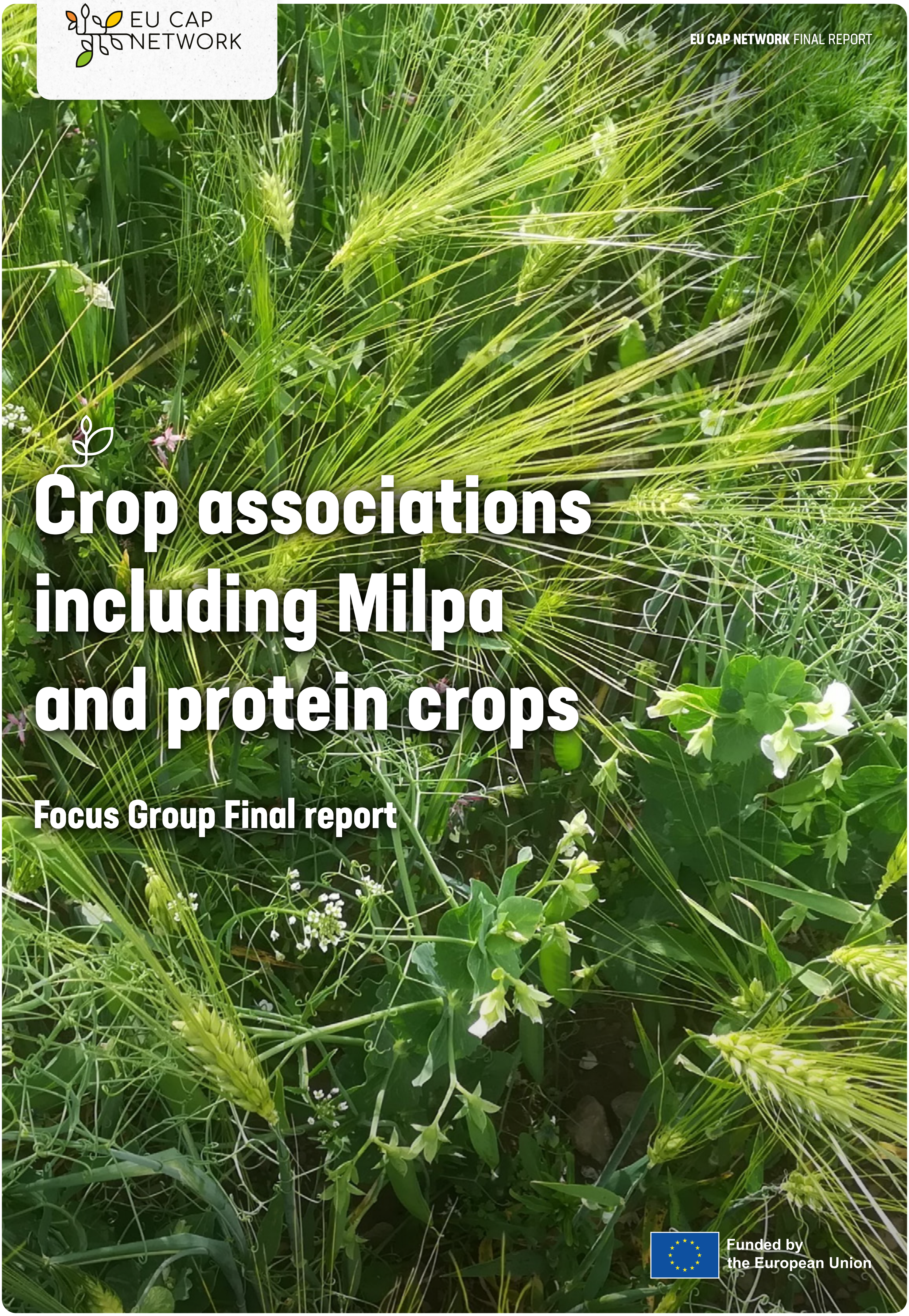

Crop associations including Milpa and protein crops

Focus Group Final report

Funded by the European Union

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Executive summary

The EU CAP Network Focus Group on Crop Associations addressed the question '**How to integrate crop associations into existing cropping systems and farm landscapes to increase farm resilience and efficient use of natural resources while reducing the dependency on external inputs?**'

An analysis of published literature and reports identified **at least 90 crop association types** practised in arable, horticulture and agroforestry systems across the pedoclimatic zones of Europe. These included crop associations grown traditionally or reinvigorated for current systems in Europe, and new crop associations suitable for adapting to changing climatic and market conditions. Good practice examples included strip cropping, cover crops, forage/fodder crops, intercropped protein crops, agro/silvo-pastoral systems, and using crop associations as a 'precision cropping' tool. Crop associations were perceived to provide specific ecosystem services, such as greater biodiversity, improved pest control, and soil fertility, although the impacts on air and water quality were less understood. The economic outcomes were uncertain, although fewer agro-inputs, improved yield stability, and increased land use efficiency are often reported and have the potential to increase profitability.

Success factors of implementing crop associations included their potential for reducing external inputs, diversifying the farm business, increasing income from subsidies, using land more efficiently, and spreading the farming workload throughout the year. Agronomic, economic and social **barriers to uptake** included the perceived additional complexity of managing diversified cropping systems, and potentially higher costs and labour, creating reluctance to invest effort when returns are uncertain.

Innovative practices or mechanisms to overcome the challenges of crop associations and encourage uptake included novel ways to:

- **Mechanise crop associations** by making use of existing equipment, with machinery adaptations as and where needed, and also by tapping into the practical experiences of others engaged in crop mechanisations
- **Adapt breeding and variety testing schemes to test mixing ability** that allow suitable plant cultivars and varieties to be identified
- **Add value to crop association produce** to increase economic viability
- **Introduce crop association practices gradually** using practices that provide 'stepping stones' in the transition from monocrops
- **Seek out existing knowledge** from a variety of information sources using systematic search strategies

Needs from research and practice focused on developing basic principles for growing crop associations, selecting crop varieties suited to crop associations, making equipment affordable and accessible, and developing markets for crop association produce. Popular **ideas for operational groups** were the testing of mobile seed cleaners and separators, developing agronomic protocols for specific crop associations and novel digital tools for information sharing, and participatory evaluation of crop varieties for crop association mixing ability in national testing schemes.

1. Introduction

This report is a synthesis of the work of the EU CAP Network Focus Group on Crop associations, including Milpa and protein crops (FG). The group was launched in November 2023 and brought together 19 experts from across Europe to address the question:

'How to integrate crop associations into existing cropping systems and farm landscapes to increase farm resilience and efficient use of natural resources while reducing the dependency on external inputs?'

The FG members met for the first time in Vienna, Austria, on 28-29 November 2023 to share experiences of crop associations in practice, identify crop associations already in use, their benefits, and the challenges they face. The FG characterised the main issues for adopting crop associations at the farm level and what needs to be done to enable their wider use, which also informed the selection of topics for specific Mini Papers.

A discussion paper was prepared before the first meeting, which provided an overview of crop associations documented in recent EU-funded projects as an initial inventory of crop association types. It included information about published evidence for environmental and economic outcomes from crop associations, and highlighted knowledge gaps in the scientific literature.

At the meeting, the Focus Group participants contributed to activities designed to respond to the first three tasks of the FG and provide preliminary information for the fourth task:

1. identify, describe, and classify with adequate examples existing or new plant associations adapted to each farming system within their landscapes and local/regional conditions
2. analyse the impact of the most promising crop associations on the environment, on the farmers' productivity, profitability, and resilience to climate change
3. identify their success and failure factors and barriers for implementation and adaptation in different regions
4. explore the role of innovation and knowledge exchange in addressing the challenges identified such as crop selection, crop rotation management, machinery, and product end-use
5. propose potential innovative actions and ideas for Operational Groups to stimulate the use and improvement of crop associations at farm level considering the impact on the landscape
6. identify needs from practice and possible gaps in knowledge related to crop associations which may be solved by further research

The second FG meeting, held in Toulouse, France, on 29-30 May 2024 focused on the presentation and discussion of the Mini Papers, and activities to address tasks 4 to 6 of the FG, including field visits to two farms nearby where crop associations have been successfully integrated into cropping systems and value chains. The first farm, run by a couple who farm organically, grows a range of annual crops in monocrops and species mixtures for seed. They grow, separate and clean the seed using a variety of equipment including an optical seed sorter, which they bought with support provided by new farming entrant grants. They occasionally sort seed for neighbouring farmers. The second farm, also an organic family farm, grows several annual crops as intercrops, also incorporating fruit trees. They have a specific focus on producing heritage barley, intercropped with faba bean, for malting and beer production in their own brewery.

2. Crop associations characteristics

European cropping systems are dominated by specialised farms growing simplified crop sequences, frequently based on cereals or grasslands (>60% crop sequences). This simplification of cropping systems based on high input monocultures, consisting of a small number of crop species, has contributed towards environmental degradation and biodiversity losses in agricultural landscapes.

Crop associations can increase crop diversity within a field, not only to provide resources for wider agrobiodiversity, but also to improve crop productivity, regulate pests and diseases, increase soil fertility, and reduce pollution through decreased use of pesticide and fertiliser inputs.

2.1. Defining crop associations

There is no single definition of crop associations, but crop associations include a collection of cropping practices where two or more species are grown together in different spatial and/or temporal arrangements for a range of purposes. Crop associations are often a key component in agroecological farming practice. Five broad groupings can be defined: **Intercrop**. Cultivating two or more cash crops simultaneously on the same piece of land, either as a homogeneous mixture or in alternate rows. Includes **relay intercrops**, where the life cycle of one crop overlaps that of another crop but the crops are not entirely synchronised (due to differences in the timing of sowing and/or harvesting).

Lentil-barley intercrop

Strip intercrop. Different crops are planted in alternating narrow strips.

Wheat-bean strip crop

Companion crop. Planting of different plant species together for various purposes (e.g. pest repellence, pollination, weed suppression) to support the productivity of a focal cash crop. Can include **nurse crops** (planted to shelter another species), '**push-pull**' species combinations and **trap crops** for pest management, and **cover or catch crops** used to conserve soil by preventing erosion, store/release nutrients etc.

Multi-species cover crop

Milpa. Traditional polyculture system (e.g. maize-beans-squash) from Mesoamerica aiming to maximise food production from small land holdings.

Milpa

Agroforestry. Combinations of trees or shrubs grown as perennial mixtures or around or among agricultural crops and/or animals and pasture. Includes **alley cropping**, **Dehesa** oak pasture, and the '**vinha do enforcado**' (or 'hanging vineyard') method of growing grapevines in Portugal and Spain, and could be expanded to include **multi-species hedgerows**.

Olive-cereal agroforestry

Typical crop arrangements in Europe, based on the experience of FG experts, depend on the crop association type (Annex 1: Supplementary Figure 1). Alley cropping is usual for agroforestry. Grain crops and crops grown for biomass, fibre, or forage are often grown as unstructured mixtures or as strip crops (grain crops), or in alternating rows (biomass/fibre/forage crops). Horticulture crop associations are grown in many different structural arrangements.

2.2. Inventory of crop associations in Europe

The range of potential crop associations is limited only by the number of crop species that are available and capable of being grown in a country or pedoclimate zone. Common or novel crop associations used or tested by farmers and researchers in Europe were collated from reports and practice abstracts published by recent Horizon 2020-funded projects on intercropping and crop diversification (DIVERSify, ReMIX, DiverIMPACTS, Diverfarming), agroforestry (AFINET), and weed management (IWMPRAISE). The information was supplemented by information about crop mixtures grown in Europe reported in Li et al (2023) and on the websites of recently funded Horizon Europe projects (IntercropVALUES, LEGUMINOSE, ReForest, AF4EU, MIXED, AGROMIX and DIGITAF). The crop associations identified through this process were grouped by crop type: perennial/agroforestry; annual fruit and vegetable crops; cereal and legume crops; pseudo-cereal and oilseed crops; and other multi-species mixtures (respectively described in detailed lists in Supplementary Tables 1-5: Annex 1). The country where the crop association was reported was assigned to a pedoclimatic region, as an indication of other countries where it might be suitable for growing (as shown, for example, in the latitudinal distribution of crop sequence types identified by Ballot et al., 2022).

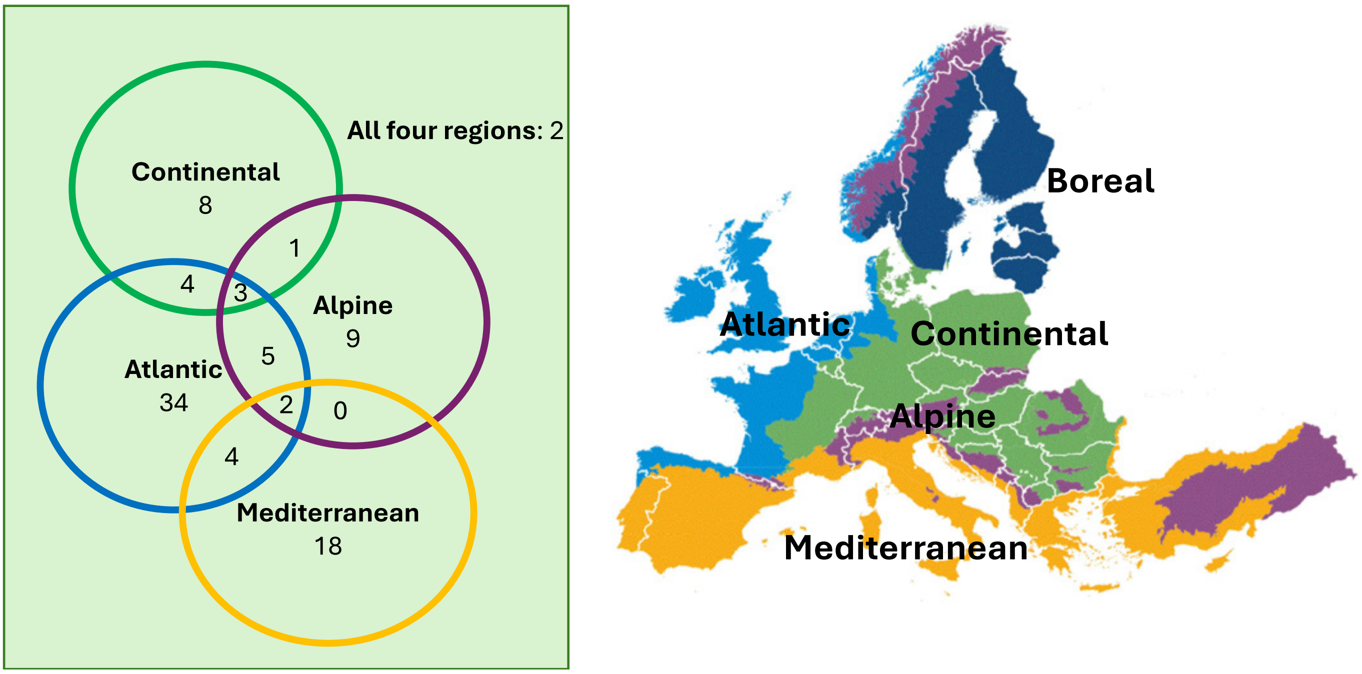
Crop associations are practised in arable, horticulture, forage/grassland and agroforestry systems distributed across the pedoclimatic zones of Europe (Figure 1, Annex 1: Supplementary Tables 1-5). The choice of crop association is often driven by the farmer's need to address certain agronomic issues; as a result, it has been a cropping practice more commonly linked with organic and other low-input farming approaches, where agrochemical inputs cannot be used or are not cost-effective.

2.2.1. Agroforestry

Although less common than in the past, traditional agroforestry systems are still practised widely in Europe, such as grazed woodland and grazed or intercropped orchards. These often centre on fruit trees or grapevine and are diverse in composition, such as: silvo-pastoral (e.g. oak trees with annual or perennial pasture); silvo-arable (e.g. walnut or almond trees grown with cereals or legumes); herbaceous understories (e.g. aromatic herbs or cover crops under grapevine); and perennial mixtures (e.g. intercropped fruit trees).

Figure 1. A summary of the frequency of different crop associations reported in pedoclimatic regions of Europe, indicating the number of combinations shared between regions

See Annex 1 (Supplementary Tables 1-5) for detailed lists of different crop association types and the pedoclimatic zones where they have been reported. Derived with authors' permission from Magnolo et al (2021).



Images sourced from the image library of the James Hutton Institute, UK
Source: European Environment Agency (2017)

2.2.2. Annual crops

Crop associations involving annual fruit crops, vegetable crops, oilseed crops, cereals, and legumes are reported for many parts of Europe; these can involve cash crops grown as intercrops harvested together or separately. Alternatively, it might involve a cash crop grown with a companion crop to control weeds or pests, or with living mulches to increase soil fertility, or with insectary plants to attract pollinators and the natural enemies of crop pests. Crop associations based on cereal or legume intercrops, or strip crops, are frequently documented by farmers and researchers, often grown as cereal-legume mixtures. Pseudocereals (e.g. buckwheat, Sorghum) and oilseeds (e.g. oilseed rape, linseed, sunflower) are gaining interest as intercrop components.

2.2.3. Biomass crops

Intercrops used for animal forage and fodder, or for ecosystem services such as reducing soil erosion and nutrient losses, are moderately popular across Europe. These often comprise grasses or cereals (or pseudocereals) grown with legumes and/or brassicas, sometimes in multi-species mixtures. They are usually harvested, destroyed, or grazed in the vegetative phase of growth.

2.2.4. Novel crop associations

Novel crop associations for Europe are emerging from research and experimentation by farmers. Sorghum, which is more typically cultivated in tropical countries, has been reported as a combination with faba bean and in multi-species mixtures in Austria. Other non-European crop species included Chinese quince (*Pseudocydonia sinensis*), Chinese mahogany (*Toona sinensis*), and bamboo as agroforestry components, and broom (*Cytisus* sp.) as a nurse shrub for immature trees.

Aromatic plants are being rediscovered as crop association components due to their ability to deter pests (e.g. *Tagetes* sp. with vegetable crops), attract beneficial insects (e.g. *Alyssum* sp. with watermelon), or both (oilseed rape grown with fenugreek, buckwheat, and clover). Aromatic plants are also used as intercrops for herbal teas (e.g. Common yarrow with faba bean) or grown for aromatic oils (e.g. lavender grown with oak trees for truffle harvesting).

Unusual intercrop pairings include barley grown with poppy (for food use), melon with cowpea (typically a tropical legume crop), and potatoes strip-cropped with grass/clover (for pest control). Milpa-type crop associations, such as maize grown with common bean, scarlet bean, or squash, are reported occasionally in Europe, and might represent a novel crop association for some regions.

2.3. Environmental and economic outcomes

2.3.1. Ecosystem services

Images sourced from the image library of the James Hutton Institute, UK

Crop associations increase plant diversity in agricultural systems, and the crop components can provide specific biological functions, both of which have direct and indirect effects on ecosystem service provision. There is evidence that crop associations support **increased species richness** of beneficial arthropods (predators, parasitoids, pollinators) and birds, which provide regulating and supporting ecosystem services such as pest control, and fruit and seed set.

Weed suppression is often a motivation for growing crop associations in low-input farming systems, as increased crop diversity reduces the amount of light and nutrients available for weeds and dilutes host availability for parasitic weeds. Improved **pest and pathogen control** is often reported in diverse crop stands. Decreased pest abundance and damage frequently correlate with higher abundances of predators and parasitoids known to provide biological control of arthropod herbivores.

Cover crops and perennial crop associations have been shown to increase **soil organic carbon** and carbon stocks and can variably affect **soil nitrogen availability**. The effects of crop associations on **air and water quality** are, however, less frequently studied.

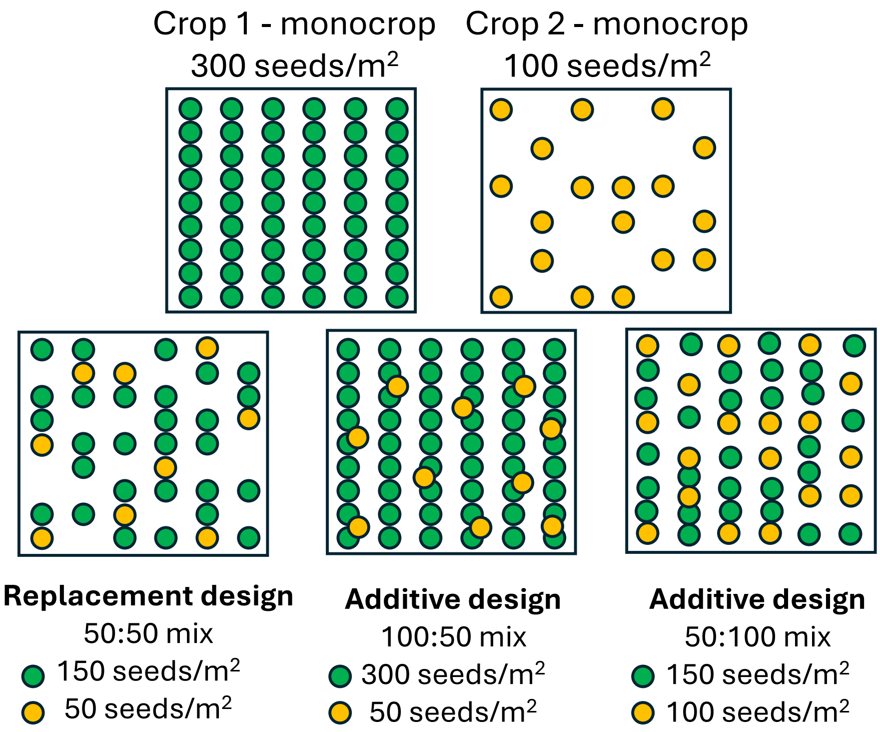
2.3.2. Productivity and profitability

Increased land use efficiency (e.g. measured as Land Equivalent Ratio[1]) of 20-30% is often reported in annual and perennial crop associations, along with increased relative yield (i.e. yield that has been adjusted to account for different sowing densities in mixtures vs. monocrops). Replacement designs can be more effective than additive designs (Figure 2) for increasing yield above the values expected from monocrops. Transgressive over-yielding is rarely reported, which means that the intercrop yield is typically less than the most productive crop component grown as a monocrop.

[1] LER values indicate the amount of land area using mono-cropping needed to produce the same yield as the intercrop (LER>1 indicates more yield is produced per unit land area than monocrops).

Figure 2. Visual illustration of replacement (or substitutive) and additive designs for crop associations involving two crops

Crop 1 could represent a cereal, such as barley, and Crop 2 could represent a legume, such as pea. Replacement designs do not increase the overall crop density, while additive designs lead to higher total crop density, compared with the monocrop densities of the constituent crops.



Source: European Commission.

The contribution of crop associations to **farm profitability** is less well described and depends both on marketable yield (crop quality) and on other costs: for example, whether crop associations can reduce the use of fertiliser and crop protection products, whether they affect fuel consumption in field operations, and whether more farm labour is needed to grow and harvest the crop.

2.3.3. Resilience

Yield stability of legume crops can improve when they are intercropped (e.g. with cereals). This outcome depends on the legume species, the spatial design (replacement designs are more stable than additive designs), and growing conditions (yield stability is higher in more productive growing conditions). In areas where harsh growing conditions are more frequent (e.g. extreme drought or heat), crop associations can **reduce the risk of crop loss** if at least one crop in the association tolerates the extreme conditions.

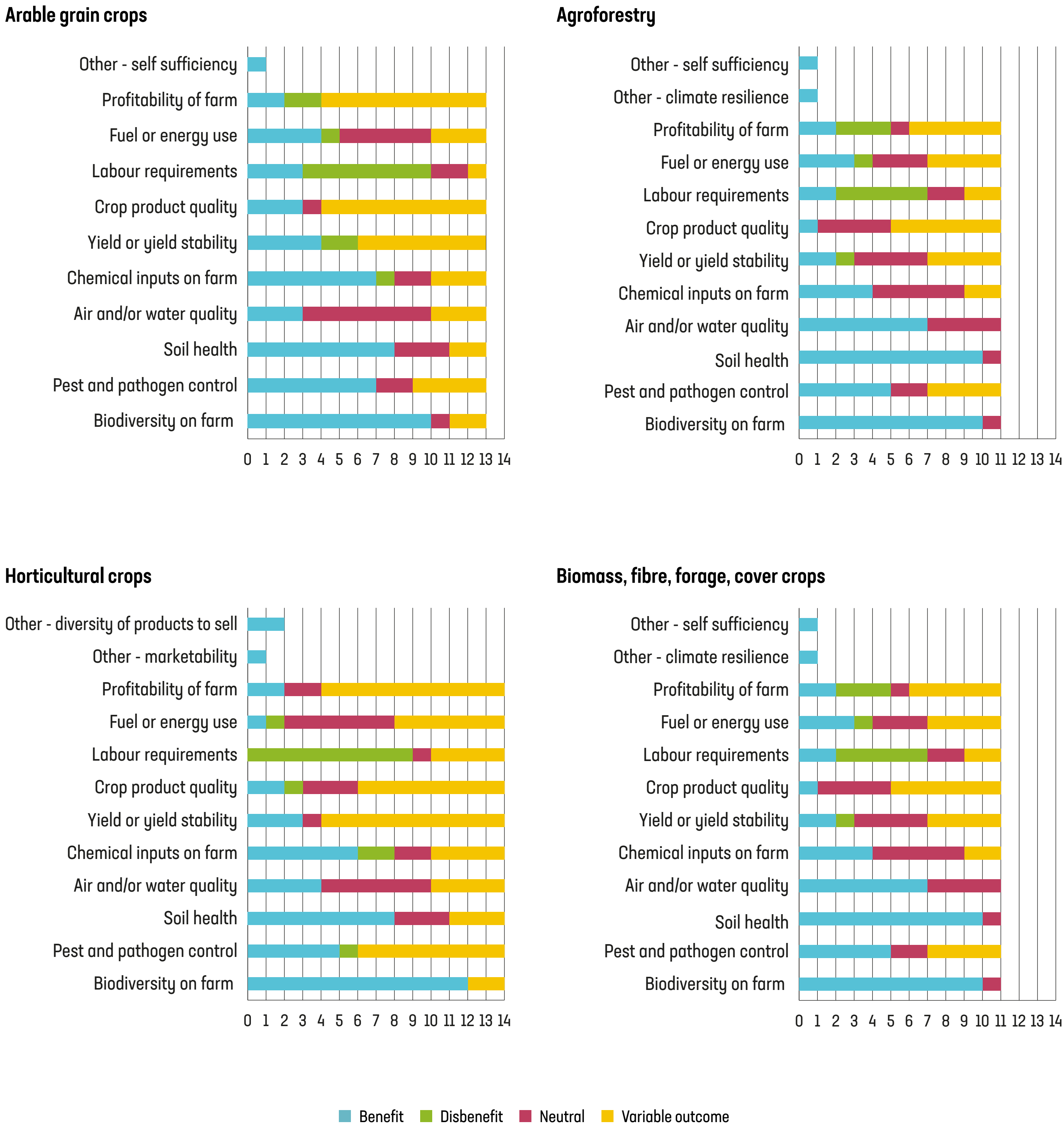
2.3.4. Promising crop associations

FG experts scored crop associations highly for environmental outcomes such as greater biodiversity and improved soil health (all crop types); better pest and pathogen regulation and reduced chemical inputs (arable grain crops); and improved air and water quality (agroforestry). Across all crop types, crop associations were considered to have variable outcomes for crop yield, yield quality, yield stability, and farm profitability. Labour requirement was considered a negative aspect of crop associations (Figure 3).

In general, FG experts were more confident about assigning scores to the environmental outcomes of specific crop associations than outcomes relating to productivity, profitability, and resilience: this is shown by the higher number of scores assigned for the former outcome compared with the latter outcomes (Annex 1: Supplementary Table 6). Overall, crop associations were perceived to offer strong environmental benefits and moderate resilience benefits, especially agroforestry and companion crops. Limited benefits of crop associations were perceived for productivity and profitability, with agroforestry and annual intercrops scoring highest (Annex 1: Supplementary Table 7).

Figure 3. The number of respondents (out of 14) scoring benefit (green), disbenefit (red), neutral (grey), or variable (yellow) outcomes for a range of environmental and economic outcomes of crop associations involving annual and perennial crops

Note that some respondents did not score every outcome for all crop association types (therefore n varies between 1 and 14).



Source: European Commission

3. Good practices

Several examples were highlighted by FG experts showing how crop associations could be integrated into mainstream farming.

3.1. Strip cropping

Image supplied by Stockbridge Technology Centre, UK

Growing different species in strips, alleys, or alternate rows can avoid some of the practical challenges of sowing and harvesting different crops in association, while still allowing some benefits of growing crops together. Strip cropping is relatively easier to mechanise (or even robotise) than are intercrops and companion crops, with wide strips managed using standard machineries, offering a halfway house between mono-cropping and intercropping. Strip cropping allows farmers to continue to grow monocultures, use existing equipment, and begin to see the benefits of diversity on their own farm. Cultivar mixtures provide another stepping stone between monoculture and mixed species cropping.

3.2. Forage and cover crops

Forage crops are easy to harvest, and growing them as crop associations can improve silage quality. The same is true of grain intercrops used for feed, for example intercropped barley or wheat with pea or faba bean, removing the need for grain separation after harvest. Crop associations grown as cover crops, green manures, and living mulches are already quite widespread and represent a practice that can be more readily adopted by farmers without making significant changes to their existing cropping systems. Cover crop planning calculators, such as the Green Cover Seed tool in the USA (https://smartmix.greencoverseed.com/), can be powerful tools to help farmers plan cover crop mixtures based on their goals, location, and budget. This type of tool engages farmers and facilitates their goals, while also teaching them about cover crops, and can help make crop associations easier to adopt.

3.3. Protein crops

Image provided by AJ Karley, James Hutton Institute, UK

High-risk crops with unstable yields, such as grain legumes, can be less risky when grown as intercrops due to reduced lodging and disease and increased yields in the crop association. This includes legume-cereal, legume-oilseed, and legume-legume intercrops (left). With the increased need to grow protein crops in Europe, crop associations could favour the production of home-grown legumes.

3.4. Precision cropping

Finally, crop associations can be viewed as a means of dealing with problematic areas on the farm, as a type of precision farming to cope with areas prone to waterlogging, drought, or weed issues. These areas of land might be regarded as low-risk and provide an area for experimenting with alternative cropping approaches.

4. Success factors and barriers to the adoption of crop associations

4.1. Success factors

The **strengths** and **opportunities** offered by different crop associations to improve success in their implementation are summarised based on the experiences of FG experts.

Image sourced from the image library of the James Hutton Institute, UK.

Decreasing reliance on external inputs, particularly fertilisers and crop protection chemicals, is a key success factor for encouraging the adoption of crop associations. Incorporating nitrogen-fixing plant species reduces the amount of synthetic nitrogen fertiliser required for other annual and perennial species in crop associations. This can be enhanced further by using cover crops and green manures to preserve soil, retain or increase soil nutrients, and improve soil water management during fallow periods. Pest and disease incidence, and pesticide use, can be reduced by using deterrent companion crop species, or species that attract natural enemies of crop pests, or crop combinations that create a barrier to pest and pathogen movement. In the latter case, barriers might operate at a large enough scale to encourage collaboration between neighbouring farms to introduce crop associations into appropriate parts of the landscape. Reducing inputs could bring economic benefits to the farm.

Increased access to subsidy schemes can result from using crop associations to qualify for agri-environment or other (e.g. protein crop) measures, which in turn improves profitability. Crop associations could offer **market opportunities through certification options** to improve economic returns. Examples might include agroforestry that delivers better animal welfare, cover or companion crops that support greater biodiversity, or cover crops or agroforestry systems that feed into carbon markets. Direct marketing of additional products from crop associations might be an option in some cases. Milpa offers a unique traditional cropping system that could be promoted through local markets, community initiatives, and social enterprises, which might favour wider adoption in the farming landscape. Crop associations create opportunities to diversify farmed products and the markets they are sold into, and therefore **diversify the farm business**, which potentially **increases resilience** to external shocks.

Image provided by AJ Karley, James Hutton Institute, UK

Cover crops grown in fallow periods and companion crops grown alongside a cash crop create opportunities for **multi-functional land uses** that can bring multiple benefits. This might include autumn grazing of an undersown cereal crop, a winter-sown cereal crop providing protection to establish a spring-sown crop, wildflower strips sown into machinery wheel lines and furrows providing resources for biodiversity, or cover cropping to increase soil organic matter. Crop associations create **a mechanism for using land more efficiently** and allowing secondary uses of a single area of land, freeing up remaining farmlands for other activities and landscape diversification. Further, this could improve the aesthetic appeal of agricultural landscapes and increased public acceptance of potentially contentious land uses (e.g. biofuel crops grown with food crops, solar panel fields undersown with herbal mixtures).

Growing associations of crops with different maturity timings and management needs could provide opportunities to **spread the farming workload** over a longer period, which might increase the efficiency of machinery use. For example, relay intercrops can be designed to fit into the existing cropping calendar of the farm. **Farmer support networks** linked to field days and demonstrations could be an effective way to share experience and advice between farmers and other stakeholders; for example, to understand how existing machinery can be adjusted to intercropping or where there are opportunities to share or borrow specialised equipment. Farmer collectives or co-operatives might be able to work collaboratively to deliver landscape-scale ecosystem services or develop infrastructure for post-harvest processing of regionally specific crop associations.

Image provided by AJ Karley, James Hutton Institute, UK

4.2. Barriers to uptake

FG experts from northern Europe (Sweden, Finland, UK, Ireland, Netherlands), central Europe (Germany, France) and southern Europe (Spain, Italy) considered that agroforestry, horticulture, and grain crop associations are rarely practised in most regions (Annex 1: Supplementary Figure 2A). Non-commodity crops, grown for biomass, fibre, forage, or as cover crops, are more likely to be grown as crop associations. These responses indicate that crop associations are not currently attractive as a cropping practice.

Reasons why farmers might not choose to grow crop associations (Annex 1: Supplementary Figure 2B) can be broadly grouped into agronomic (including supply chain), economic, and social barriers.

Image provided by M Cooper (Ian Cooper & Partners, UK)

Agronomic issues involve knowing what to grow and how to grow it, the availability of suitable inputs (seed, fertilisers, crop protection products), and whether crop associations can be implemented using existing farm equipment. The farmer or their advisor might not have sufficient knowledge to adapt machinery to sow or harvest multiple crop types, or select appropriate crops and varieties, especially for matching harvest/maturity times. Crop management guidelines and input recommendations are typically geared towards monocrops, and there is a lack of plant protection products suited to multiple crop species, all of which can prevent a move away from monoculture cropping.

Image provided by Lars Egelund Olsen (Landbrug & Fødevarer F.m.b.A., SEGES, Denmark) and Visti Møller (Buurholt, Denmark).

Economic barriers can arise from a trade-off with economic returns. This might happen because crop associations are less productive in the short term (i.e. due to agronomic issues, or time for establishing perennials). Alternatively, the market might demand product purity, but separation is costly and there are no facilities to collect and purify crop components. Any requirement to invest in specialised machinery, or an increased number or more complexity of operations, represents a financial risk if crop marketability and economic returns are not guaranteed. Further, regional policies might prevent certain crop association practices (e.g. growing trees on cropland) while favouring monoculture crops (e.g. land only allowed as pastureland). This could prevent crop associations from being incorporated broadly into farming landscapes. Finally, there is a lack of subsidies to de-risk the adoption of crop association practices.

Social considerations include the cultural acceptability of different cropping practices that may 'raise eyebrows' amongst the local farming community, where it might be expected that crops should be grown as homogenous monocultures in 'clean' weed-free fields. Alongside this, planning and executing crop associations can be time-consuming, and might not be an efficient use of staff time given that farm labour availability (and affordability) is often a limiting factor.

5. Innovations and opportunities to improve uptake

5.1. Challenges to overcome

The barriers to adoption identified above coalesce into three related challenges associated with crop associations, which affect their attractiveness to farm practitioners.

Diversity creates complexity. Growing and managing crop associations involves the same agronomic uncertainties of monoculture crops (weather and other external factors), but the additional complexity of crop associations increases the uncertainty and perceived risks. Having more diverse crops means more to consider in terms of variety choice, crop establishment, the range of potential pests and diseases, field machinery operations throughout the growth and harvesting period, and labour availability.

Complexity increases costs. Greater diversity in the crop could increase costs for seed purchase, additional machinery passes, or purchase/hire of specialised machinery to grow or purify the harvested crop; this is especially true when machinery is not available for purchase locally and must be sourced from further afield. More time might be needed to plan and implement crop associations, and the return on effort and investment might not be realised within an acceptable period.

Uncertainty creates reluctance. A lack of knowledge amongst farmers and independent advisers increases the uncertainties about the balance of costs and benefits of this cropping approach, especially for agroforestry, which takes years to establish and return profit. Further, it might not be straightforward to fit crop associations within regional regulatory schemes.

5.2. Innovations and levers

FG experts identified a multitude of ideas to address the main challenges (above) of realising crop associations at the farm level and in the wider landscapes. These ideas were grouped into five key topic areas that form the basis of the Mini Papers (Table 1). Knowledge transfer, training and education were acknowledged as cross-cutting themes of these topics.

Table 1. List of the Mini Papers and the issues they address

Mini Paper themes	Key issues
Mini Paper 1: Cultivar testing as a key to boost uptake of crop associations in breeding and farming	Which commercially available cultivars of target species, and which crop traits, will give the best outcomes when selecting and breeding crops for crop associations, and how can they be identified?
Mini Paper 2: A value chain perspective on crop associations	What mechanisms can be used to increase the uptake of crop associations in value chains?
Mini Paper 3: Integrating crop associations into farming systems	How can crop associations be readily integrated into the wider farming system? What are the main considerations?
Mini Paper 4: Crop association practices: where and how to find them?	How can land managers find out more about crop associations' practices?

Source: European Commission

Based on practical experiences discussed at the FG meetings and ideas presented in the Mini Papers, a suite of innovative practices or mechanisms were identified to overcome the challenges of crop associations and encourage uptake. More information can be found in the source Mini Papers.

Make use of existing equipment, with adaptations where needed, to mechanise the husbandry of crop associations (source: Mini Paper 1)

The mechanisation of farming has been a key factor in creating efficiency in farming operations and reducing the demand for manual labour. Investment in machinery and crop storage facilities represents a significant financial outlay for farmers. Solutions include:

- Adapt existing machinery used for mono-cropping to handle multiple crops. The types of adaptations needed are likely to be specific to the crop association design and the available equipment, but some general principles can be derived by looking at specific examples on YouTube or other social media platforms. Mini Paper 1 provides links to videos showing how to adjust plough settings for different cultivation intensities, calibrate seed drill settings when sowing multiple seed types, calibrate fertiliser spreaders, adjust mechanical weeders for different crop growth stages and arrangements, and harvest strip crops.
- Take advantage of training opportunities available through machinery suppliers, co-operatives, and agronomy companies to allow farm staff to increase their familiarity with adjustments that can be made to existing farm machinery.
- Find machinery co-operatives/machinery rings or work with neighbouring farmers to share machinery or cooperate in buying specialised equipment.
- Work with contractors to carry out machinery operations that are not feasible with existing equipment, as long as contractors have a sound understanding of the crop association management needs (guidelines could be provided).
- Mobile small-scale equipment exists and can be rented for some operations, such as mobile grain separators and seed de-hullers, equipment for heat-treating, milling or pressing seed, and storing seed (e.g. using stacked crates in place of grain silos).

Use suitable plant cultivars and varieties (source: Mini Paper 1)

Choosing the best crop cultivars for crop associations is uncertain because there is limited information in seed catalogues about crop and cultivar mixing ability. Innovations to ease the process of genotype selection for crop associations are:

- Use information from cultivars tested in monocrops to guide selection. Certain plant traits can indicate their ability to be complementary with other plant types by avoiding competition for resources, and/or to support and facilitate the growth of other plants. These include traits for crop phenology (early versus late vigour, flowering and maturity timings), canopy dynamics (plant growth rate, height and spread), susceptibility to biotic and abiotic stresses (including allelopathy) and resource acquisition (ability to access different nutrient sources, for example by nitrogen fixation or root phosphatase release). Some of these key traits are reported in seed catalogues, and although the information is generally provided from monocrops, it is often a suitable, if approximate, indicator of mixture performance.
- Participate in, or make use of information from, informal cultivar testing schemes, such as those conducted by universities, research institutes, or farmer experimentation. Mini Paper 2 gives two examples of successful participatory approaches to crop and variety testing using Living Labs: i) the UK Innovative Farmers Network to test arable crop cultivars on-farm in organic or alternative management approaches; and ii) the DiverIMPACTS project where crop cultivars were tested on farms in multiple European countries to assess their performance in crop associations. Additional sources of information include seed cooperatives, community seedbanks and other seed-sharing initiatives (see, for example, the DIVERSIFOOD project).
- Make use of existing digital tools created to share data from research or on-farm trials testing varieties of different species for crop association suitability. An example is DIVERSIplotter (https://ics.hutton.ac.uk/diversify/#/) developed from the Horizon 2020 project DIVERSify. These tools can be located through targeted online search strategies (see below).
- Include mixing ability in formal and informal cultivar testing and registration schemes. Cultivars are not typically assessed for this characteristic, except in certain cases, such as the selection of clover-grass forage mixtures in Switzerland (described in Mini Paper 2). A key finding from scientific studies is that cultivar evaluation for crop associations is important only when the focal species tends to be outcompeted because of its intrinsically low competitive ability or the adopted crop management. Further, the 'general mixing ability' of a crop cultivar tends to be higher than the 'specific mixing ability', indicating that only a few combinations need to be tested for crop mixing ability. Mixing ability is greatly affected by the growing environment, indicating that multi-site trials and/or management conditions are necessary. Incomplete factorial trial designs are recommended to make efficient use of field space and staff time in running mixing ability variety testing trials.

Add value to crop association produce to increase economic viability (source: Mini Paper 2)

Farmers will be more willing to grow crop associations if there is sufficient demand and/or if the value of crop association products is high. Crop associations are, however, typically grown for low-value products such as animal forage or feed.

To overcome this barrier, solutions are proposed that create demand for, and value-addition to, crop association produce.

- Undertake collaborative consultation with end users (processors, consumers) to raise awareness about crop associations and assess their needs in terms of produce type, volume and quality. This allows the component crops of crop associations, and how the crops are planted in different spatial arrangements, to be chosen for a pre-defined market; and ensures that they yield the required volume of harvested produce. Strong examples are described in the Mini Paper where this approach has been successful for herb/flower and vegetable produce in The Netherlands, and for grains and hops used in beer production in France.
- Access certification or good practice schemes recognising the environmental and social benefits from crop associations. A valuable example is the scheme used for shade coffee production, which could provide a template for certifying other crop associations, providing there is evidence to back up the certification claims.
- Take advantage of government-supported initiatives that can be achieved using crop associations. An emerging example of value addition to crop associations is the increasing use of wheat-legume mixtures for protein-rich pasta, supporting policy goals in agriculture and human health for increased plant protein production and consumption.

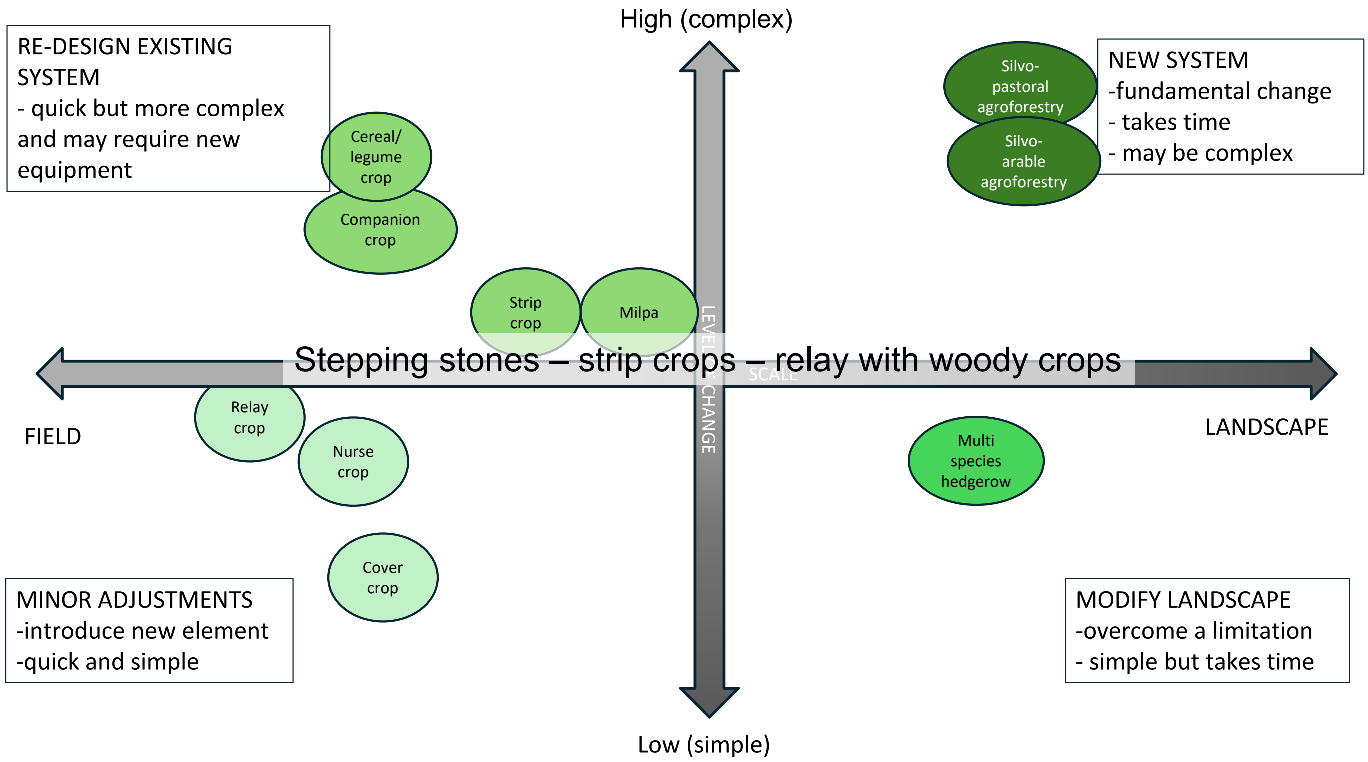
Introduce complexity one step at a time (source: Mini Paper 3)

There is a gradient in the complexity of crop associations, depending on the goal (product or service) that is to be achieved using crop associations and the scales at which they deliver benefits (field to landscape). The degree of complexity in integrating crop associations into cropping systems is affected by whether crop selection needs to be adjusted within the cropping sequence (pre- and post-crop association), the type and level of inputs and machinery required, and labour needs through the cropping cycle and farm calendar.

By classifying crop associations according to their biophysical complexity (based on the number of crops and how much they differ in their growth habits, lifespan and agronomy) and the spatial-temporal scale of operation (whether the crop association is practised at field, farm, or landscape scale, and over one or several growing seasons) (Figure 4), land managers can deduce how readily they can implement a specific crop association of interest or identify simple crop associations that are 'stepping stones' in the creation of more complex farm systems. Examples of these stepping stones include:

- Add a new component to existing field crops, such as a trap crop to intercept insect pests. The Mini Paper provides as an example the use of winter cress, planted around cruciferous crops, as a dead-end trap crop for diamondback moth.
- Substitute a single species cover crop (e.g. ryegrass) with a multi-species cover crop mixture (e.g. adding in legumes or mustards), which has the potential to provide more diverse functions than a single species crop stand (e.g. protect from erosion, trap/add/mobilise nutrients, add organic matter, increase moisture retention, break up and aerate compacted soil).
- Grow cereals and legumes as intercrops to improve crop quality with less fertiliser. Cereals and legumes are complementary in their growth habit and resource use, especially climbing legumes such as peas, grass peas, and lentils, which perform better when given structural support from a cereal 'scaffold'. Less nitrogen fertiliser is needed because legumes fix atmospheric nitrogen, allowing cereals to take up more of the soil mineral nitrogen, and these processes can lead to higher grain nitrogen concentrations compared with monocultures (higher protein can add value to the grain – see above). The intercrop is better than monocrops at covering the ground, starving weeds of sunlight for growth. Spatial arrangements can vary from simple (strip or row intercrops) to more complex (within-row mixtures), allowing the level of complexity to be selected according to the practitioner's knowledge and preference.
- Use strip crops to simplify the mechanisation of crop associations while retaining some of the benefits of intercropping. Growing crops in strips equivalent to the working width of existing seed drills, spray booms, and combine harvesters allows different crops to be grown side-by-side without the need for new or specialist machinery: each strip can be managed separately. Strip cropping can reduce pest and disease incidence and can be aligned with topographical contours to minimise soil erosion and nutrient loss. Diversity at the field scale can be further increased by growing multiple crop types within a field, including spring and winter crops.
- Integrate perennials into relay intercrops as a step towards agroforestry. Agroforestry systems typically require more planning and commitment from land managers, and are often seen as more costly than other crop associations, although they offer an array of benefits at field, farm and landscape scales. One way to ease the transition into economically productive silvo-arable systems is to start the process with relay crops, by introducing perennials (e.g. perennial vegetables or fruit bushes) alongside annual crops. This allows income to be generated from faster-growing cash crops while slower-growing trees become established.

Figure 4. A schematic visualisation of how complex it is to establish crop associations and how they fit at different spatial scales (from Mini Paper 3), along with practices that provide 'stepping stones' from monocrops to crop associations



Source: European Commission

Seek out existing knowledge (source: Mini Paper 4)

Information about crop association combinations and practices is dispersed across different data sources and types. It is, however, possible to find reliable and useful practical advice using a structured search strategy:

- Define the practitioner needs by identifying the goal of using crop associations (i.e. is the aim to tackle an agronomic problem, improve an ecosystem service, or introduce new crops) and, therefore, 'asking the right question' in the search. This will help the practitioner to consider the scale at which the goal should be addressed (field vs. landscape) and the farm system characteristics (climate, soil, current crops and markets), which influence how the goal is achieved; and ultimately identify the keywords and terms to be used in the search.
- Interrogate a range of information sources, such as: i) other people (verbal conversations with existing networks, social media), ii) digital tools (from the scientific literature to artificial intelligence tools, search engines and data/media-sharing platforms) and iii) printed media; while being aware of the reliability and robustness of each data source. Many recent national and EU projects have developed searchable online databases (see Annex 2).
- Carry out small-scale tests to experimentally assess the search findings and use the results of these tests to inform further information searches in an iterative process.

6. Future opportunities and recommendations

Despite significant effort invested in understanding the outcomes from crop associations and how to implement them, several knowledge gaps were identified. The potential solutions or challenges to address these needs from practice and research are summarised into five main topics identified by the experts.

6.1. Needs from research and practice

The equitable balance of researchers and practitioners within the Focus Group allowed for a comprehensive assessment of where further work is needed to support crop association knowledge, implementation, and future innovation.

1. **Basic principles for growing crop associations**

To address the lack of standard advice on crop associations, agronomic recipes or guidelines need to be developed describing the basic principles of each crop association type with examples of how these basic principles are applied for specific crop combinations and pedoclimatic or market contexts.

2. **Innovation pathway to make mechanisation affordable**

Applied research is needed to develop innovative pathways for making equipment accessible and affordable, whether through adaptations to existing machinery, hiring contractors' equipment, sharing equipment, or looking at new technologies that create efficiencies. This includes economic analyses (i.e. cost-effectiveness of options) and developing business models, or taking advantage of rural development funding to ensure that such innovations are more economically viable.

3. **Guidelines on selecting crop varieties suited to crop associations**

To support decisions about which crop varieties to choose for crop associations, more needs to be known about the varietal traits that lead to better crop association performance, along with a better understanding of how these traits support the mechanisms underpinning crop association outcomes. Guidelines are needed on how to interpret existing information of pure stand variety trials for variety performance in crop associations. This might take the form of an app or online decision aid. Further development could include the inclusion of crop associations in variety testing trials to test varietal performance in these cropping systems, along with research to identify varietal traits that contribute towards better performance.

4. **Developing markets for crop association produce**

Market research should examine social and economic factors affecting the attractiveness and value of crop association products to processors, retailers and consumers, particularly their 'ecosystem service' credentials. To maximise their contribution to the farm business, crop association products should be evaluated for their nutrient content, the ability to process the produce, and contribution to dietary health, alongside their environmental credentials, ethical acceptability and profitability, as a means of adding value to produce. Consumer education is a key part of breaking down barriers to transformation and behaviour change along the supply and value chain.

5. **Novel research approaches**

Initiatives are needed that regularly bring together different actors for condensing and transferring their knowledge into research programmes. This might take place through multi-actor workshops, Living Labs, and participatory research projects that involve end users in the research process, thereby expanding the knowledge base, accessing a greater breadth of resources (e.g. crop landraces, trial sites) and translating results into real-world conditions.

6.2. Ideas for Operational Groups

The FG experts identified 13 ideas for Operational Groups, which are grouped into topics (Table 2). The highest-ranked ideas are highlighted.

Table 2. Ideas for Operational Groups identified by the FG experts

Topic	Operational Group proposal
Machinery for Crop Associations	› **Mobile trailers can supply equipment for short-term use on farm; mobile equipment for optical sorting, cleaning, and packaging could be tested on-farm for different types of mixed products and bag sizes.** › Develop guidelines for calibration, adjustment, and selection of equipment for crop associations according to the farmer's specific needs; adjusting existing equipment is particularly favoured as an option. › Identification of crop association components that are easy to separate with available machinery in multiple on-farm trials, where many farmers test 1-2 crop association combinations and share their experiences.
Crop association arrangements	› **Integrating perennial cereals into mixtures (e.g. with legumes) to identify the best sowing proportions and management methods (strip crop or intercrop) in different farm situations.** › Testing relay intercropping of winter cereals with summer crops in the Mediterranean area. › Integrating annual crops with permanent crops (specifically olive orchards) through trials, machinery adaptation, and producing basic principles for crop association use in these systems.
Improving market access	› Test whether crop associations (cover crop) plus integrating legumes can be used to extend perennial cash crop productivity. › Designing and testing a perennial agroforestry crop association system based on perennial vegetables (e.g. hosta) to ensure revenue is generated from year one, with a plan for the crop components to generate revenue steadily over the next 10-15 years. › Trial crop associations as a method to convert tobacco farms (a declining cash crop in Spain) into more environmentally-friendly production systems.
Climate resilient farming	› **Establish methods of creating and maintaining a mulch/litter layer over the soil using annual and perennial ground covers and test ways of establishing cash crops into this layer without soil disturbance.** › Evaluate the ability of established or known crop associations to cope with extreme weather events to determine if they can be used as practical strategies to cope with the changing climate.
Knowledge base	› **Develop a digital decision tree where farm conditions are entered and results returned about possible intercropping methods or crops that fulfil local/regional demands and conditions.** › **Test crop varieties for crop association performance by i) extending official testing schemes and ii) outsourcing trials to spread the additional workload (e.g. to research institutes and/or to farmers for participatory evaluation).**

Source: European Commission

7. Conclusions

In addressing the six tasks of the Focus Group, experts identified good practice examples and possible solutions to address the key challenges of adopting crop associations. A common message emerging from the FG discussions and Mini Papers included the fact that crop associations are more likely to be attractive, despite their potential complexity, if they provide a solution to an existing agronomic issue, enhance a desired ecosystem service, or allow a new crop to be introduced to the farm.

Finding cost-effective methods for implementing crop associations was considered key to their adoption by overcoming any additional costs resulting from greater complexity of crop operations. This includes balancing the mechanisation costs of crop growing, harvesting and cleaning, with costs from time investment in the planning process, and income from value-addition to crop association produce (i.e. compared with monocrop produce).

People involved in agri-food systems, and the knowledge they hold, emerged as the most significant asset for encouraging uptake of crop association practices. Local knowledge was clearly important when identifying low-risk crop associations (e.g. cover cropping, strip cropping, relay cropping) that fit readily into local supply chains and economies. More ambitious approaches, where crop associations can break new ground and disrupt lock-ins to existing commodity markets, are possible if knowledge can be shared between regional actors. This could occur through the Living Labs approach promoted by Horizon Europe and other funding sources, supported by digital infrastructure to preserve and make public the information from publicly funded projects.

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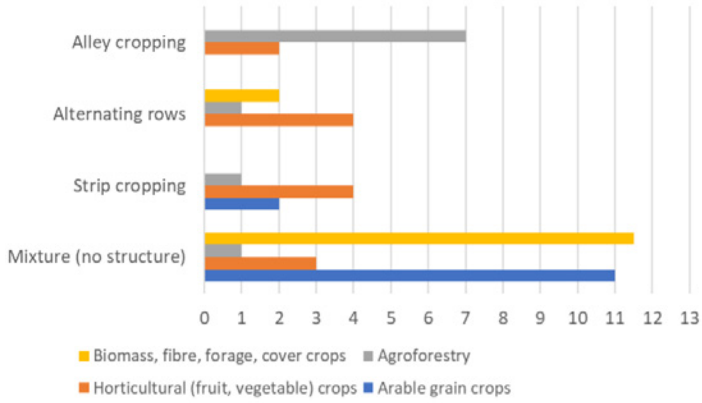
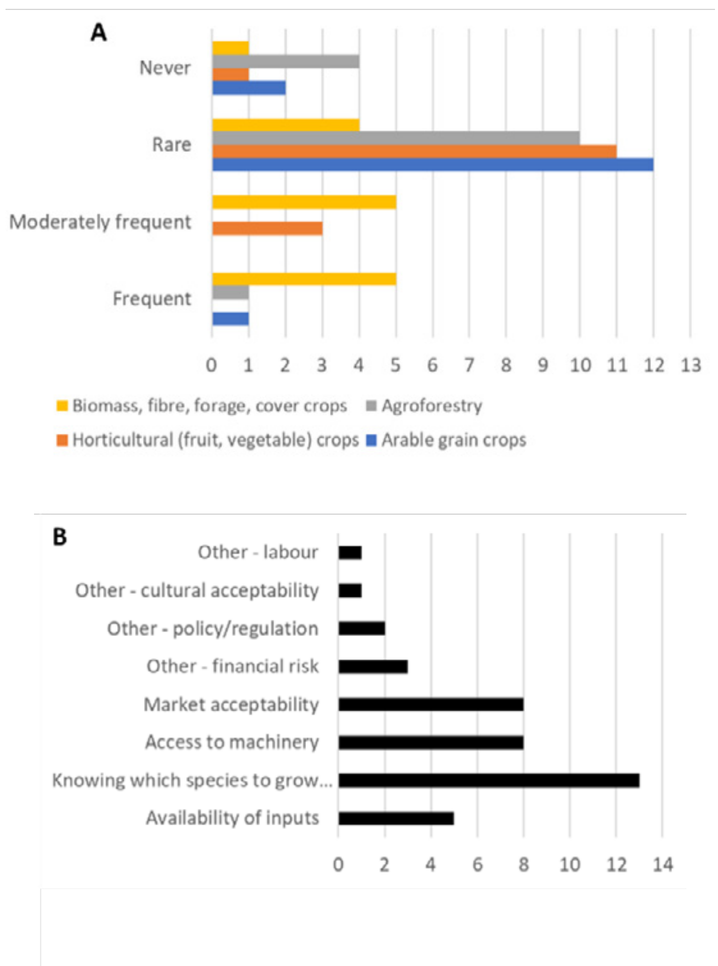
Annex 1: Supplementary material

Supplementary Figure 1. Frequency of different structural arrangements used for crop associations according to the experience of FG members



Supplementary Figure 2. (A) Frequency of practising different types of crop associations and (B) Reasons why farmers might choose not to grow crop associations, according to the experience of FG experts



Supplementary Table 1. Perennial fruit and agroforestry crop associations reported for different European countries and regions

Component 1	Component 2	Country	Region
Walnut (+grass/herb understory)	Vegetables	BE	Atlantic
	Maize	BE, ES	Atlantic, Mediterranean
	Faba bean	BE, ES	Atlantic, Mediterranean
	Wheat	BE, ES	Atlantic, Mediterranean
	Rye	ES	Mediterranean
	Clover-grass	UK	Atlantic
Grapevine	Herbs	DE	Continental
	Cover crops	HU	Continental
	Plane, Ash, Willow, Elm	PT, ES	Mediterranean
	Mulberry, Walnut	PT, ES	Mediterranean
Olive	Asparagus	IT	Mediterranean
	Oat-vetch	ES	Mediterranean
	Saffron	ES	Mediterranean
	Lavender	ES	Mediterranean
Almond	Oat	ES	Mediterranean
Mandarin	Purslane	ES	Mediterranean
	Faba bean	ES	Mediterranean
Poplar	Maize	FR	Atlantic
	Sulla-Ryegrass	IT	Mediterranean

Supplementary Table 2. Annual fruit and vegetable crop associations reported in European countries and regions

Component 1	Component 2	Country	Region
Broccoli	Vetch	ES	Mediterranean
	Clover	IT	Mediterranean
Cauliflower	Clover	IT	Mediterranean
Aubergine	Clover	IT	Mediterranean
Melon	Cowpea	ES	Mediterranean
Cabbage	Broccoli	ND	Global analysis
	White cabbage	ND	Global analysis
	Cauliflower	ND	Global analysis
	Onion	ND	Global analysis
	White clover	ND	Global analysis

Supplementary Table 3. Cereal- and legume-based intercrops in European countries and regions

Component 1	Component 2	Country	Region
Oat [1]	Triticale	FR	Atlantic
	Barley	UK	Atlantic
Barley [1]	Maize	FR	Atlantic
	Sorghum	CH	Alpine
Wheat [1]	Triticale	CH	Alpine
Faba bean [2]	Pea	FR, DK	Atlantic
	Lathyrus	AT	Continental
Wheat	Pea	BE, DK, LT, CH, GR, UK, PL	Atlantic, Continental, Alpine, Mediterranean
	Faba bean	DK, IT, FR, NL	Atlantic, Mediterranean
	Lupin	DK, CH	Atlantic, Alpine
	Alfalfa	FR	Atlantic
	Clover	FR, CH	Atlantic, Alpine
	Lentil	FR, ES	Atlantic, Mediterranean
	Lucerne	FR	Atlantic
	Chickpea	TR, ES	Mediterranean
	Soyabean	DK	Atlantic
Durum wheat	Faba bean	IT	Mediterranean
	Lentil	TR	Mediterranean
	Pea	FR	Atlantic
Barley	Pea	FR, AT, LT, IT, CH, UK, ES	Atlantic, Continental, Mediterranean, Alpine
	Lentil	DE, FR	Atlantic, Continental
	Lupin	DK	Atlantic
	Faba bean	CH	Alpine
	Lucerne	UK	Atlantic
	Lathyrus	FR	Atlantic

1 Cereal-cereal crop associations 2 Legume-legume crop associations

Component 1	Component 2	Country	Region
Oat	Faba bean	DK, CH, PT, ES, UK, FR	Atlantic, Alpine, Mediterranean
	Pea	CH, FI, DE, LT, AT, FR	Alpine, Continental
	Lentil	DE, FR, UK	Atlantic, Continental
	Vetch	FR, AT	Atlantic, Continental
	Lupin	CH	Alpine
	Chickpea	UK	Atlantic
Maize	Soyabean	FR	Atlantic
	Common bean	UK, AT, CH	Atlantic, Continental, Alpine
	Squash	CH	Alpine
	Peanut	CH	Alpine
	Clover	FR	Atlantic
Triticale	Pea	FR, LT, CH, AT	Atlantic, Continental, Alpine
	Lupin	FR, DK	Atlantic
	Faba bean	CH	Alpine
	Vetch	AT	Continental
Rye	Pea	CH, AT, NL	Alpine, Continental, Atlantic
	Vetch	CH, AT, DK	Alpine, Continental, Atlantic
	Clover	NL	Atlantic

Supplementary Table 4. Pseudocereal- and oilseed-legume intercrops in European countries and regions

Component 1	Component 2	Country	Region
Buckwheat	Faba bean	FR	Atlantic
	Vetch	UK	Atlantic
	Clover	UK	Atlantic
	Soyabean	FR	Atlantic
Camelina	Lentil	UK, FR	Atlantic
	Pea	CH	Alpine
	Nigella	UK	Atlantic
	Soyabean	CH	Alpine
Sorghum	Common bean	AT	Continental
Oilseed rape	Clover	FR, UK	Atlantic
	Fenugreek	FR	Atlantic
	Lentil	FR	Atlantic
	Faba bean	FR	Atlantic
	Lucerne	CH	Alpine
Sunflower	Clover	CH, FR	Alpine
	Buckwheat	FR	Atlantic

Supplementary Table 5. Multi-species crop associations and cover crops in European countries and regions

Species mixture	Country	Region
Maize-Common bean-Buckwheat	AT	Continental
Maize-Common bean-Phacelia	AT	Continental
Oilseed rape-Vetch-Buckwheat	UK	Atlantic
Oilseed rape-Clover-Buckwheat	UK	Atlantic
Oilseed rape-Oat-Fenugreek	FR	Atlantic
Oilseed rape-Fenugreek-Lentil	FR	Atlantic
Oilseed rape-Pea-Faba bean-Clover	FR	Atlantic
Oilseed rape-Camelina-Clover	FR	Atlantic
Oilseed rape-Clover-Lucerne	FR	Atlantic
Oilseed rape-Mustard-Lucerne	UK	Atlantic
Barley-Oat-Pea-Lupin-Mustard-Linseed	DK	Atlantic
Oat-Barley-Wheat-Triticale-Pea	DK	Atlantic
Barley-Clover-Rye	UK	Atlantic
Barley-Oat-Pea	FR, DK	Atlantic
Oat-Linseed-Vetch-Clover-Buckwheat	UK	Atlantic
Oat-Clover-Trefoil	UK	Atlantic
Sorghum-Common bean-Buckwheat	AT	Continental
Sorghum-Common bean-Phacelia	AT	Continental
Sorghum-Buckwheat-Pea	FR	Atlantic
Red/White/Berseem Clover-Trefoil	UK	Atlantic
Camelina-Lentil-Lupin	CH	Alpine

Supplementary Table 6. Summary of the number of scores assigned by FG experts for different categories of outcomes for crop association types

Crop association type	Category of outcome			
	Environment	Productivity	Profitability	Resilience
Agroforestry (n=16)	14	10	8	9
Cover/forage/fodder crops (n=16)	16	5	4	3
Companion crops (n=23)	16	14	15	15
Milpa (n=3)	1	2	2	2
Annual intercrops (n=31)	24	8	6	6
Strip crops (n=3)	3	3	3	3
Total (n=92)	**75**	**42**	**38**	**39**

Supplementary Table 7. Average score values for different categories of outcomes for crop associations within each type

Positive values indicate beneficial outcomes, with higher scores indicating stronger benefits and values close to zero indicating neutral effects. Average values are not provided for categories where n<5 (see Supplementary Table 1).

Crop association type	Category of outcome			
	Environment	Productivity	Profitability	Resilience
Agroforestry	1.6	0.7	1.1	1.7
Cover/forage/fodder crops	1.1	0.5		
Companion crops	1.5	0.7	0.5	1.1
Milpa				
Annual intercrops	1.3	0.8	1.0	1.2
Strip crops				
Overall average	**1.3**	**0.7**	**0.6**	**1.2**

Annex 2: Initial database of crop associations projects and resources

Recent Horizon 2020 and Horizon Europe-funded projects that are relevant to crop associations include:

- Intercropping and crop diversification: DIVERSify, ReMIX, DiverIMPACTS, Diverfarming, INTERCROPVALUES, LEGUMINOSE
- Agroforestry: AFINET, ReForest, AF4EU, MIXED, AGROMIX, DIGITAF
- Weed management: IWMPRAISE

Some of the resources developed by these projects are summarised in the table below. This type of database could be expanded in the future and hosted as part of the EU open data infrastructure.

Country	Year	Record inserted by	Type(1)	Crop combination	Notes	Link / Contact
France			Database		A global dataset of experimental intercropping and agroforestry studies in horticulture.	https://www.nature.com/articles/s41597-023-02831-7#ref-CR211 https://entrepot.recherche.data.gouv.fr/dataset.xhtml?persistentId=doi:10.57745/HV33V1
Italy	2023	AIAB FVG APS	On-farm trial	Lentil/ Linseed	Linseed growing season is longer than that of lentil. Reduced lodging and weed biomass.	info@aiab.fvg.it
UK	2023	The James Hutton Institute	On-farm trials	Cereal-legume mixtures	Pick-a-Mix tool shows crop yields and agronomy from intercrop trials at commercial and research farms across Scotland.	https://ics.hutton.ac.uk/pick-a-mix/#/
EU	2021	Organic Research Centre	Website and associated resources	Cereal-legume mixtures	Guides and toolboxes for practitioners; making research and on-farm trial data available along with agronomic information and practical advice.	https://plant-teams.org/infohub/ https://plant-teams.org/#fieldscaletrials

Country	Year	Record inserted by	Type(1)	Crop combination	Notes	Link / Contact
EU	2017		Website		The Organic Farm Knowledge platform provides access to a wide range of tools and resources about organic farming that can help improve production. It also aims to serve as a virtual meeting place for cross-border learning.	https://organic-farmknowledge.org/
EU		FiBL	Website		The cluster projects are working together to demonstrate the benefits of crop diversification.	https://www.cropdiversification.eu/working-groups.html
EU	2017	AGFORWARD	Website/ research project	Agroforestry	Multi-year research project covering agroforestry in Europe including arable, livestock, forestry, and other systems.	https://www.agforward.eu/
EU	(ongoing)	Agroforestry Business Innovation Network (AF4EU)	Website/ research project	Agroforestry		https://af4eu.eu/
EU	(ongoing)	Digital Tools to Boost Agroforestry (DigitAF)	Website/ development project	Agroforestry	DigitAF provides tailored, user-friendly and open-source digital tools for everyone involved in the farming industry, from policymakers and farmers to final consumers.	https://digitaf.eu/

Annex 3: List of FG experts

Family name	First name	Expertise	Country
Badenes-Pérez	Francisco Rubén	Researcher	Spain
Barka	Essaid Ait	Agronomist	France
Baranger	Alain	Researcher	France
Bortolussi	Stefano	Farm advisor	Italy
Bourke	Martin	Farm advisor	Ireland
Brünning	Fokko	Farmer	Germany
Finch	Joshua	Farm advisor	Finland
Fogelberg	Fredrik	Researcher	Sweden
Hatt	Severin	Researcher	Germany
Hohmann	Pierre	Breeder	Spain
Giamoustaris	Athanasios	Farm director	Greece
Karley	Alison	Researcher	UK
Kussmann	Sebastian	Breeder	Switzerland
Pampana	Silvia	Researcher	Italy
van Buuren	Arjen	Farmer	Netherlands
van Dorst	Ivar	Farmer	Netherlands
van Schie	Robin	Entrepreneur	Netherlands
Schöb	Christian	Researcher	Spain
Stomph	Tjeerd Jan	Researcher	Netherlands
Watson	Christine	Researcher	UK

Annex 4: Mini Papers

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