieties, phytosanitary treatments, fertilizer 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 protein levels were considered an important strategy, despite barriers. Understanding barriers to

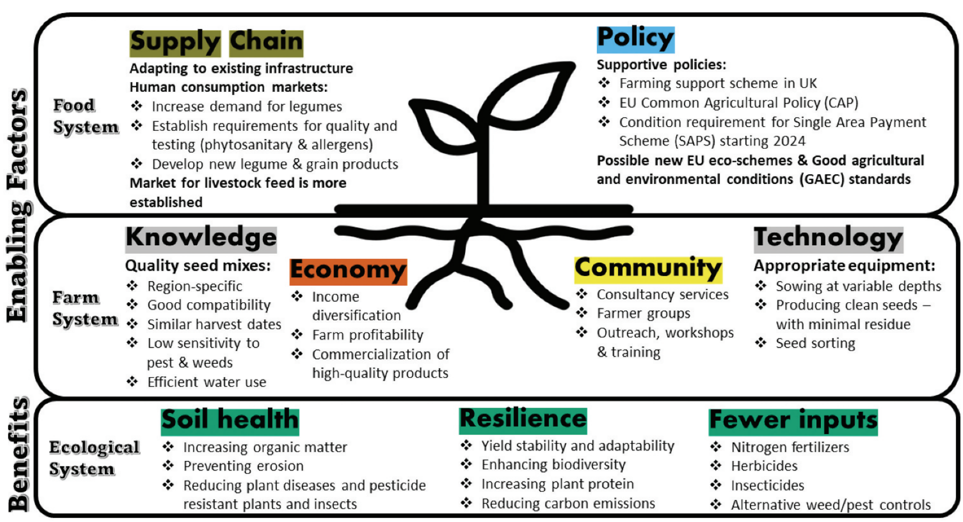


Figure 3. Enabling factors and benefits of grain legume-cereal intercropping.

intercropping in a specific regional context is important to enable the broader adoption of intercropping in Europe.

The interaction between intercropping and climate change risk is an important unknown for focus group participants. Intercropping was at once considered an opportunity to enhance climate-resilient agriculture (CZ, DK) and a threat by enhancing climate change risks (CZ). Yield uncertainties were common; focus groups in five countries listed yield increase as a strength (DE, DK, PL, UK), while Poland underlined annual yield variability based on weather conditions (e.g., meteorology) as a weakness. Denmark also listed potential future yield reduction as a threat. These different perceptions in our focus groups related to climate change risk and yields highlight uncertainties and underscore the need for accessible, evidence-based information to guide farmers and stakeholders to understand the impacts and risks of intercropping systems.

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 enabling intercropping to expand (Figure 3).

3.3. Strategies for grain legume–cereal intercropping

Five critical systems were identified where strategic initiatives and innovations are necessary within the farm system, food system, advice system, governance system and a fifth networking system that fosters communication across the other four systems (Figure 4).

At the farm system scale, developing and testing regional seed combinations were emphasized by the focus groups in Europe (Figure 4). In some cases, developing high-quality seed mixes may involve plant breeding to enhance positive intercropping characteristics. However, given the lack of tested regional intercrop seed mixes, 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 4).

Focus groups emphasized that the lack of supply chain infrastructure at the food system scale is combined with management uncertainties, lack of appropriate equipment and labor challenges at the farm system scale.

These interconnected challenges are compounded by the perceived increase in risk and complication and altogether make it difficult to adopt intercropping practices at the farm scale. Critical food system strategies include commercializing supply chains and increasing demand for intercropped grains by developing high-protein products as both food and feed. The focus groups in our study all agreed that intercrop feed markets are more established. Perceptions differed about the importance of developing intercrop markets for human consumption. For example, in Poland, focus groups discussed the development of a wide range of human food products and market streams, whereas in Spain, the focus groups emphasized further development of current intercropping systems primarily for livestock feed.

A new farmer-led advice system was a strategy identified by many European countries, where farmers exchange with one another and are consulted by other stakeholders (e.g., researchers, policy makers). This strategy included three parts. First, 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. Second, 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 organize, advertise and connect experienced farmers with new or interested farmers. Third, increasing education and awareness across the supply chain. The education

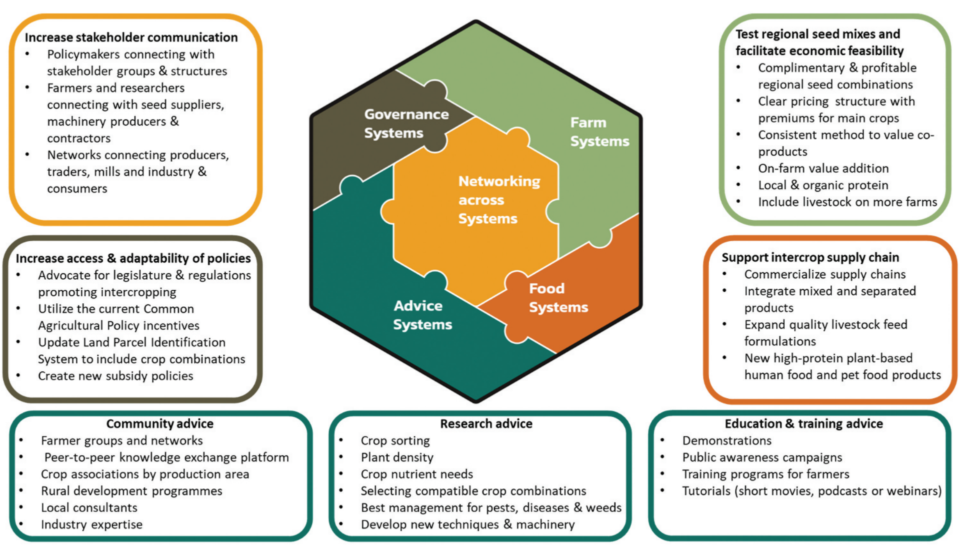


Figure 4. Strategies for grain legume-cereal intercropping. Image used with permission from ESCI.

efforts should start with farmers, creating accessible short online tutorials, demonstrations, and training opportunities.

Governance systems can provide important support for farm, food, and advice systems through appropriate funding and incentives. Focus groups across Europe expressed that policies providing the financial, research and risk-sharing infrastructure during the transition to intercropping would be crucial. Many focus groups discussed possible incentives (subsidies, eco schemes) provided in the Common Agricultural Policy that could encourage further adoption of intercropping. Some systems also need to be adjusted to enable intercrop-friendly regulations. For example, adding crop combinations as an option within the European Union Land Parcel Identification System would make it possible to identify intercropped fields.

Building networks and supporting communication channels between policymakers, government organizations, researchers, industry leaders and farmers were identified as key strategies to increase adoption of intercropping. The intercropping strategies identified were not considered additive, as the systems have interconnected, interdependent and nested components across scales. Instead, a well-functioning advice system, policy support and networking are critical components of effective pathways to support sustainable transitions via production at the farm scale and effective supply chain development at the food system scale.

4. Discussion

The key strengths identified by our focus groups and the foundational reason intercropping attracts sustained farmer and research interest and support across Europe and beyond is due to the wide range of environmental benefits. A wide range of benefits from improved biodiversity, plant health, biological nitrogen fixation, erosion prevention, fertilizer and pesticide input reduction and reduced need for alternative weed and pest controls are well supported in the scientific literature (Brooker et al. 2015; Curtright and Tiemann 2021; Glaze-Corcoran et al. 2020; Jensen et al. 2020; Księżak, Staniak, and Stalenga 2023). However, implementation of intercropping has not been widely adopted, indicating that there is an opportunity for further adoption by improving the enabling environment for farmers and value chains. The focus group participants in this study used SWOT analyses to discuss and shape strategies to reduce barriers and maximize opportunities for grain legume-cereal intercropping.

4.1. Farm system strategies

Our focus group analysis highlighted a diverse set of interconnected strengths, weaknesses, opportunities and threats at the farm system scale. Strengths and opportunities clustered around themes of environmental benefits initiated at the farm scale. Identifying and testing environmentally complementary and profitable regional seed combinations were considered an important first step toward effectively expanding intercropping at the farm scale. In Germany, a study found that the adoption of species mixtures was shaped primarily by farm system factors, including perceptions of crop mixture performance, suitability within the farm, and management, knowledge and technology due to increased complexity (Timaeus et al. 2022). A study in Denmark found similarly that locally adapted species mixtures for intercropping are an important gap that would require farmers and researchers to invest time and resources in participatory approaches to build the data and knowledge base needed (Aare, Lund, and Hauggaard-Nielsen 2021). 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. Comprehensive studies that provide a useful combination of social, technical, environment and economic considerations based on site conditions and food system contexts are important for selecting appropriate cultivars and represent a gap that needs to be addressed before intercropping can be widely adopted in Europe.

Farm scale profitability was considered both a strength and a weakness of intercropping. Focus groups additionally identified the lack of market channels appropriate for legumes and mixed grains as a critical weakness for grain legume-cereal intercropping. In Europe, legumes produce gross margin shortfalls of €70–100 per hectare (Zander et al. 2016). In addition, farmers consider intercropping to be more time-consuming than monocultures due to farm management (sowing, harvesting, storage) and potential additional processing requirements (sorting, cleaning, drying) (Hauggaard-Nielsen et al. 2021). The economic uncertainties associated with legumes make creating farm-scale regional economic models for intercropping and commercialized supply chains for new intercrop products important strategies to support adoption across scales.

Our focus groups identified increased biodiversity and resilience as a strength of intercropping, although the yield stability and climate change adaptation potential associated with intercropping were unclear. In a systematic literature review, Ditzler et al. (2021) found that European studies on intercropping with legumes have been heavily market-based, leaving a knowledge gap about how increasing legumes on the landscape can support a wider range of ecosystem services. Although studies support greater climate resilience, water use efficiency, and increased yield per land unit with intercropping compared to monocropping, stakeholders in our focus groups were uncertain about its effects and this is an opportunity for better knowledge dissemination (Glaze-Corcoran et al. 2020; Himanen et al. 2016).

A farm-scale strategy that includes developing regional seed combinations and testing the connection between grain legume-cereal intercropping and various ecosystem services could inform effective eco-schemes and other governance support systems. One review found similarly that the multifaceted and interconnected barriers to crop diversification include economic performance and risk perceptions (Brannan et al. 2023). Participatory and transdisciplinary agricultural research could provide an increased understanding of how farmers make decisions, which is essential to increasing on-farm crop diversification (Brannan et al. 2023).

4.2. Food system strategies

Focus groups in our study highlighted two potential strategies for increasing intercropped products across the supply chain. The first and more established is developing feed for livestock and pets. The second less tested and more challenging is developing products that incorporate legumes for human consumption. Other studies found similar food system scale challenges related to intercropping supply chains. A study of Finnish farmers found that unlike forage mixtures and green manures, selling to markets for human food was considered more risky and difficult for cereal crop farmers to adopt intercropping (Himanen et al. 2016). A German study found that in specific, quality standards in the food value chain were an important factor influencing the adoption of species mixtures and the economic potential at the farm scale was also considered highly variable based on crop value and post-harvest efforts to attain food quality (Timaeus et al. 2022). Difficulties in cleaning and sorting grains at the farm scale also influenced opportunities for improved and differentiated high-protein flour from intercropped species, highlighting the importance of research developing supply chains that complement developments at the farm scale (Hauggaard-Nielsen et al. 2021).

4.3. Advice system strategies

Weaknesses and threats identified by focus groups in this study clustered around themes of lacking knowledge and technology (Table 2). Other studies also found the importance of appropriate technical support, research, training, and agricultural advisory services as critical to supporting a large-scale transition to intercropping (Hauggaard-Nielsen et al. 2021; Himanen et al. 2016; Mamine and Farès 2020; Timaeus et al. 2022). For example, Himanen et al. (2016) found that markets, technical/agronomic, knowledge, and political/institutional concerns were similarly weighted by farmers as a means to support intercrop adoption. A new advice system must also be partnered with public and policy awareness and funding opportunities to enhance support across the supply chain.

4.4. Governance and network support strategies

The focus groups in this study categorized social themes as a weakness (risk, time, complication), opportunity (stakeholder interactions, workshops, training) and threat (low farmer adoption), whereas political support was considered both an opportunity and a threat (Table 2). At the food system scale, supply chain development and policy support were identified as enabling factors. Other studies found that policies reducing individual farmer risk and involving a diverse range of farmers through adaptable intercropping schemes would be an effective strategy for increasing adoption of intercropping. For example, farmers in Finland highlighted production and knowledge gaps within the operational environment markets and policies as critical challenges that limit adoption of intercropping (Himanen et al. 2016). Mamine and Farès (2020) found in a study of barriers to intercropping in Europe that public policy obstacles, together with technical, advice and economic uncertainties, compounded the temporal, spatial and logistical organization supporting intercrop market and product integration. Hauggaard-Nielsen et al. (2021) suggested policies via regulation, subsidies, funding, information/promotion, and strategies, particularly when co-produce by diverse and action-oriented actor networks could all play a role in supporting intercrop adoption (Leclère, Loyce, and Jeuffroy 2023). For example, these researchers highlighted that reforms and regulatory measures in the Common Agricultural Policy restricting fertilizer and pesticide use could support intercropping and a shift toward the agroecology paradigm more broadly (Hauggaard-Nielsen et al. 2021).

To confront the interconnected structural, agronomic, technological and social barriers to intercropping, a Danish case study also emphasized the need for increased collaboration, transparency and equitable partnerships across the value chain, as farmers do not operate independently but are instead part of a food system with power relations (e.g., large agribusinesses) that can enable or hinder farmers' ability to adopt intercropping in practice (Aare, Lund, and Hauggaard-Nielsen 2021). Effective strategies for food system transitions would require holistic planning across the supply chain from a systems perspective (Himanen et al. 2016). Other studies have found similar interconnections between scales. For example, Kiær et al. (2022) found that intercropping benefits are dependent on both the specific species and genotypes combined (at the farm scale) and on the end use and market channels available (food system scale). One promising approach to support intercropping was through the development of multi-actor experimental networks that have produced important innovations across transition pathways in the context of intercropping design and adoption (Salembier et al. 2023). Based on our findings, developing a multidimensional agenda for farm and supply chain research and governance supporting an agroecological green transition could create the enabling environment to support the adoption of legume-grain intercropping in Europe and beyond (Aare, Lund, and Hauggaard-Nielsen 2021; Mamine and Farès 2020).

4.5. Pathways toward sustainable food system transitions

Many theories and models describing agricultural technology adoption have been used to support understanding and, ultimately, pathways toward adoption, which can be useful in the context of adopting new practices to support the green transition. Dissanayake et al. (2022) conducted a literature review on technology adoption in agriculture using a collective approach model of technology adoption with the theory of planned behavior to identify four critical factors: 1) adopters' (e.g., farmer or food system stakeholders) perceptions of usefulness, ease of use, compatibility; 2) the technology itself (e.g., intercropping, other transition toward a sustainable food system); 3) institutional factors; and 4) availability of capital sources (economic factors). Importantly, the personal attributes of adopters, as well as social factors, influence the adoption of innovations across the food system (Dissanayake et al. 2022). In the context of grain legume-cereal intercropping, our study highlighted that many characteristics influencing the intention to adopt were uncertainties for stakeholders in our study. For example, questions around intercropping compatibility, ease of use, relative advantage, and result demonstrability at farm and food system scales and untested economic and institutional support networks increased perceptions of risk for all adopters. A useful framework to understand intercropping pathways is the innovation adoption curve. Currently, intercropping is an example of a production system innovation in the innovator phase (Dissanayake et al. 2022) – to support adoption of intercropping for early and late majority adopters, we argue that it is critical to build five-point strategies to address farm, food, advice, governance, and networking in tandem. Similarly, it could be useful to organize pathways for green transitions using the community capitals framework to identify place-based SWOT and strategies (Flora, Bregendahl, and Renting 2012; Flora, Flora, and Gasteyer 2016).

Agri-food system transitions require stakeholder alignment regarding both challenges and solutions. One study analyzing visions for the Dutch agri-food system found that environmental and social challenges were usually well-aligned, but the transition or solution required were often misaligned, especially for economic issues where growth-oriented paradigms conflict with more holistic paradigms like agroecology and hinder effective change

(Wojtynia et al. 2021). Weituschat et al. (2022) used crop diversification as a case to understand how technological, economic, institutional, political, social, and cognitive lock-ins slow transitions toward sustainability. This study found three traps that slow sustainable transitions through historic misalignment (normative environmental goals disconnected from food security), incentive misalignment (gain-oriented goals unsupported), and disregarding discomfort (hedonic goals uncompensated). Our study found that a key strength of intercropping is the possibility of normative environmental gains without reducing yield on a field scale. However, lack of incentives (increased risk) and discomfort (lacking information) are barriers that must be addressed to enable wider adoption of intercropping. Organizing strategies that incorporate considerations for farm, food, advice, governance, and networking systems could help to overcome barriers, supporting green transitions in Europe.

5. Conclusions

Grain legume-cereal intercropping is a promising agroecological practice supporting sustainable cropping systems by 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 for dual grain production for food-quality plant-based protein, action needs to be taken across the food system to enable this shift in cropping systems. Focus groups from nine countries identified strengths, weaknesses, opportunities, and threats, as well as enabling factors and strategies for increasing grain legume-cereal intercropping in Europe. These findings highlight the global relevance of understanding farmer perceptions and adapting strategies accordingly. Across the food system common threads emerged for both benefits and risks. Many strengths and opportunities related to more resilient farming systems, while many weaknesses and threats related to lacking knowledge or untested farm, food, and policy system infrastructure.

We identified five strategies to support farmer adoption of grain legume-cereal intercropping for food production: 1) regionally tested seed ratios and farm scale economic feasibility, 2) food system supply chains, 3) advice systems based on research, community and education, 4) governance systems, and 5) networks connecting stakeholders. At the farm system scale, regionally specific and optimized intercrop seed mixture ratios were lacking. Specific combinations of varieties need to be identified and tested on a regional basis to mitigate risk and support the largest range of environmental and economic benefits possible. Increasing food system scale collaboration and communication to create innovation across the supply chain and raising public awareness would also enable adoption of grain legume-cereal intercropping across a wide range of different farming systems and scales. Appropriate and user-friendly intercropping information could also bolster the food system's value chain and policy infrastructure. Establishing farmer-led advice systems supported by research, community and governmental partners is critical to the successful adoption of intercropping in Europe. Knowledge and technical barriers regarding the seed selection and management of intercropping at the farm scale could be overcome through greater networking across the food system with support from effective advice and governance systems.

Agroecosystem living labs could enable the collection and distribution of technical information required by farmers while also developing opportunities for innovative supply chains that support multiple objectives (environmental, economic, social, institutional) across scales (McPhee et al. 2021). 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. The five strategies identified through these geographically diverse focus groups could act as a guide to inform initiatives and future research to support intercrop adoption in areas where monocropping remains the dominant cropping system.

Acknowledgments

The authors would like to thank all the stakeholders who have taken time to participate in the focus groups that form the basis of this article. We thank ESCI for designing and granting us permission to use the puzzle graphic in the graphical abstract and Figure 4. We also thank Dr. Agata Gryta and Prof. Magdalena Frąc for taking the photographs used in Figure 1.

Disclosure statement

No potential conflict of interest was reported by the author(s).

Funding

This work was funded under the European Union's Horizon Europe research and innovation programme: Grant agreement No [101082289]. Additional funding has been provided from UK Research and Innovation (UKRI) under the UK government's Horizon Europe funding guarantee [grant numbers 10057156 and 10039837]. work was funded under the European Union's Horizon Europe research and innovation programme: Grant agreement No [101082289]. Additional funding has been provided from UK Research and Innovation

(UKRI) under the UK government's Horizon Europe funding guarantee [grant numbers 10057156 and 10039837].

Authors' contributions

Conceptualization, M.H.T. and T.F.S.; Methodology, M.H.T. and T.F.S.; Investigation, [J.A., P. H.B., M.A.M.E, A.H.E., M.J.C.E., M.F., J.A.F., J.C.G.G., K.K., J.T.M., S.I.P., C.P., J.R., C.R., M. H.T.]; Formal analysis, T.F.S; Visualization, T.F.S.; Writing – Original Draft, T.F.S.; Writing – Review & Editing, [T.F.S, J.A., P.H.B., M.A.M.E, A.H.E., M.J.C.E., M.F., J.A.F., J.C.G.G., K.K., J. T.M., S.I.P., C.P., J.R., C.R., M.H.T.]; Funding Acquisition, S.I.P.; Supervision, M.H.T.

Consent to participate

Informed consent was obtained from all individual participants included in the study.

Availability of data and material

The datasets generated during and/or analyzed during the current study are available from the corresponding author on reasonable request.

References

Aare, A. K., S. Lund, and H. Hauggaard-Nielsen. 2021. Exploring transitions towards sustainable farming practices through participatory research – the case of Danish farmers' use of species mixtures. *Agricultural Systems* 189. doi:10.1016/j.agsy.2021.103053.

Allen, T., and P. Prosperi. 2016. Modeling sustainable food systems. *Environmental Management* 57 (5):956–75. doi:10.1007/s00267-016-0664-8.

Bedoussac, L., E.-P. Journet, H. Hauggaard-Nielsen, C. Naudin, G. Corre-Hellou, E. S. Jensen, L. Prieur, and E. Justes. 2015. Ecological principles underlying the increase of productivity achieved by cereal-grain legume intercrops in organic farming. A review. *Agronomy for Sustainable Development* 35 (3):911–35. doi:10.1007/s13593-014-0277-7.

Blanco-Gutiérrez, I., C. Varela-Ortega, and R. Manners. 2020. Evaluating animal-based foods and plant-based alternatives using multi-criteria and SWOT analyses. *International Journal of Environmental Research and Public Health* 17 (21):1–26. doi:10.3390/ijerph17217969.

Bonke, V., M. Michels, and O. Musshoff. 2021. Will farmers accept lower gross margins for the sustainable cultivation method of mixed cropping? First insights from Germany. *Sustainability* 13 (4):1631. doi:10.3390/su13041631.

Brahimi, S., O. Toumatia, J. J. Drevon, A. Zitouni, and M. Lazali. 2022. Intercropping legumes and cereals increases resource use efficiency and crop productivity in low phosphorus soils under semi-arid Mediterranean conditions. *Agroecology & Sustainable Food Systems* 46 (10):1482–501. doi:10.1080/21683565.2022.2121951.

Brannan, T., C. Bickler, H. Hansson, A. Karley, M. Weih, and G. Manevska-Tasevska. 2023. Overcoming barriers to crop diversification uptake in Europe: A mini review. *Frontiers in Sustainable Food Systems* 7:7. doi:10.3389/fsufs.2023.1107700.

Brooker, R. W., A. E. Bennett, W. F. Cong, T. J. Daniell, T. S. George, P. D. Hallett, C. Hawes, P. P. M. Iannetta, H. G. Jones, A. J. Karley, et al. 2015. Improving intercropping: A synthesis of research in agronomy, plant physiology and ecology. *The New Phytologist* 206 (1):107–17. doi: 10.1111/NPH.13132.

Bybee-Finley, K. A., and M. R. Ryan. 2018. Advancing intercropping research and practices in industrialized agricultural landscapes. In *Agriculture (Switzerland)*, vol. 8, Issue 6. MDPI AG. doi: 10.3390/agriculture8060080.

Corbin, J. M. 1998. Alternative interpretations. *Theory & Psychology* 8 (1):121–28. doi:10.1177/0959354398081007.

Curtright, A. J., and L. K. Tiemann. 2021. Intercropping increases soil extracellular enzyme activity: A meta-analysis. In *Agriculture, ecosystems and environment*, vol. 319. Elsevier B.V. doi: 10.1016/j.agee.2021.107489.

Dergan, T., A. Ivanovska, T. Kocjančič, P. P. M. Iannetta, and M. Debeljak. 2022. 'Multi-swot' multi-stakeholder-based sustainability assessment methodology: Applied to improve Slovenian legume-based Agri-food chains. *Sustainability* 14 (22):15374. doi: 10.3390/su142215374.

Dissanayake, C. A. K., W. Jayathilake, H. V. A. Wickramasuriya, U. Dissanayake, K. P. P. Kopiyawattage, and W. M. C. B. Wasala. 2022. Theories and models of technology adoption in agricultural sector. In *Human behavior and emerging technologies*, vol. 2022. Wiley-Hindawi. doi: 10.1155/2022/9258317.

Ditzler, L., D. F. van Apeldoorn, F. Pellegrini, D. Antichi, P. Bàrberi, and W. A. H. Rossing. 2021. Current research on the ecosystem service potential of legume inclusive cropping systems in Europe. A review. *Agronomy for Sustainable Development* 41 (2):26. doi: 10.1007/s13593-021-00678-z.

Dorneich, M. C., C. C. Krejci, N. Schwab, T. F. Stone, E. Huckins, J. R. Thompson, and U. Passe. 2023. Producer and consumer perspectives on supporting and diversifying local food systems in central Iowa. *Agriculture and Human Values* 41 (2):661–81. doi: 10.1007/s10460-023-10504-9.

Ferreira, H., E. Pinto, and M. W. Vasconcelos. 2021. Legumes as a cornerstone of the transition toward more sustainable agri-food systems and diets in Europe. In *Frontiers in sustainable food systems*, vol. 5. Frontiers Media S.A. doi: 10.3389/fsufs.2021.694121.

Flora, C. B., J. L. Flora, and S. P. Gasteyer. 2016. Community capitals and rural landscape. In *Rural communities*, 5th ed. New York: Routledge.

Flora, C., C. Bregendahl, and H. Renting. 2012. Collaborative community-supported agriculture: Balancing community capitals for producers and consumers. *Journal of Sociology of Agriculture* 19 (3):329–46. http://ijsaf.org/archive/19/3/flora_bregendahl.pdf.

Flores-Sanchez, D., A. Pastor, E. A. Lantinga, W. A. H. Rossing, and M. J. Kropff. 2013. Exploring maize-legume intercropping systems in Southwest Mexico. *Agroecology & Sustainable Food Systems* 37 (7):739–61. doi:10.1080/21683565.2013.763888.

Ghosh, P. K., K. K. Bandyopadhyay, R. H. Wanjari, M. C. Manna, A. K. Misra, M. Mohanty, and A. S. Rao. 2007. Legume effect for enhancing productivity and nutrient use-efficiency in major cropping systems - an Indian perspective: A review. *Journal of Sustainable Agriculture* 30 (1):59–86. doi: 10.1300/J064v30n01_07.

Glaze-Corcoran, S., M. Hashemi, A. Sadeghpour, E. Jahanzad, R. Keshavarz Afshar, X. Liu, and S. J. Herbert. 2020. Understanding intercropping to improve agricultural resiliency and environmental sustainability. In *Advances in agronomy*, vol. 162, 199–256. Academic Press Inc. doi: 10.1016/bs.agron.2020.02.004.

Grinberga-Zalite, G., and A. Zvirbule. 2022. Analysis of waste minimization challenges to european food production enterprises. *Emerging Science Journal* 6 (3):530–43. doi:10.28991/ESJ-2022-06-03-08.

Guiducci, M., G. Tosti, B. Falcinelli, and P. Benincasa. 2018. Sustainable management of nitrogen nutrition in winter wheat through temporary intercropping with legumes. *Agronomy for Sustainable Development* 38 (3):31. doi:10.1007/s13593-018-0509-3.

Hauggaard-Nielsen, H., S. Lund, A. K. Aare, C. A. Watson, L. Bedoussac, J. N. Aubertot, I. R. Chongtham, N. Bellostas, C. F. E. Topp, P. Hohmann, et al. 2021. Translating the multi-actor approach to research into practice using a workshop approach focusing on species mixtures. *Frontiers of Agricultural Science and Engineering* 8 (3):460–73. doi: 10.15302/J-FASE-2021416.

Haysom, G., E. G. A. Olsson, M. Dymitrow, P. Opiyo, N. T. Buck, M. Oloko, C. Spring, K. Fermskog, K. Ingelhag, S. Kotze, et al. 2019. Food systems sustainability: An examination of different viewpoints on food system change. *Sustainability (Switzerland)* 11 (12):1–17. doi: 10.3390/su10023337.

Helenius, J. 1991. Insect numbers and pest damage in Intercrops vs. Monocrops. *Journal of Sustainable Agriculture* 1 (3):57–80. doi:10.1300/J064v01n03_06.

Himanen, S. J., H. Mäkinen, K. Rimhanen, and R. Savikko. 2016. Engaging farmers in climate change adaptation planning: Assessing intercropping as a means to support farm adaptive capacity. *Agriculture (Switzerland)* 6 (3). doi: 10.3390/agriculture6030034.

Holzer, J. M., N. Carmon, and D. E. Orenstein. 2018. A methodology for evaluating transdisciplinary research on coupled socio-ecological systems. *Ecological Indicators* 85:808–19. doi:10.1016/j.ecolind.2017.10.074.

Jensen, E. S., I. R. Chongtham, N. R. Dhamala, C. Rodriguez, N. Carton, and G. Carlsson. 2020. Diversifying European agricultural systems by intercropping grain legumes and cereals. *International Journal of Agriculture and Natural Resources* 47 (3):174–86. doi:10.7764/ijanr.v47i3.2241.

Justes, E., R. Vezy, S. Munz, K. Paff, L. Bedoussac, N. Gaudio, P. Lecharpentier, D. Ripoche, and M. Launay. 2021. The 4C approach as a way to understand species interactions determining intercropping productivity. *Frontiers of Agricultural Science and Engineering* 8 (3). doi: 10.15302/J-FASE-2021414.

Kiær, L. P., O. D. Weedon, L. Bedoussac, C. Bickler, M. R. Finckh, B. Haug, P. P. M. Iannetta, G. Raaphorst-Travaille, M. Weih, and A. J. Karley. 2022. Supply chain perspectives on breeding for legume–cereal intercrops. *Frontiers in Plant Science* 13:13. doi: 10.3389/fpls.2022.844635.

Krueger, R. A., and M. A. Casey. 2015. *Focus groups: A practical guide for applied research*, 5th ed. Thousand Oaks, California, USA: Sage Publications Inc.

Księżak, J., M. Staniak, and J. Stalenga. 2023. Restoring the importance of cereal-grain legume mixtures in low-input farming systems. *Agriculture (Switzerland)* 13 (2):341. doi: 10.3390/AGRICULTURE13020341.

Kwabiah, A. B. 2005. Biological efficiency and economic benefits of pea-barley and pea-oat intercrops. *Journal of Sustainable Agriculture* 25 (1):117–28. doi:10.1300/J064v25n01_09.

Leclère, M., C. Loyce, and M. H. Jeuffroy. 2023. A participatory and multi-actor approach to locally support crop diversification based on the case study of camelina in northern France. *Agronomy for Sustainable Development* 43 (1). doi: 10.1007/s13593-023-00871-2.

Mamine, F., and M. Farès. 2020. Barriers and levers to developing wheat–pea intercropping in Europe: A review. *Sustainability* 12 (17):6962. doi: 10.3390/SU12176962.

McPhee, C., M. Bancerz, M. Mambrini-Doudet, F. Chrétien, C. Huyghe, and J. Gracia-Garza. 2021. The defining characteristics of agroecosystem living labs. *Sustainability* 13 (4):1718. doi:10.3390/su13041718.

Mthembu, B. E., T. M. Everson, and C. S. Everson. 2018. Intercropping maize (Zea mays L.) with lablab (lablab purpureus L.) for sustainable fodder production and quality in smallholder rural farming systems in South Africa. *Agroecology & Sustainable Food Systems* 42 (4):362–82. doi:10.1080/21683565.2017.1393649.

Pelzer, E., M. Bazot, D. Makowski, G. Corre-Hellou, C. Naudin, M. Al Rifaï, E. Baranger, L. Bedoussac, V. Biarnès, P. Boucheny, et al. 2012. Pea–wheat intercrops in low-input conditions combine high economic performances and low environmental impacts. *The European Journal of Agronomy* 40:39–53. doi: 10.1016/J.EJA.2012.01.010.

Salembier, C., A. K. Aare, L. Bedoussac, I. R. Chongtham, A. de Buck, N. R. Dhamala, C. Dordas, M. R. Finckh, H. Hauggaard-Nielsen, M. Krysztoforski, et al. 2023. Exploring the inner workings of design-support experiments: Lessons from 11 multi-actor experimental networks for intercrop design. *The European Journal of Agronomy* 144:126729. doi:10.1016/j.eja.2022.126729.

Silverman, D. 2011. *A guide to the principles of qualitative research*, 5th ed. Cornwall, Great Britain: SAGE.

Sonnino, R., C. L. S. Tegoni, and A. De Cunto. 2019. The challenge of systemic food change: Insights from cities. *Cities* 85 (August 2018):110–16. doi: 10.1016/j.cities.2018.08.008.

Timaeus, J., T. Ruigrok, T. Siegmeier, and M. R. Finckh. 2022. Adoption of food species mixtures from farmers' perspectives in Germany: Managing complexity and harnessing advantages. *Agriculture (Switzerland)* 12 (5):697. doi: 10.3390/agriculture12050697.

Weituschat, C. S., S. Pascucci, V. C. Materia, P. Tamas, R. de Jong, and J. Trienekens. 2022. Goal frames and sustainability transitions: How cognitive lock-ins can impede crop diversification. *Sustainability Science* 17 (6):2203–19. doi:10.1007/s11625-022-01156-5.

Wojtynia, N., J. van Dijk, M. Derks, P. W. G. Groot Koerkamp, and M. P. Hekkert. 2021. A new green revolution or agribusiness as usual? Uncovering alignment issues and potential transition complications in agri-food system transitions. *Agronomy for Sustainable Development* 41 (6). doi: 10.1007/s13593-021-00734-8.

Zander, P., T. S. Amjath-Babu, S. Preissel, M. Reckling, A. Bues, N. Schläfke, T. Kuhlman, J. Bachinger, S. Uthes, F. Stoddard, et al. 2016. Grain legume decline and potential recovery in European agriculture: A review. In *Agronomy for sustainable development*, vol. 36, Issue 2. Springer-Verlag France. doi: 10.1007/s13593-016-0365-y.