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# RESEARCH BRIEF

# R&I priorities for the diversification of cropping systems

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# CONTENTS


Executive summary ..... **1**

1. Introduction ..... **5**

1.1 Status of crop diversification in the EU ..... 5

1.2 EU support to Research and Development on crop diversification ..... 7

2. Methodology ..... **9**

2.1 Aim of the research ..... 9

2.2 Approach ..... 9

2.3 Participatory approach ..... 12

2.4 Scientific Committee ..... 12

3. Key research results from EU-funded projects on crop diversification ..... **13**

3.1 Results at the conceptual/framing level ..... 13

3.2 Results to address upstream barriers ..... 17

3.3 Results to address farm-level barriers ..... 17

3.4 Research results at the mid- and downstream stage of value chains ..... 20

4. K&I opportunities to tackle barriers to crop diversification ..... **21**

4.1 Research axes for upstream ..... 21

4.2 Research axes at the field and farm level ..... 24

4.3 Research axes for the mid-and-downstream level ..... 28

5. Integration of the recommendations in the EU policy framework ..... **32**

5.1 Recommendations for effective approaches for impactful research ..... 32

5.2 Research axes for Horizon Europe ..... 34

5.3 Recommendations for the Common Agricultural Policy ..... 35

5.4 Actions on regulations ..... 36

6. Conclusions ..... **37**

7. References ..... **38**

APPENDIX ..... **43**

# EXECUTIVE SUMMARY

Crop diversification is defined as « the increase, in space and time, of in-field crop diversity, by using cropping practices, including crop rotation extension, multiple cropping, intercropping, and genetic diversification » (Messéan et al., 2021). Crop diversification is recognised as a central strategy to improve productivity, delivery of ecosystem services (e.g., biodiversity conservation, water quality preservation, enhance natural pest and disease control, improved soil quality, and climate change mitigation) and resilience of cropping systems. It has the potential to effectively boost an effective agroecological transition of the EU farming systems.

This research brief is based on a review of the main results of nine EU-funded research projects related to the diversification of cropping systems carried out between 2017 and 2024. Main operational results include knowledge development, largely in the field of ecology and agronomy; and new tools such as contractual modalities and assessments of farm, logistics and market options. These outputs have the potential to facilitate further uptake of crop diversification.

Two important conceptual frameworks have been developed to guide future policies and actions. First, typologies of innovation settings reveal that crop diversification can be rolled out in a variety of situations including short or long value chains, organic and conventional sectors, and niche or commodity markets. Second, typologies of diversification pathways showcase contrasted timeframes and levels of ambitions of crop diversification processes (Brannan et al., 2023; Morel, Revoyron, Cristobal, et al., 2020; Revoyron et al., 2022). These multiple modalities indicate that a large range of farming systems could benefit from engaging in crop diversification and therefore call for distinct operational and policy support.

Research projects have mapped and described barriers which hinder the development of diversified cropping systems. These factors are related to inputs, knowledge, support and advice, technical, economic, socio-cultural, and organizational aspects. The barriers to crop diversification are context-specific, interconnected, and occur simultaneously at multiple levels along the supply chains (Brannan et al., 2023; Morel, Revoyron, Cristobal, et al., 2020).

This research brief outlines a Research & Innovation agenda with 17 priorities to tackle these barriers with a coordinated approach, to accelerate the uptake of crop diversification in farming systems at the upstream, midstream and

downstream stages of value chains. This is based on a review of all policy briefs published by the nine selected research projects, relevant deliverables, and advice from a Scientific Committee.

Lessons learnt for effective research projects are also indicated. To achieve an ambitious impact, upcoming research projects should showcase a theory of change, indicate which types of crop diversification systems they cover and define the expected impact in consistency with the framework of barriers already developed. Research based on systems approaches has the highest potential to address the current lock-in. To reach a wide uptake of crop diversification, multiple actors need to be engaged beyond the small circle of pioneer actors.

Recommendations are provided to include the above research axes into the next European Research Funding Program (Table ES1), along with making improvements in the Common Agricultural Policy and other regulations to further encourage and support crop diversification (Table ES2).

Finally, three key factors for crop diversification to contribute to a paradigm shift towards agroecology are multi-actor participation, strategic scales of action, and relevant size of farms and value chains. Research projects are invited to be more precise and ambitious in terms of impact, by designing a clear theory of change towards this paradigm shift.

**Table ES1: A research agenda to further develop knowledge, tools and contents for advocacy**

| Stage of value chain | Categories of barriers | Research & Innovation axes |
|---|---|---|
| 1. **Upstream of value chains** / Access to adapted farming inputs | Seeds | **#1**. Roll out breeding programs focusing on traits that are relevant for diversified cropping systems |
| | Plant protection | **#2**. Study and develop novel pest management approaches, products and describe scenarios of uptake |
| | Machinery | **#3**. Research how current machinery can be adapted and used; develop innovative machinery when existing machinery does not cover technical requirements for diversified systems (especially for sowing and harvesting) |

| Stage of value chain | Categories of barriers | Research & Innovation axes |
|---|---|---|
| | | **#4**. Develop new technologies that support diversification |
| **2. Farm level** | Agronomic performance | **#5**. Deepen scientific knowledge on the ecology of diversified cropping systems<br>**#6**. Assess the relevance of crop diversification in the context of climate change<br>**#7**. Provide evidence on successful crops and farming practices for crop diversification<br>**#8**. Research evidence of improved pest, disease and weed control in cropping systems |
| | Profitability | **#9**. Assessment of costs and benefits of diversified cropping systems vs conventional farming systems |
| | Support & advice | **#10**. Investigate the variability behind diversification success and identify key factors to support decision making |
| | Socio-cultural | **#11**. Assess conditions and information flows for the successful introduction of non-typical crops in EU regions |
| **3. Midstream and downstream of value chain** | Markets | **#12**. Research is needed to identify market opportunities for specific value chain and crops which have the greatest potential of sustainable development |
| | Investment | **#13**. Investigate mechanisms for sharing the investment costs and risks of innovation |
| | Market coordination | **#14**. Improve transparency of market data and value distribution in value chains and at the sector level |
| | Market organisation | **#15**. Assess power dynamics in value chains, and the impact of these dynamics on the implementation of diversification<br>**#16**. Develop tools for value chain partnerships and coordination towards crop diversification |
| | Others | **#17**. Develop tools for monitoring the uptake of diversification processes |

**Table ES2: A research agenda to further develop knowledge, tools and contents for advocacy**

| Policy/Regulation | Recommendations |
|---|---|
| **CAP design** | • Ensure further recognition of crop diversification as a key strategy for sustainable farming systems<br>• Set targets and monitor progress towards crop diversification<br>• Provide subsidies per worker rather than per hectare<br>• Improve inclusiveness of stakeholders' consultation<br>• Make reporting easier |
| **CAP (EAGF[1])** | • Increase the integration of intercropping and crop diversification in Good Agricultural and Environmental Conditions (GAECs) and eco-schemes |
| **CAP (EAFRD[2])** | • Increase the integration of intercropping and crop diversification in Measures for environment, climate and animal welfare (ENVCLIM) |
| **CAP Network** | • Continue supporting crop diversification through the EU CAP Network |
| **Breeding policies** | • The registration criteria for new cultivars should consider traits that are relevant for intercropping and diversified systems |
| **Nutrition/health campaigns** | • Promote the production and consumption of legumes, minor crops, etc |
| **Quality and food safety policies** | • Develop specific quality standards in consistency with crop diversification |

[1] European agricultural guarantee fund (often referred to as the "first pillar" of the CAP)
[2] European agricultural fund for rural development (often referred to as the CAP's "second pillar")

# 1. INTRODUCTION

## 1.1 Status of crop diversification in the EU

European farming and food systems are facing multiple challenges, both from environmental and economic perspectives. Environmental challenges include climate change and increased frequency of extreme events, pesticide or nitrate-based pollution, and biodiversity loss (Rockström et al., 2020). Economic challenges range from the resilience of farms' profitability to fairness of trade and power dynamics in value chains. To address the environmental challenges, policy strategies at EU level have proposed targets to reduce agricultural fertiliser and pesticide use, reduce nutrient losses and greenhouse gas emissions, increase the use of organic and regenerative farming methods, reduce food waste, and put biodiversity on a path to recovery by 2030 (European Union, 2022).

Increased crop diversification is identified as a key factor for promoting sustainability within the agricultural sector at both farm and landscape levels (Reckling et al., 2023). Crop diversification, encompassing practices such as extending crop rotation, implementing cover cropping and intercropping techniques, and cultivating minor crops, has gained significant attention due to its potential to deliver multiple benefits (Altieri, 1999; Barman et al., 2022; Meynard et al., 2013). These benefits include improved crop and soil health, reduced inputs, increased land efficiency, and enhanced private gains for farmers, as well as the provision of public goods such as greater biodiversity, carbon sequestration, and increased climate resilience for society (Table 1). Those benefits are recognized in the scientific arena and are underlined in the recent EU farming and food sustainability strategies (European Union, 2020).

**Table 1: Environmental and socio-economic outcomes of crop diversification, according to scientific studies.**

| Environmental and socio-economic outcomes | Effects of crop diversification |
|---|---|
| **Climate change adaptation** | Having a greater diversity of species, varieties and ecosystems makes production systems more resilient to shocks and stresses. Besides securing food production, diversification allows farmers to diversify their income streams |
| **Climate change mitigation** | Crop diversification can be done through legume crops, cover crops, and no-till farming practices with a capacity for carbon sequestration |

| Environmental and socio-economic outcomes | Effects of crop diversification |
|---|---|
| **Soil health maintenance** | Fertility maintenance through crop diversification has been worldwide reported. Both the diversity of crops and the integration of crops with a specific positive effect on soil contribute to soil health |
| **Reduced inputs** | Temporal crop diversification could reduce pesticide use by increasing the proportion of crops with low pesticide use (dilution effects) or enhancing the regulation of pests, weeds and diseases (regulation effects) |
| **Increased land efficiency**[3] | Increased land efficiency can be achieved by including additional crops in the rotation, as well as through the positive effect of compatible crops on one another. Land efficiency, understood as a higher total crop output produced on a unit of land, can be a source of enhanced private gains for farmers |
| **Biodiversity** | Crop diversification increases agricultural biodiversity (genetic, species and ecosystem) and non-cultivated biodiversity (e.g. plants, animals) |

*Scientific references: (Convention on Biological Diversity, n.d.; Crop Associations Including Milpa and Protein Crops, 2024; Kremen & Miles, 2012; Magrini et al., 2016; Meynard et al., 2018; Moraine et al., 2016; Reckling et al., 2016; Zander et al., 2016)*

Current indicators show that farming systems with short crop rotation and low cultivated diversity are still dominant in Europe. At the EU level, **75% of the total arable land is cultivated with only 10 species** (European Commission DG ENV., 2020). Crop rotations are on average short (EUROSTAT, n.d.), with recent modelling of the EU crop rotations suggesting that **68% of the arable land is grown with a two to four crops rotation** (Ballot et al., 2023). These simplified cropping systems, based on high-input monocultures of a small number of crop species grown in short rotations, have contributed towards environmental degradation in agricultural landscapes (Messéan et al., 2021). However, the remaining **25% of arable land has more than 500 species** listed, which suggests there is a large pool of species already on-land for diversification. Significant

[3] Land efficiency is often measured as Land Equivalent Ratio. This indicator evaluates the amount of land area using monocropping needed to produce the same yield as an intercrop (Crop Associations Including Milpa and Protein Crops, 2024; Paut et al., 2020)

variations are observed across countries, minor crops[4] representing 1-35% of national cultivated acreage (MUCF Secretariat, 2023). EU countries with farms smaller than 10 ha show the highest local diversity (Machefer et al., 2024). **The challenge lies in rendering the adoption of these crops feasible on a wider scale, at the farm, value chain and market level**.

Despite all these well-known benefits, studies have revealed the **existence of multiple barriers** at all levels of the food systems that limit the adoption of diversification practices at a larger scale (Aare et al., 2021; Antier et al., 2021; Brannan et al., 2023; Magrini et al., 2016; Meynard et al., 2018; Morel, Revoyron, San Cristobal, et al., 2020). To unlock this situation, a combination of further research, supportive policies, and innovation within value chains are required to tackle barriers and provide effective conditions for farmers and value chains to implement crop diversification (Antier et al., 2021, 2022).

## 1.2 EU support to Research and Development on crop diversification

Several projects funded through the European Union's research and innovation Horizon program have been addressing crop diversification at the EU level. These include six projects rolled out between 2017 and 2022: **Diverfarming; DiverIMPACTS; DIVERSify; ReMIX; LEGVALUE; TRUE**. These projects have also been contributing to the **Crop Diversification Cluster**[5]. In addition, three EU-funded projects have started since 2022 that are enlarging the body of knowledge of crop diversification: IntercropVALUES; VALPROpath; and LegumES. In terms of scope, some have looked at crop diversification in all its forms (e.g. Diverfarming, DiverIMPACTS), other focused on crop diversification through intercropping and crop mixtures (e.g. ReMIX, DIVERSify, IntercropVALUES), while another set of projects focused specifically on legume crops (e.g. LEGVALUE, TRUE, VALPROpath and LegumES)[6]. Out of the nine projects, six have addressed both the farm and value level (Table 2, Table 5). Together with other important independent research, the outcomes of these projects offer a valuable opportunity to feed into

[4] The term « minor crop » has a heterogeneous definition across countries. Most often it refers to crops that cover less than 10% of the total acreage (MUCF Secretariat, 2023).

[5] The Crop Diversification Cluster brings together research projects which operate in countries across Europe to increase the impact of crop diversification research. The Cluster encourages sustained uptake of diversification measures by European farmers and through innovations across the agri-value chain. The projects in the Cluster - Diverfarming, DiverIMPACTS, DIVERSify, LegValue. ReMIX and TRUE - received funding from the EU Horizon 2020 research and innovation programme. See www.cropdiversification.eu.

[6] Projects focusing on legume crops are included here as these can contribute to the diversification and sustainability of cropping systems and food value chains.

debates and strategic planning of both EU food systems' actors and public policies.

**Table 2: Overview of the scope and levels of application of the nine EU-funded projects related to crop diversification**

| | All modalities | | Specifically on intercropping | | | Specifically on legume crops | | | |
|---|---|---|---|---|---|---|---|---|---|
| | Diverfarming | DiverIMPACTS | Diversify | ReMIX | IntercropVALUES | LEGVALUE | TRUE | VALPROpath | LegumES |
| **Farm level** | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ | ✓ |
| **Value chain level** | ✓ | ✓ | | | ✓ | ✓ | ✓ | ✓ | |

# 2. METHODOLOGY

## 2.1 Aim of the research

The research presented here aims to provide recommendations for research and innovation (R&I) priorities at the European level in relation to the diversification of cropping systems, based on existing scientific research results from past and current European projects within Horizon 2020 and Horizon Europe.

## 2.2 Approach

***Identification and selection of sources***

Key sources were retrieved from the European research projects database Cordis, from projects' websites and from the publications database Zenodo. Sources reviewed include peer-reviewed scientific papers (109), policy briefs (18), projects deliverables if they included specific research or policy recommendations (8) as well as additional sources suggested by the Scientific Committee (Table 3). A comprehensive list of the sources is available in the Appendix.

**Table 3: Overview of sources reviewed to inform the research brief, number of documents reviewed and their utilisation.**

| Context | Scientific Papers | Policy Briefs | Project deliverables | Other sources | TOTAL |
|---|---|---|---|---|---|
| **Source overview** | | | | | |
| DIVERSify | - | - | 4 | | 4 |
| ReMIX | 2 | 5 | | | 7 |
| LEGVALUE | - | 4 | | | 4 |
| TRUE | 33 | 3 | 2 | | 38 |
| Diverfarming | 28 | | | | 44 |
| DiverIMPACTS | 4 | | | | 33 |
| IntercopVALUES | - | | | | 5 |
| VALPROpath | - | | | | - |
| LegumES | - | | | | - |

| Context | Scientific Papers | Policy Briefs | Project deliverables | Other sources | TOTAL |
|---|---|---|---|---|---|
| Scientific Committee | | | | | 8 |
| Total | 109 | | | | 143 |
| **Utilisation of sources** | | | | | |
| Summary of results | X | | | X | |
| R&I agenda | | X | X | X | |
| Policy recommendations | | X | X | X | |

Other sources include: (A Value Chain Perspective on Crop Associations, 2024; AgroDiversity Toolbox, n.d.; Crop Association Practices: Where and How to Find Them?, 2024; Crop Associations Including Milpa and Protein Crops, 2024; Cultivar Testing as a Key to Boost Uptake of Crop Associations in Breeding and Farming, 2024; Integrating Crop Associations into Farming Systems, 2024; "Our Projects," n.d.; Dib et al., 2024)

### *Review of results from previous projects*

To produce a summary of results from the Research projects, all scientific papers listed in projects' website were retrieved. Papers were classified, according to their topic, into five categories: (i) ecology and agronomy; (ii) market analysis and product development; (iii) value chain modalities; (iv) identification of barriers and levers; and (v) planning, monitoring and elaborating a vision for the uptake of crop diversification. Key deliverables were also reviewed. Finally, other sources recommended by a Scientific Committee were added to the review.

### *Identification of R&I topics and policy recommendations*

Policy briefs and projects deliverables were screened for research gaps and opportunities for innovation. The 14 research axes identified were classified from the upstream to the downstream of value chains, in consistency with the framework of barriers (Brannan et al., 2023). The **upstream** refers to the supply of inputs. The **farm-level** refers to fields and farms (barriers related to agronomic knowledge, farm profitability, investment, support and advice, socio-cultural aspects). The **midstream** and downstream stages concern midstream and **downstream** value chain actors, operating between harvest and consumption, i.e. collectors, food industry actors, retailers, (barriers in the supply chains and markets in terms of competition, demand, investment, innovation, logistics and

transport, market coordination and market organisation) (Figure 1). The Research axes were reviewed by the Scientific Committee and relevant suggestions of 3 additional axes were integrated. The R&I agenda is composed of these 17 research axes (Figure 2). Recommendations for policies and regulations are listed separately. Other instruments, beyond the scope of this study, are listed in the Appendix.

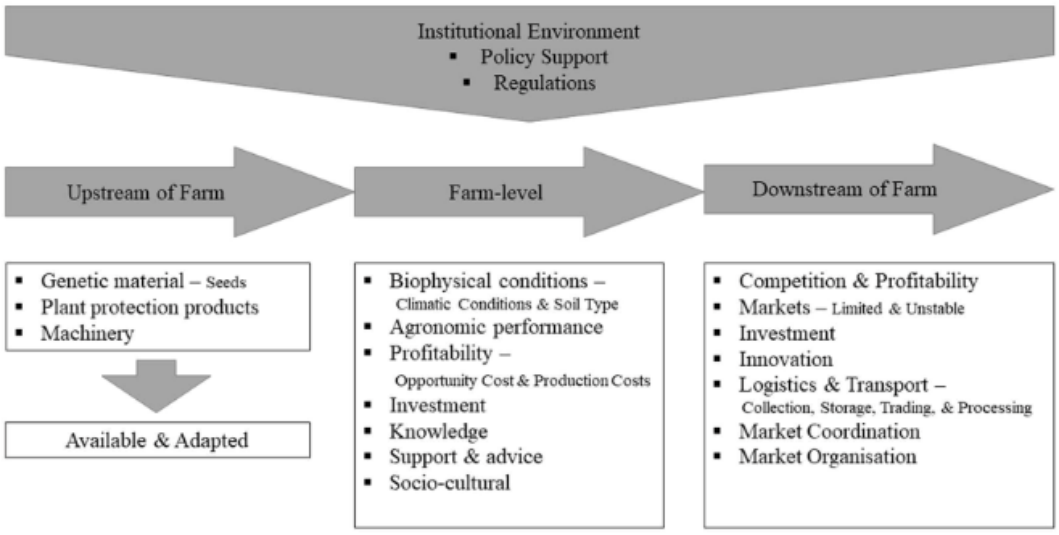


**Figure 1: Conceptual framework of barriers to crop diversification based on a review of agricultural innovation literature and specific literature on barriers to crop diversification (Brannan et al., 2023).**

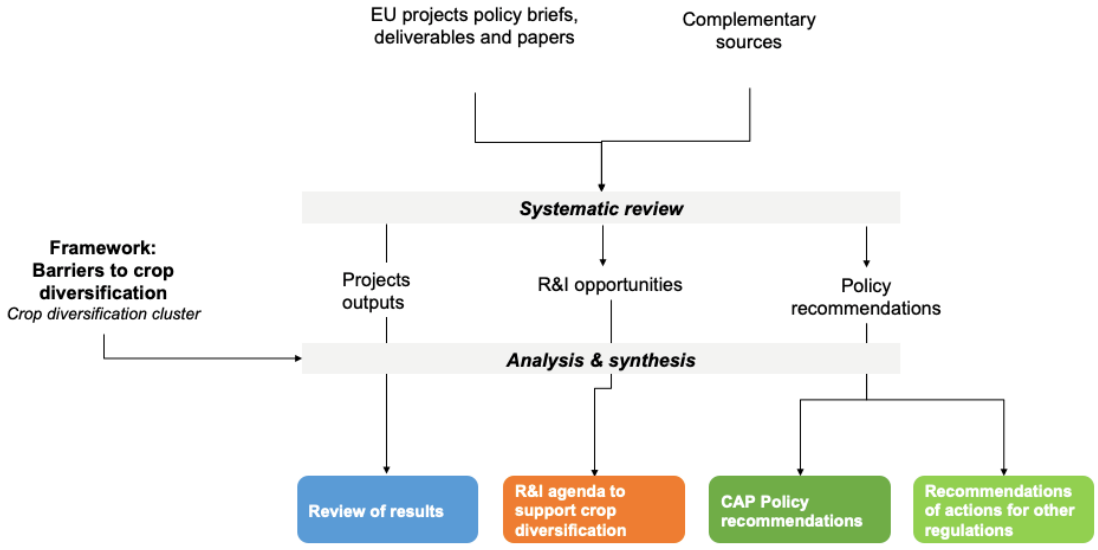

**Figure 2: Data flow from the review of deliverables to the recommendations.**

## 2.3 Participatory approach

This research paper is produced as part of the European Sustainable Agriculture Dialogue (ESAD) research papers series. The ESAD is a trusted community of key stakeholders in the EU food and agriculture sectors across the whole food supply chain and beyond. For the elaboration of this document, three rounds of exchange were organised with the members of the ESAD platform in 2024 during which members were first introduced to the theme of crop diversification, the recommendations were presented and discussed with them and finally the written draft of the final report was shared with the platform providing opportunity for feedbackAll feedback received was assessed in terms of relevance and was included in the draft accordingly.

## 2.4 Scientific Committee

A scientific committee was created with researchers who have been involved in the member projects of the Crop Diversification Cluster, in the working groups of this Cluster and possibly in other European projects related to crop diversification; and who have published relevant work that can feed into the recommendations for a R&I agenda. The Committee was invited to comment on the review of materials and provide feedback and advice on R&I recommendations. The contributions of the scientific committee were assessed according to the relevance to inform the research agenda, coherence vs other sources and level of scientific consensus.

# 3. KEY RESEARCH RESULTS FROM EU-FUNDED PROJECTS ON CROP DIVERSIFICATION

The nine selected EU-funded projects focused on crop diversification (Table 3) have been contributing to deepening knowledge, designing conceptual frameworks, developing tools and engaging actors for the diversification of cropping systems. A synthesis of their research results is presented below with the results grouped as: conceptual/framing, upstream, farm-level and mid- and downstream of value chains. A key output for policy development is the conceptual framework that describes crop diversification modalities and maps barriers at all levels of the farming and food system.

At a first glance, we observed that **agronomic research at the field/farm level has concentrated most of the scientific efforts** (Figure 4, Table 2). While agronomy remains an important field of research for encouraging the uptake of sustainable cropping systems, the economic and socio-cultural aspects of the adoption of crop diversification remain under-investigated. Economic and cultural barriers and levers have been identified for which further research will be relevant at the farm, value chain and sector levels.

## 3.1 Results at the conceptual/framing level

***Result #1: A framework to characterize crop diversification modalities***

Crop diversification has been defined by the Crop Diversification Cluster as « the increase, in space and time, of in-field crop diversity, by using cropping practices, including: crop rotation extension, multiple cropping, intercropping, and genetic diversification » (Messéan et al., 2021) (Figure 3). Crop associations can be defined in terms of species composition (annual, perennial, or a mixture) and spatio-temporal arrangement (Crop Associations Including Milpa and Protein Crops, 2024). The diversification of rotations implies the integration of new crops, possibly with « minor crops » (i.e. crops that are not largely used so far (MUCF Secretariat, 2023).

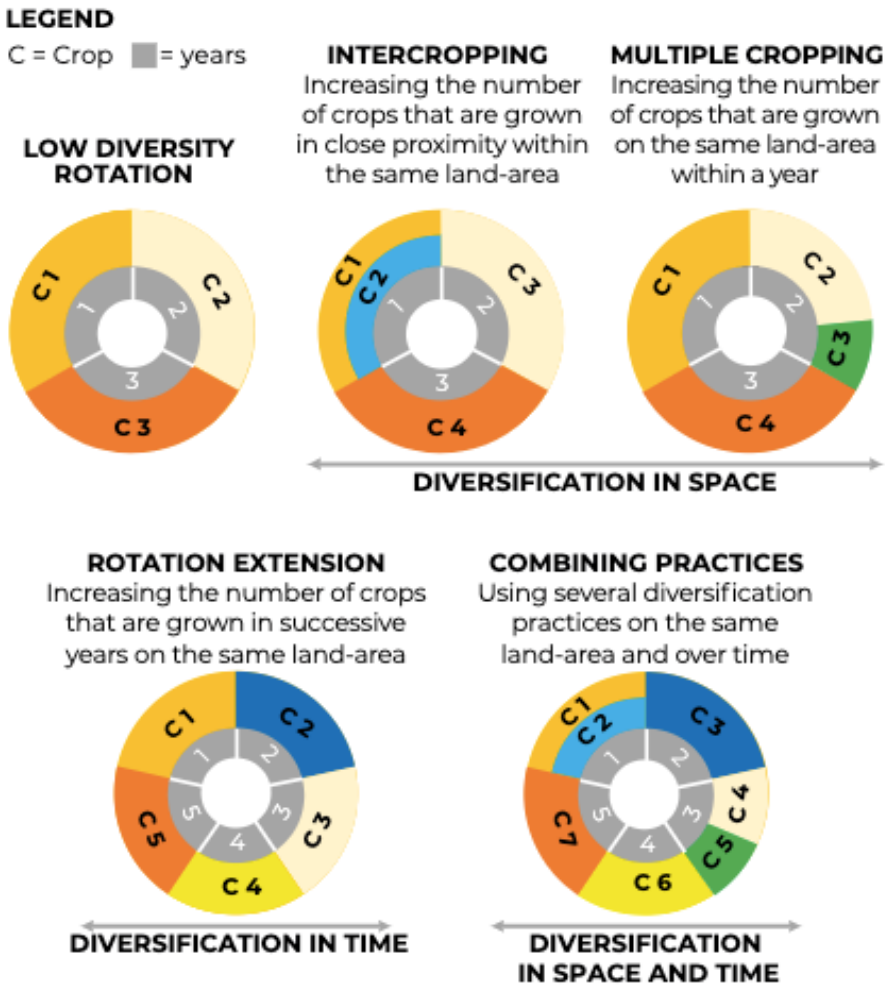


**Figure 3: Illustration of the shift from low diversity rotation toward diversified rotation, produced in the context of the Crop Diversification Cluster (Messéan et al, 2021).**

Crop diversification is implemented in various innovation settings[7], including short or long value chains, farmers' networks, niche or commodity markets, both in the conventional and organic sectors (Brannan et al., 2023; Morel, Revoyron, San Cristobal, et al., 2020). These multiple options have been documented as

[7] The concept of "food system innovation setting" was introduced by (Morel, Revoyron, San Cristobal, et al., 2020) to characterise the diversity of crop diversification innovation strategies at the food system level, combining: (i) the type of innovative practice promoted at farm level; (ii) the type of value chain supporting that innovation; and (iii) the type of agriculture involved (organic or conventional).

typologies[8], and synthetized as a set of variables (Dib et al., 2024). Various pathways to crop diversification were identified, which are contrasted in terms of the number of crops included, the share of arable land dedicated to these new crops, and the speed of adoption of the new crops (Revoyron et al., 2022). These pathways are correlated to technical, economic, organizational and cognitive contexts, and call for distinct operational and policy support.

The combination of these variables offers a framework for framing projects and policies, making sure to target innovation settings that are relevant for crop diversification, and which can deliver the highest impact.

**Table 4: How to classify crop diversification systems? Overview of the variables used in crop diversification typologies developed in EU projects.**

| Domain | ID | Variables | Values |
|---|---|---|---|
| **Production** (in farms and downstream) | **A1** | **Type of agriculture** | Conventional / Organic |
| | **A2** | **Type of diversification** | Temporal / Spatial / Combined |
| | **A3** | **Diversification trajectory types** | Small / Medium / Large share of the arable land<br>Few additional crops / Many additional crops<br>Slow / Steady / Fast |
| | | Area being diversified<br>Number of crops<br>Speed of diversification | |
| | **A4** | **Industrial pathways**<br>Acreage at the regional level<br>Number of processing units<br>Ownership of midstream facilities | Minor crop (<10% of land) / Major crop (>10%)<br>One centralized unit / Several decentralized units<br>Farmer / Farmers / Midstream actor |
| | **B1** | **Value chain size** | Short value chain / Value chain with at least one intermediary / Value chain with many intermediaries |
| | **B2** | **Value chain approach** | Low / Medium / High |
| | **B3** | **Stage of value chain development** | Setting-up stage / Enhancing / Further developing |
| | **B4** | **Adoption of fair governance mechanisms** | Low / Medium / High |

[8] A typology refers to the systematic classification or categorization of entities based on shared characteristics or attributes. This classification enables the grouping of similar elements or recurring configurations according to specific criteria, thereby facilitating the analysis and understanding of structures, dynamics, and interactions within the systems. Typologies are useful for purposes of research, action and policy making (Dib et al., 2024).

| | | | |
|---|---|---|---|
| **Governance** | **B5** | **Coordination lead** | By the market /<br>By midstream or downstream actors /<br>Co-constructed between farmers and mid/downstream actors /<br>Short supply chains lead by the farmers between the farmers /<br>Coordination between farmers |
| | **B6** | **Organisational model**<br>Innovation lead<br>Governance | Farmer(s) / Midstream or downstream actors<br>Based on selling processing services /<br>Based on contracts for production |
| | **B7** | **Consumers engagement** | Low / Medium / High |
| **Market** | **C1** | **Consumers groups** | Local market / Commodity market /<br>Farmer-to-farmer exchange |

Source: adapted from (Dib et al., 2024). Variables based on data from Antier et al. (2022), Morel et al. (2020), Revoyron (2022), Riera et al. (2022), Villa (2022), Weituschat (2018).

### *Result #2: A systemic mapping of barriers to crop diversification*

**The analysed projects offer a solid framework to analyse barriers to crop diversification**. and which can be used in the framing of future projects, to clarify how projects intend to tackle barriers.

46 barriers to crop diversification were identified throughout project's case studies. Barriers to crop diversification are related to a wide range of dimensions including knowledge, support and advice, technical, economic, socio-cultural, and organizational aspects such as farm management, value chain logistics and value chain coordination (Brannan et al., 2023). The identified barriers also occur at different stages and levels of the food system:

- at the **farm level** (e.g. lack of technical knowledge and references, the lack of resources for investing in adapted machinery, the limited access to reliable inputs, cognitive barriers);
- **from harvest to retail** (e.g. volumes are too limited to be profitably collected, or the conditions for innovation and investment are not met);
- at the **market level** (e.g. low consumers' awareness and understanding of crop diversification as a sustainable practice, variable willingness to pay and uncertain markets);
- and in the **coordination between value chain actors** (ranging from the unbalance of power between value chain actors, the need for specific contractual conditions, and challenges of communication and coordination between actors (Morel, Revoyron, Cristobal, et al., 2020)).

Overall, the identified **barriers to crop diversification are context-specific, interconnected, and occur at multiple levels simultaneously along the supply chain** (Brannan et al., 2023; Morel, Revoyron, Cristobal, et al., 2020).

In response to these barriers, more than 200 operational solutions were identified with experts and actors (Amrom et al., 2021). A total of 18 policy briefs were addressed to policymakers. For crop diversification to be more widely implemented in EU farming systems, levers include further research, innovation, knowledge management, investment, and policy support.

## 3.2 Results to address upstream barriers

***Result #3: A framework for breeding seeds for diversified systems***

Dedicated research within REMIX has provided an integrative methodological framework to design breeding programs for mixed cropping systems. Breeding of varieties based on this framework will ensure that the seed market offers varieties and mixes best suited for diversified systems.

***Result #4: Assessment of machinery innovation needs and opportunities***

The solutions regarding machinery innovation are based either on the adaptation of the existing machines to the new cultivation methods, or the other way around i.e., adapting the cultivation system to the existing machines available. Both approaches are observed in case studies. For a number of crop diversification practices, utilisation (or simple adaptation) of existing machinery has been assessed as possible. Innovation needs are identified for mechanical weeding, harvesting, strip-cropping and no-till systems. Developing new machines or adapting current machines will be necessary to create good solutions for diversified cropping systems, and could turn out to be market opportunities for machinery manufacturers (Van der Voort et al., 2021).

## 3.3 Results to address farm-level barriers

***Result #5: Findings in ecology and agronomy***

More than 50 papers were published by the nine reviewed EU-funded projects in scientific journals that focussed on the ecology and agronomy of diversified cropping systems (Figure 4). This research, which identified and assessed multiple crop rotations, provides us with a better understanding of, and further scientific proof that, crop diversification effectively delivers ecosystem services and leads to improved agro-environmental sustainability The studies also look into the conditions needed to create such positive impact.

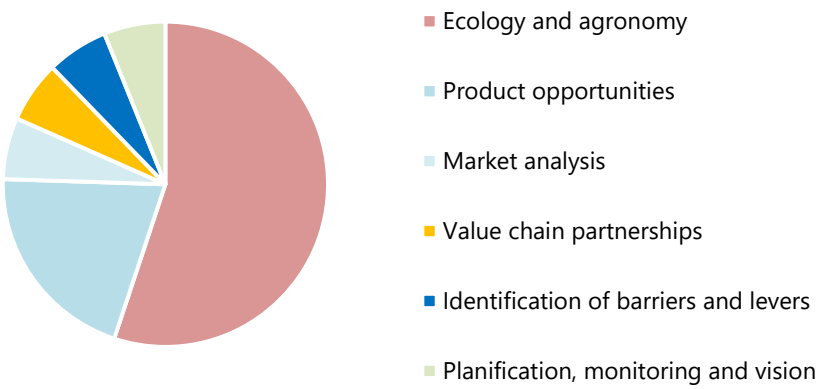


**Figure 4: Repartition per topic of scientific articles published by nine EU projects related to crop diversification (source: based on 109 scientific articles retrieved from projects' websites and research repository Zenodo – classification by the authors).**

***Result #6: Access to technical databases and assessment tools***

Several databases and tools have been produced to render technical data and impact assessment easier to access and use:

- The Crop Diversification Cluster has developed an integrated database of available indicators and a toolbox to assist in the selection of sustainability indicators tailored to assess the impact of crop diversification.

- The web platform AgroDiversity Toolbox, developed from REMIX along with two other EU-funded projects and three German-funded projects, is an interactive user-fed knowledge source of regionally relevant information about the diversification of cropping systems. It provides a description of principles and key concepts of intercropping and diverse cropping systems, along with a database of subsidiary crops, links to databases and tools such as the ecosystems services calculation tool created in the context of ReMIX (AgroDiversity Toolbox, n.d.).

- The LegumeHub is another communication platform where projects' results that link research and crop development practice are disseminated. The platform provides a combination of results for specific crops[9] ("Our Projects," n.d.).

[9] Faba beans, lucerne, lupin, pea, soybean.

The effects of crop diversification on agronomic and economic performance have been assessed in various conditions. Concrete tools have been made available for farmers and advisors in various formats such as calculators, databases, decision making tools, games, guides, or videos. One example is the Ecosystems service tool developed by ReMIX (which combines scientific and empirical literature to provide a decision support tool linking crop mixtures with services they deliver). Inventories of these tools are also provided (see the AgroDiversity Toolbox and the DiverIMPACTS toolbox). Practice abstracts showcase concrete options of crop diversification, farming practices, and profitability in various climatic regions through case studies.

The Diversify project has specifically worked to understand how to optimise the performance of crop species mixtures or 'plant teams' to improve yield stability, reduce losses to weeds, pests and diseases, and enhance resilience to environmental change. Best combinations of crops were studied, that may reduce economical risks for farmers and improve farm-level technical and economic performance. Further assessment is needed in longer timeframes, for a wider range of crops and rotations, and under contrasted pedoclimatic conditions.

***Result #7: Economic aspects at the farm level***

Research on costs and benefits of crop diversification have been implemented in the context of Diverfarming and DiverIMPACTS. The farm-level economic assessment in case studies across Europe indicates that crop diversification doesn't often provide significant changes in farm-level economic results and, in when it does, they are expected to be acceptable, positive or even significantly positive (Viguier et al., 2021; Zabala et al., 2023). An assessment extended to market and non-market value shows that in the medium and long term, most diversifications perform economically better than the expected results from monocultures. The internalization of environmental externalities is a key factor in increasing the market value of diversified cropping systems (Alcon et al., 2024).

Results from case studies provide important indications of the expected economic impact of crop diversification but are insufficient to draw global conclusions. Further regional comparisons within each pedoclimatic region and crop diversification modality are suggested to create a more comprehensive economic assessment framework.

## 3.4 Research results at the mid- and downstream stage of value chains

***Result #8: Assessment and tools for crop diversification value chains***

Relevant **arrangements of value chain partnerships** were identified, along with suitable contractual modalities. Better coordination of value chains stands out as a key factor to encourage, strengthen and sustain value chains based on crop diversification (Dib et al., 2024). In this regard, the projects provided insights to improve this by: (i) covering challenges, strategies and tools for value chain coordination, (ii) listing sustainable-development indicators for legume-based value chains to help manage the key facilitative capacities and dependencies, (iii) assessing the added value of new value chains based on crop diversification and (iv) identifying the value chains' intervention entry points for increased impact.

***Result #9: Market data and analysis***

Market-related research included: (i) the assessment of the willingness-to-pay (WTP[10]) for crop diversification products in various countries; (ii) the identification of processing opportunities to foster food innovation out of crops from diversified systems; and (iii) the evaluation of contributions to nutrition and health of minor crops and innovative products. Studies were also developed that assess the demand for specific crop diversification products (legume crops) and present scenarios of adoption of diversified systems.

[10] In behavioural economics, willingness to pay (WTP) is the maximum price at or below which a consumer would buy a product.

# 4. K&I OPPORTUNITIES TO TACKLE BARRIERS TO CROP DIVERSIFICATION

The following research agenda is based on the evidence and outputs produced in the context of the previous and current Horizon EU-funded projects supporting crop diversification. The Research agenda intends to:

- point out research and innovation relevant to address the operational challenges of crop diversification, in order to facilitate its uptake;
  - propose a framework to ensure consistency across the various axes of the research programs, taking into consideration the systemic nature of crop diversification
  - facilitate the integration of the relevant research and suggested research principles within the next European Research Framework Programme

Seventeen topics are identified that need to be further researched to support the update of crop diversification. Research axes are presented according to the conceptual framework of barriers (Brannan et al., 2023; Morel, Revoyron, Cristobal, et al., 2020), working from upstream of the farm (with the supply of inputs), to the farm-level and farmers (agronomic knowledge, profitability, investment, support and advice, socio-cultural aspects), and lastly the mid- and downstream stage (competition, markets, investment, innovation, logistics and transport, market coordination and market organisation).

## 4.1 Research axes for upstream

***Research axis #1: Roll out breeding programs focusing on traits that are relevant for diversified cropping systems***

| | |
|---|---|
| **Objective** | *Provide varieties that render crop diversification more feasible and reliable, in consistency with crop diversification modalities and contexts.* |
| **Opportunity** | Breeding, cultivar testing and cultivar information systems are acknowledged as key factors for the successful implementation of crop associations in farming systems.<br>Breeding programs should make progress on: (i) minor crops; (ii) common crops focusing on traits that are relevant for diversified cropping systems; and (iii) crop mixtures; addressing the diversity of EU climatic conditions and considering market opportunities and food processing requirements. |

| | |
|---|---|
| **Examples of actions** | Studying the impact of mixed cultivation; building on existing examples such as mixed cultivation of corn and beans, rotation with winter and spring crops, adoption of early varieties or catch crop mixtures in rotation for specific climatic conditions and market requirements. |
| **Recommended by** | Projects: DiverIMPACTS;<br>Scientific committee;<br>Other scientific publications (Cultivar Testing as a Key to Boost Uptake of Crop Associations in Breeding and Farming, 2024; Vanloqueren & Baret, 2008, 2009) |

***Research axis #2: Study and develop novel pest management approaches, products and describe scenarios of uptake***

| | |
|---|---|
| **Objective** | *Provide adapted, efficient alternatives to mainstream pesticides.* |
| **Opportunities** | • Temporal crop diversification can reduce pesticide use by increasing the proportion of crops with low pesticide use (dilution effects) or enhancing the regulation of pests, weeds and diseases (regulation effects).<br>• Novel biocontrol products are being developed, that could contribute to reducing the use of chemical pesticides in diversified systems.<br>• An assessment of the potential for adoption and impact of these various strategies would allow envisioning how they can contribute to reducing the use and risks of pesticides in consistency with EU plans, policies and regulations. |
| **Examples of actions** | Further studies are required to identify crop sequences that maximize regulation and dilution effects while achieving other facets of cropping system multi-performance. |
| **Recommended by** | Stakeholders' consultation;<br>Scientific committee;<br>Other publications (Butault & et al, 2010; Guinet et al., 2023; Zhang et al., 2024). |

### *Research axis #3: Study and develop novel pest management approaches, products and describe scenarios of uptake*

| | |
|---|---|
| **Objective** | *Provide advice and relevant machinery adapted to diversified systems.* |
| **Opportunity** | Crop diversification involves specific crops and farming practices, for which innovative machinery is required (especially for sowing and harvesting).<br><br>In several cases, current machinery can be adapted for innovative farming practices, while in other cases, innovative machinery is required to meet the technical requirements of diversified systems. Significant efforts have been made by the machinery industry to develop innovative tools. However new technical needs have emerged with the development of crop diversification, and in relation to farmers' preferences. The diversification pathways are closely related to the machinery available at the farm level. Two approaches have been observed from farmers: to adapt crops to machinery farmers already have vs adapting their machinery to adopt new crops in the context where they are.<br><br>The financial accessibility to new machinery also remains an important barrier to tackle through subsidies, new business models and collaborative modalities. |
| **Examples of actions** | • Develop suitable machinery for mixture production and separation;<br>• Innovation development for designing combine-harvesters more suited for species mixtures;<br>• Technical research aimed at identifying the best combinations of equipment and settings for harvesting and sorting. |
| **Recommended by** | Projects: Diversify; ReMIX; DiverIMPACTS;<br>Scientific committee |

***Research axis #4: Develop new technologies that support diversification***

| | |
|---|---|
| **Objective** | *Render crop diversification easier to implement.* |
| **Opportunity** | Previous projects provide a set of validated technological instruments. They are the basis for further research and innovation aiming at finding new technology supporting crop diversification. |
| **Examples of actions** | • Further develop tools of Spatial Decision Support Systems;<br>• Precision agriculture technology could help overcome a number of barriers and improve uptake of plant teams. |
| **Recommended by** | Projects: Diversify; Diverfarming. |

## 4.2 Research axes at the field and farm level

***Research axis #5: Deepen scientific knowledge of the ecology of diversified cropping systems***

| | |
|---|---|
| **Objective** | *Provide farmers and the upstream industry with a solid scientific background to optimize the design and management of diversified systems* |
| **Opportunity** | Developing further scientific knowledge of the ecology of diversified cropping systems, and especially on mechanisms and traits that deliver ecosystem services and optimal performance in plant teams, will provide a solid ground to orientate farmers and breeders towards relevant development options.<br>Minor crops and multi-species mixes seeds and farming practices can be more costly than mainstream crops. Improving the scientific assessment of its benefits will facilitate farmers choices. |
| **Examples of actions** | • Research on the ecology of cover crops (composition of mixes, and what mixes are beneficial pre or post another crop; interaction with the soil in the crop rotation and effect on pH, N, fungal ratio etc.);<br>• Research on the ecology of intercrops (Improved modelling of plant mixtures, soil-plant intimal functioning);<br>• Research on the ecology of legume crops. |
| **Recommended by** | Projects: Diversify, ReMIX, LEGVALUE;<br>Stakeholders' consultation;<br>Scientific committee. |

### *Research axis #6: Identify mitigation and adaptation strategies to combat climate change through crop diversification*

| | |
|---|---|
| **Objective** | *Improve the climate resilience of farming systems.* |
| **Opportunity** | Crop diversification is recognized as a relevant approach to face climate change. Crop diversification can improve resilience against extreme and variable weather conditions. Specific modalities of crop diversification have the potential to increase carbon sequestration in soils while mitigating greenhouse gas emissions (Crop Diversification as an Efficient Tool for Ensuring Food Security and Mitigating the Impact of Climate Change., 2023).<br><br>At the same time, participatory experiments in the EU-funded projects have shown that the choices of cultivars, plant team (crop species mixtures) species and management options need to be taken into account in line with a changing climate. |
| **Examples of actions** | Identify relevant cultivars, plant team species, rotation arrangements and field/farm management options that: (i) contribute to tackle climate change; and (ii) are resilient in the context of climate change. |
| **Recommended by** | Projects: Diversify, TRUE;<br>Scientific committee |

### *Research axis #7: Provide evidence on successful crops and farming practices for crop diversification.*

| | |
|---|---|
| **Objective** | *Render crop diversification more reliable to implement.* |
| **Opportunity** | Identifying best varieties, successful plant combinations and rotations, related agronomic data and farming practices (with a priority on sowing and harvesting) will render crop diversification easier for farmers to adopt, especially for those who are more reluctant to innovate in uncertain conditions. Successful options should be provided to cover the diversity of pedo-climatic conditions, farm characteristics, and value chain contexts across European regions. |
| **Examples of actions** | • Develop further knowledge and data on best varieties, sowing density, farming practices; |

| | |
|---|---|
| | • Develop a menu of plant teams with different seeding and mixing ratios to achieve different objectives. |
| **Recommended by** | Projects: Diversify, DiverIMPACTS;<br>Scientific committee. |

***Research axis #8: Research evidence of improved pest, disease and weed control in cropping systems.***

| | |
|---|---|
| **Objective** | *Highlight the agronomic benefits of crop diversification.* |
| **Opportunity** | Evidence of improved pest, disease and weed control in cropping systems using plant teams (crop species mixtures) is increasing, but remains insufficient. Skepticism around plant team efficacy in pest and disease control is identified as a factor that limits the uptake of crop diversification.<br><br>There is a lack of quantification and understanding of long-term benefits. |
| **Examples of actions** | • Experiments under controlled conditions and in the field, with specific mixtures and under determined environmental conditions, will further shed light on the mechanisms underlying these improvements.<br>• Scientific studies should assess the final yield effect rather than the level of plant injury (which might not affect yield or quality of the final product). |
| **Recommended by** | Projects: Diversify, TRUE, DiverIMPACTS;<br>Scientific committee. |

### *Research axis #9: Assessment of costs and benefits of diversified cropping systems vs conventional farming systems*

| | |
|---|---|
| **Objective** | *Provide an economic argument for diversified systems.* |
| **Opportunity** | Further economic assessment of costs and benefits of diversified systems, and comparison with conventional farming practices, will provide farmers with a financial rationale for implementing diversification. There is a potential to draw lessons learnt and cost-effective methods to manage crop mixtures and diversified systems based on previous implementation. Assessments should be made both on an annual basis, as well as over longer transition timeframes (5-20 years). |
| **Examples of actions** | Assess difference of cost of inputs individually and compare with the total costs and benefits of diversified systems vs simplified systems, through case studies. |
| **Recommended by** | Projects: Diversify;<br>Scientific committee;<br>Other scientific publications. |

### *Research axis #10: Investigate the variability behind diversification success and identify key factors to support decision-making*

| | |
|---|---|
| **Objective** | *Support farmers in decision-making.* |
| **Opportunity** | Providing a better understanding of key success factors will render crop diversification more reliable to implement. Variability is related to the diverse modalities of diversification, the crops chosen, as well as spatial and seasonal variability.<br><br>Due to the complexity and high variability of diversified systems, decision-making tools will help farmers consider the options for diversification at reach. Success factors should consider both benefits and challenges. In some cases, the challenges in implementation will be balancing the known benefits of a certain practice, for example in terms of fertiliser management or agrobiodiversity. |
| **Examples of actions** | • The enormous variability between individual farm characteristics requires on-farm trials by farmers in parallel with research experimentation;<br>• Advice and financial support are identified as critical for farmers to engage in on-farm trials to establish the optimal |

| | |
|---|---|
| | plant teams for their local conditions, as such experiments can expose them to reduced profit (or income foregone);<br>• Intercropping specific research and tools to support decision-making. |
| **Recommended by** | Projects: Diversify, ReMIX;<br>Scientific committee;<br>Other scientific publications. |

***Research axis #11: Assess conditions and information flows for the successful introduction of non-typical crops in EU regions***

| | |
|---|---|
| **Objective** | *Uncover conditions for the adoption of new crops.* |
| **Opportunity** | As climate changes, there is a great uncertainty on how farmers and value chains are going to integrate new crops, either based on constraints or opportunities. Better understanding of the conditions, pathways and information flows will allow to model and envision how diversification can be implemented in the mid to long-term across EU regions. |
| **Examples of actions** | • Identify socio-cultural conditions for the adoption of new crops;<br>• Map and model information flows along a crop diversification process at the regional level. |
| **Recommended by** | Scientific committee;<br>Other scientific publications. |

## 4.3 Research axes for the mid-and-downstream level

***Research axis #12: Identify market opportunities for specific value chain and crops***

| | |
|---|---|
| **Objective** | *Target advice and support towards promising crops and value chains.* |
| **Opportunity** | Market opportunities can be identified for crops that have the greatest potential for sustainable development. Criteria to identify the greatest potential include the current level of development of value chains, their potential environmental and social impact, and their technical and economic resilience. |

| | |
|---|---|
| **Examples of actions** | • Design a strategic approach taking into consideration feasibility and potential impact, addressing the various innovation settings in which crop diversification can take place.<br>• Assess the technical feasibility of feed value chains using intercropping-derived products without sorting. |
| **Recommended by** | Scientific Committee;<br>Other scientific publications (Paut et al., 2020). |

***Research axis #13: Investigate mechanisms for sharing the investment costs and risks of innovation***

| | |
|---|---|
| **Objective** | *Develop value chains for crop diversification products.* |
| **Opportunity** | Crop diversification involves innovation at the farm and value chain levels. Investment and risk barriers are identified at both levels that hinder the adoption of new crops and products. Mechanisms to share investment costs and risks can encourage all types of actors to collaborate in setting an innovation. |
| **Examples of actions** | • Study and support crop diversification value chains which are based on shared efforts.<br>• Design innovative mechanisms for sharing investment costs and risks. |
| **Recommended by** | Projects: DiverIMPACTS, Diverfarming;<br>Scientific Committee;<br>Other scientific publications (Dib et al., 2024) |

***Research axis #14: Improve transparency of market data and value distribution in value chains and at the second level***

| | |
|---|---|
| **Objective** | *Inform actors about market development.* |
| **Opportunity** | Transparency at the sector level about investment costs, margins and benefits will help to ensure fairness, coordination and the efficiency of financial support. Such data can be of use for farmers, value chain, market, research and policy actors. |
| **Examples of actions** | • Demonstrate the added value of integrated legume value chains.<br>• Assess the demand for the minority crops (market pull) vs. investment costs of processing facilities. |

| | |
|---|---|
| | • Assess extra costs for all actors in key crop diversification value chains. |
| **Recommended by** | Projects: LEGVALUE, TRUE, DiverIMPACTS;<br>Stakeholders' consultation;<br>Scientific Committee. |

***Research axis #15: Assess power dynamics in value chains, and the impact of these dynamics on the implementation of diversification***

| | |
|---|---|
| **Objective** | *Encourage fair value chains.* |
| **Opportunity** | What are the power dynamics that hinder the adoption of crop diversification innovations in current value chains?<br>New crop diversification value chains offer the opportunity to encourage the added value to be more fairly spread between actors. |
| **Examples of actions** | • Analyze power links in both existing and new value chains.<br>• These analyses should address the food system as a whole from the upstream to the downstream of value chains, and map possible power dynamics and relationships between actors. |
| **Recommended by** | Scientific Committee |

***Research axis #16: Develop tools for value chain partnerships and coordination towards crop diversification***

| | |
|---|---|
| **Objective** | *Overcome the value chain level lock-in through coordination.* |
| **Opportunity** | Successful cases are based on coordinated development of crop production and value chain development, shared vision, and contracts or partnership tools. Various levers and tools have been identified in previous projects, but the conditions for their adoption at a wider scale remain undescribed. Coordination mechanisms are still insufficiently documented. |
| **Examples of actions** | • Assess how tools identified in previous projects can be generalized and further implemented in value chains.<br>• Analyse, test and disseminate successful coordination mechanisms. |

| | |
|---|---|
| **Recommended by** | Scientific Committee,<br>Other scientific publications (Dib et al., 2024) |

***Research axis #17: Develop tools for monitoring the uptake of diversification process***

| | |
|---|---|
| **Objective** | *Measure progress at the local, regional, national and EU level; and inform public policies towards strategic diversification across EU regions.* |
| **Opportunity** | A better monitoring of crop diversification can provide important indications for the design of public policies. Optimal diversity can only be achieved by addressing diversification across scales, i.e. combining an increase in biodiversity at the local, landscape and national/EU level. |
| **Examples of actions** | • Propose indicators to document and monitor crop diversification at all scales;<br>• Set targets at each scale, to be achieved by 2050;<br>• Develop scenarios of uptake of crop diversification, modelling the diversity of crops, timeframe of adoption and expected impact. |
| **Recommended by** | Projects: Diversify; DiverIMPACTS;<br>Scientific Committee;<br>Other scientific publications (Machefer et al., 2024). |

# 5. INTEGRATION OF THE RECOMMENDATIONS IN THE EU POLICY FRAMEWORK

## 5.1 Recommendations for effective approaches for impactful research

For a successful impact to be achieved, research should not only focus on the most pressing topics but also be designed with effective approaches and adapted governance. Recommended approaches are presented below and relate to (i) relevant research frameworks such as typologies of farming systems and value chains and multi-level systems approaches; and (ii) actors' engagement.

### *Relevant research frameworks*

**Rooting research in crop diversification typologies**. Crop diversification can be implemented with various modalities, levels of ambition and timeframes. These multiple options have been documented in crop diversification typologies and provide useful variables to frame research and policies (Table 5). Future projects are invited to anchor their theory of change in the typologies of crop diversification systems.

**Table 5: Relevant variables of crop diversification systems useful for framing research and policies**.

| | |
|---|---|
| **Type of agriculture** | Conventional / Organic |
| **Type of diversification** | Temporal / Spatial / Combined |
| **Value chain size** | Short value chain / Value chain with few intermediaries / Long value chain |
| **Consumers groups** | Local market / Commodity market / Farmer-to-farmer exchange |

Note: Variables extracted from the review of crop diversification typologies (see Table 4).

**Framing projects according to the barriers they intend to address.** Crop diversification is hindered by barriers throughout the agri-food system. The framework of the barriers to crop diversification established herecould be used in the framing of future projects, to clarify how projects intend to tackle barriers, along with a theory of change towards impact. The utilisation of this framework can also serve to assess projects' achievements.

**Designing projects and methodologies with a systems approach.** Food systems are recognized as complex and facing multiple barriers operating as a lock-in. Such lock-in can only be removed through systems approaches, which

take the whole system into account to overcome systemic lock-in, by identifying the components of the system[11] and mapping how they interact with one another.

**Designing projects and methodologies with a multi-level perspective.** Research questions, methodologies and tool development should be articulated at complementary scales (i.e. field/farm level, value chain and sector level, policy level). The articulation between levels (field/farm/sector) remains a major challenge and should be emphasized in future projects. The value chain level remains under-investigated despite studies demonstrating the importance of barriers at that level and suggesting relevant levers (Dib et al., 2024). The interface between the farm level and policy level is a is a key space to design change levers.

### *Actors' engagement and support from research*

**Engaging actors for upscaling crop diversification.** To reach a wide phenomenon of crop diversification, multiple actors need to be engaged beyond the small circle of pioneer actors. Actors shall be engaged from the conception stage of projects. Participatory approaches during project implementation are also recognized as key. Living Labs are a form of participation currently implemented and that could be further rolled out to reach a wider range of actors.

**Supporting actors through research.** Effective research will provide new knowledge for all relevant actors and stakeholders including farmers (e.g. agronomic knowledge, machinery design, on-farm management tools); value chain actors (e.g. partnership tools, identification of barriers & strategic levers) and policymakers (e.g. monitoring tools, analysis of policies relevance for crop diversification innovation settings, etc.). Research should address the various innovation settings, diversification pathways and modalities in which crop diversification can be implemented.

[11] The system studied can be a combination of crops, a field, a farm, a value chain or a whole sector.

## 5.2 Research axes for Horizon Europe

**Table 6: R&I identified to address barriers to crop identification.**

| Stage of value chain | Categories of barriers | Research & Innovation axes |
|---|---|---|
| **1. Upstream of value chains /** Access to adapted farming inputs | Seeds | #1. Roll out breeding programs focusing on traits that are relevant for diversified cropping systems |
| | Plant protection | #2. Study and develop novel pest management approaches, products and describe scenarios of uptake |
| | Machinery | #3. Research how current machinery can be adapted and used; develop innovative machinery when existing machinery doesn't cover technical requirements for diversified systems (especially for sowing and harvesting);<br>#4. Develop new technologies that support diversification |
| **2. Farm level** | Agronomic performance | #5. Deepen scientific knowledge on the ecology of diversified cropping systems<br>#6. Assess the relevance of crop diversification in the context of climate change<br>#7. Provide evidence on successful crops and farming practices for crop diversification<br>#8. Research evidence of improved pest, disease and weed control in cropping systems |
| | Profitability | #9. Assessment of costs and benefits of innovative farming practices vs conventional practices |
| | Support & advice | #10. Investigate the variability behind diversification success and identify key factors to support decision-making |
| | Socio-cultural | #11. Assess conditions and information flows for the successful introduction of non-typical crops in EU regions. |
| **3. Midstream and downstream of value chains** | Markets | #12. Research is needed to identify market opportunities for specific value chains and crops which have the greatest potential for sustainable development. |
| | Investment | #13. Investigate mechanisms for sharing the investment costs and risks of innovation |
| | Market coordination | #14. Improve transparency of market data and value distribution in value chains and at the sector level |
| | Market organisation | #15. Assess power dynamics in value chains, and the impact of these dynamics on the implementation of diversification<br>#16. Develop tools for value chain partnerships and coordination towards crop diversification |
| | Others | #17. Develop tools for monitoring the uptake of diversification processes |

The following barriers, although part of the barriers framework (Brannan et al., 2023), are not listed here as no research axis was identified throughout the review: at the farm level, barriers related to investment and access to knowledge; at the midstream and downstream stage of value chains: barriers related to competition, innovation, and Value chain logistics and transport. However, these barriers are likely to require other instruments beyond the scope of research, such as subsidies and regulations.

## 5.3 Recommendations for the Common Agricultural Policy

The nine EU-funded research projects reviewed produced policy briefs with recommendations in relation to the CAP design, administration and monitoring. They also included recommendations for specific interventions within the European Agricultural Guarantee Fund (EAGF, also known as first pillar) and the European Agricultural Fund for Rural Development (EAFRD, also known as second pillar).

At the design, administration and monitoring level, specific recommendations include to set targets and monitor progress towards crop diversification; to adjust rules and reporting systems to render implementation of crop diversification easier; to shift rules for calculating payments towards effort-based measurement units; and to improve the inclusiveness of stakeholders' consultation. Specific recommendations on interventions include strenghtening the integration of diversification in eco-schemes and in standards of Good Agricultural and Environmental Condition (GAECs), strenghtening the integration of diversification in Measures for environment, climate and animal welfare (ENVCLIM) and in the Rural Development Programme (RDP). Finally, further support from the EU CAP Network is invited (Figure 5).

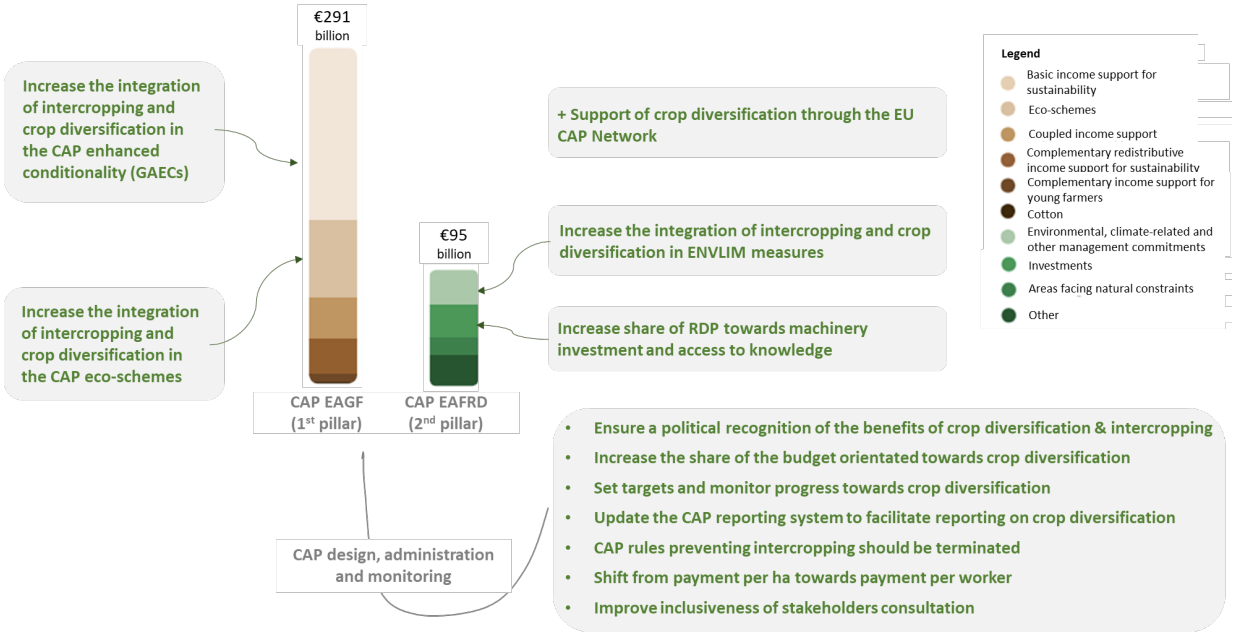


**Figure 5: Overview of recommendations to the CAP, based on policy briefs from the nine EU-funded research projects reviewed**

## 5.4 Actions on regulations

Complementary actions on regulations are identified to support the uptake of crop diversification:

- In **breeding policies**, the registration criteria for new cultivars should consider traits that are relevant for intercropping and diversified systems;
- In public **procurement policies**, increase the share of crop diversification products;
- In **nutrition and health** public communication campaigns, promote the production and consumption of legumes, minor crops, etc.;
- In **quality and safety** policies, develop specific quality standards in consistency with crop diversification.

# 6. CONCLUSIONS

Over the last decade, an important number of research projects have been implemented to investigate the potential of crop diversification to contribute to the sustainability of European farming and food systems. Solid results have been obtained from a scientific and agronomic perspective and various tools and assessments have been developed to support actors in the uptake of more diversified systems and their products.

This research brief proposes an agenda of 17 R&I priorities to tackle remaining issues and further encourage the uptake of crop diversification in farming systems. Complementary research could contribute to emphasising the advantages of crop diversification, especially in the context of climate change, and must further investigate value chain level mechanisms and tools for the integration of products from diversified cropping systems into the European food system.

Crop diversification has the potential to boost an effective agroecological transition. However, an ambitious process of crop diversification implies in-depth reconfiguration of the farming and food systems. Actors will need to accept a higher variability of production and build food chains accordingly. Farming decisions should consider working with natural dynamics and balancing yields and ecosystem services. On a conceptual level, the agricultural sector should be reassessed and organized within a *Onehealth* framework. Across value chains, coordination and fair value repartition should be improved to better support sustainable transitions. At the market level, the concept of « added value » will need to be redefined, taking into account the ecosystem services provided by sustainable farming systems.

In addition to research efforts, policies can play an important role in accelerating the uptake and success of crop diversification. In the CAP, uptake for crop diversification would benefit from better integration and alignment of measures that currently support these practices, in addition to increasing the share of funding and setting targets.

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# APPENDIX

**Table A1. List of crop diversification related projects funded through the EU's research and innovation Horizon programs.**

| Funding period | Project acronym | Full name | Grant number | Funding (M€) |
|---|---|---|---|---|
| 2017-2021 | DIVERSify* | Designing InnoVative plant teams for Ecosystem Resilience and agricultural Sustainability | 727284 | 5,0 |
| | ReMIX* | Redesigning European cropping systems based on species MIXtures | 727217 | 6,0 |
| | LEGVALUE* | Fostering sustainable legume-based farming systems and agri-feed and food chains in the EU | 727672 | 6,0 |
| | TRUE* | TRansition paths to sUstainable legume-based systems in Europe | 727973 | 5,0 |
| 2017-2022 | Diverfarming* | Crop diversification and low-input farming cross Europe: from practitioners' engagement and ecosystems services to increased revenues and value chain organisation | 728003 | 10,0 |
| | DiverIMPACTS* | Diversification through Rotation, Intercropping, Multiple cropping, Promoted with Actors and value-Chains Towards Sustainability | 727482 | 11,1 |
| 2022-2026 | IntercropVALUES | Developing Intercropping for agrifood Value chains and Ecosystem Services delivery in Europe and Southern countries | 101081973 | 7,4 |
| | VALPROpath | new VALue landscapes for plant PROtein Pathways | 101059824 | 9,6 |
| 2024-2027 | LegumES | Valorising and balancing the ecosystem service benefits offered by legumes, and legume-based cropped systems | 101135512 | 4,6 |

**Table A2: List of policy briefs and deliverables reviewed**.

| Project acronym | Type of document | Title |
|---|---|---|
| Diversify | Deliverable | D10. Policy guide on plant teams for intercropping |
| | Deliverable | D2. Report on socio-economic factors affecting farmer adoption of plant teams |
| | Deliverable | D31. Report on practical restrictions imposed by plant teams |
| | Deliverable | Deliverable 4.6 Report on trouble shooting matrix of PAT practical solutions |
| REMIX | Policy Brief | Intercropping Redesigned cropping strategies for food production and environmental services |
| | Policy Brief | Policy brief 2: Intercropping for boosting organic farming in Europe |
| | Policy Brief | Policy brief 3: Contribution of intercropping to pesticide use reduction |
| | Policy Brief | Policy brief 4: Improved support for intercropping will reduce fertiliser inputs and nutrient losses |
| | Policy Brief | Policy brief 5: Harvesting and separating crop mixtures: yes we can! |
| LEGVALUE | Deliverable (4 Policy Briefs) | D6.11 Final report on knowledge transfer activities for policy makers |
| | Deliverable | D7.4. Policy briefs and recommendations |
| | Policy Brief | PB1: Policy Brief: Promoting sustainable food and feed systems |
| | Policy Brief | Policy Brief: The Common Agricultural Policy (CAP) and the transition to legume supported food systems |
| | Policy Brief | PB3 : Environmental policies |
| | Deliverable | D9.9 Project review, impact and legacy plan |
| DiverIMPACTS | Policy Brief | Promoting crop diversification for more sustainable agri-food systems |
| | Policy Brief | Recommendations for overcoming barriers to crop diversification towards sustainable agriculture |
| | Policy Brief | Producing Actionable Knowledge for Crop Diversification |
| | Policy Brief | How to support the development of crop diversification? The importance of an approach at the value chain level |
| | Policy Brief | Increasing crop diversification requires diversity in teaching, training and learning |
| Diverfarming | Deliverable | D9.3. White Paper on sustainable diversified cropping systems to scientifically support relevant EU policies |
| | Deliverable | D9.2. Recommendations to preserve the environment and the long-term agricultural viability and competitiveness |
| IntercropVALUES | Policy Brief | Policy brief 1: How to design “intercrops friendly” policies? Lessons from the analysis of the barriers to intercropping in Europe |

**Table A3: List of additional sources of information on diversified cropping systems.**

| Source[1] | Related projects | Type | Contents |
|---|---|---|---|
| AgroDiversity Toolbox | ReMIX*; OSCAR*; INSUSFAR; BAKWERT; SOLIBAM*; ZIL | Wiki | This website is an interactive user-fed knowledge source of regionally relevant information about the diversification of cropping systems. Information included comes from personal experience reports, from the scientific literature and experiments conducted in research projects this wiki is based on. The website also provides links to related resources such as policy briefs, practice abstracts, videos and related projects. |
| Legumes Translated | Legumes Translated* | Thematic network | The overall aim of Legumes Translated is to increase the production and use of grain legume crops as part of a European Protein Transition.<br>Legumes Translated supports production and use of grain legumes ('protein crops'). As a thematic network, it helps farmers benefit from relevant research, particularly research funded by the European Union. This addresses how we obtain and use protein which is a fundamental factor in the resilience, performance and acceptance of our farming systems.<br>Legumes Translated is part of the European Innovation Partnership for Agricultural Productivity and Sustainability (EIP Agri). The consortium comprises 17 partners in 9 countries with 14 local innovation groups (Actor groups).<br>The project produces practice notes and abstracts, practice and development guides, and videos on a multi-lingual knowledge internet platform (The Legume Hub). |
| LegumeHub.eu | Legumes Translated* | Web platform | A knowledge-sharing platform that provides videos, images and articles on the production and use of legume crops in Europe. |
| EU CAP Network / EIP | | | This Focus Group works on identifying plant associations, analyse their impact, identify success and fail factors and barriers, identify needs and propose innovations. Four papers are available that aim at providing input to the Focus Group discussions and final report. |

**Table A4: Other instruments listed through the review, besides R&I.**

| Other instruments recommended | # occurrences |
|---|---|
| **1.** Support to investment & risk taking | 15 |
| **2.** Improve access to knowledge (data and advisory services) | 14 |
| **3.** Promote the production, processing and consumption of legumes, minor crops, etc. from diversified cropping systems | 6 |
| **4.** Identify value chain actors and receptive markets for crop diversification products | 4 |
| **5.** Include crop diversity in certification schemes | 3 |
| **6.** Support farmers' organization and cooperation towards crop diversification | 3 |
| **7.** Adjust standards, regulatory and admin procedures | 3 |
| **8.** Increase public procurement of products from diversified systems | 3 |
| **9.** Promote crop diversification farming methods | 2 |
| **10.** Assess barriers in terms of access to inputs locally and support actors in addressing those barriers | 1 |
| Total | 53 |

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