

Redesigning cropping systems for holistic IPM: synergies and trade-offs of biodiversity-based preventive approaches across weeds, insect pests and fungal pathogens.

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1. Introduction

The transition towards pesticide-free agriculture cannot rely solely on replacing pesticides with alternative control methods. Drawing on the agroecological transition framework proposed by Gliessman, moving beyond input substitution requires the redesign of cropping systems to strengthen ecological processes and reduce reliance on external interventions. In this context, cropping-system redesign is an essential component of the transition, aiming to create production systems that are inherently less favourable to pest development and less dependent on direct control measures (Gliessman, 2015). Preventive strategies are therefore a cornerstone of pesticide-free cropping systems. Rather than relying primarily on curative interventions, they aim to limit pest establishment and population growth by creating cropping conditions that enhance crop competitiveness, disrupt pest life cycles and strengthen ecological regulation. Crop diversification is one of the main biodiversity-based tools available for this purpose. It fits well with cropping-system redesign because it changes the biological and agronomic conditions in which crops and pests interact.

Diversification can be introduced in different ways. Temporal diversification includes more diverse crop rotations, cover or catch crops, and the inclusion of minor crops that interrupt repeated host availability and reduce pest specialisation. Spatial diversification includes intercropping, undersowing, living mulches and crop or cultivar mixtures. These approaches combine species or genotypes with different functional traits and can improve crop competition, resource use and resistance to biotic stress.

Most of these practices have been studied for many years. There is a large literature on their effects on single ecosystem services, such as weed suppression, insect regulation, disease reduction, soil fertility or yield. Much less work has examined how the same diversification practice affects several pest groups at the same time. This is a major limitation if the objective is to redesign the whole agroecosystem rather than optimise one single control target.

A more holistic assessment is needed because pest groups do not respond independently. A practice that strongly suppresses weeds may have a neutral or negative effect on an insect pest, a plant pathogen or its natural enemies. Conversely, the same practice may provide simultaneous benefits against more than one pest group. These interactions are also relevant beyond the single plot because crop sequence, host continuity, vegetation structure and the surrounding landscape influence pest movement and persistence.

2. Methodology

The aim of this report is not to provide a complete systematic review of all crop-diversification studies. It is a targeted evidence synthesis designed to identify studies that are informative for multi-pest responses. The starting point was the evidence base developed in the EU FORTUNA project, where more than 13,000 scientific papers were screened to identify solutions for pesticide reduction and pesticide-free agriculture. The FORTUNA project provided a broad picture of solutions for weeds, insect pests and fungal diseases. It also suggested an important gap which is that many studies addressed individual pest groups, whereas comparatively few assessed the response of different pest groups within the same diversification experiment.

In the current work, the synthesis was restricted to arable cropping systems in the EU countries. The time window was expanded to 2010-2026. Only original empirical studies were considered for the strict core. The focus was on biodiversity-based crop-diversification practice, including diversified crop rotations, cover or catch crops, intercropping, undersowing or living mulches, crop species mixtures, and cultivar or genetically diverse crop mixtures. To be included in the selected core of papers, a study had to assess at least two focal pest groups among weeds, fungal diseases and insect pests, and the effect of the diversification treatment had to be distinguishable from a sole-crop, no-cover-crop or otherwise less-diversified control.

To expand the search beyond FORTUNA and cover the full 2010-2026 period, three complementary Scopus search strings were run in September 2026. The search strings targeted the three pairwise combinations of the

focal pest groups. Search A returned 152 records, Search B 56 records and Search C 68 records. This gave 276 raw records and 246 unique records after deduplication. Of these 246 records, 169 were published within the 2014-2024 period covered by the FORTUNA review, while 77 fell outside that time window and were necessarily part of the extension performed here.

Search A (weeds + fungal diseases)

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TITLE-ABS-KEY(("crop diversification" OR "crop rotation" OR intercrop* OR undersow* OR "living mulch" OR "cover crop" OR "catch crop" OR "service crop" OR "service plant" OR "companion crop" OR "cultivar mixture" OR "varietal mixture" OR "variety mixture") AND weed* AND (fung* OR disease* OR pathogen*)) AND PUBYEAR > 2009 AND PUBYEAR < 2027 AND DOCTYPE(ar)
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Search B (weeds + insect pests)

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TITLE-ABS-KEY(("crop diversification" OR "crop rotation" OR intercrop* OR undersow* OR "living mulch" OR "cover crop" OR "catch crop" OR "service crop" OR "service plant" OR "companion crop" OR "cultivar mixture" OR "varietal mixture" OR "variety mixture") AND weed* AND ("insect pest" OR "insect pests" OR "pest insect*" OR herbivor* OR aphid* OR weevil* OR beetle* OR midge* OR moth* OR bruchid* OR thrip*)) AND PUBYEAR > 2009 AND PUBYEAR < 2027 AND DOCTYPE(ar)
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Search C (fungal diseases + insect pests)

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TITLE-ABS-KEY(("crop diversification" OR "crop rotation" OR intercrop* OR undersow* OR "living mulch" OR "cover crop" OR "catch crop" OR "service crop" OR "service plant" OR "companion crop" OR "cultivar mixture" OR "varietal mixture" OR "variety mixture") AND (fung* OR disease* OR pathogen* OR fusarium OR rust* OR mildew*) AND ("insect pest" OR "insect pests" OR "pest insect*" OR herbivor* OR aphid* OR weevil* OR beetle* OR midge* OR moth* OR bruchid* OR thrip*)) AND PUBYEAR > 2009 AND PUBYEAR < 2027 AND DOCTYPE(ar)
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The 246 unique records were assessed against the predefined eligibility criteria. Titles and abstracts were used for the first relevance check, and candidate studies were then examined in more detail using the available bibliographic information and full texts. A study was retained in the strict core when it provided a field-based comparison of a diversification treatment and a relevant control, and when at least two focal pest groups were measured within the same experimental framework. Studies were not retained when diversification was only the background system, when the changing treatment was another management factor, when pest groups were not measured under comparable treatments, or when the study was modelling, greenhouse or mesocosm research.

The final strict core contains 14 studies. Four were already present in the retained FORTUNA evidence database and ten were added through the targeted search extension. For each study, responses were classified as follows: + = significant improvement in pest regulation; 0 = assessed but no significant effect; - = significant deterioration; ± = mixed (species-dependent, year-dependent or context-dependent response); NE = assessed but not evaluable because pest or disease pressure was absent or too low; NA = not assessed.

3. Results

The final core was small despite the broad starting evidence base. From the 246 unique records returned by the targeted searches only a limited number satisfied all criteria for a field-based and biodiversity-based solutions and multi-pest comparison. The final core contained 14 studies of which four already present in the retained FORTUNA database and 10 additional studies identified through the targeted extension. Most studies focused on within-field diversification through intercropping, crop mixtures or undersowing. Cover and catch crops were represented by only a few studies.

Core studies on crop diversification and multi-pest responses in European arable systems.

Paper	Country / practice	Weeds	Fungal diseases	Insect pests	Yield / other outcomes	Pest-specific effects
Tratwal, A. & Walczak, F. (2010). Powdery mildew (<i>Blumeria graminis</i>) and pest occurrence reduction in spring cereal mixtures. <i>Journal of Plant Protection Research</i> , 50(3), 402-407. https://doi.org/10.2478/v10045-010-0068-3	Poland Cereal mixtures: wheat, barley and oat in two- and three-component mixtures	NA	+	+	Yield was maintained or increased	Fungi: Powdery mildew (<i>Blumeria graminis</i>) was generally reduced in mixtures, but the size of the effect varied among combinations and sites. Insects: Aphidodea, Oulema spp. and Agromyzidae were monitored and several mixtures reduced their abundance.
Gronle, A., Böhm, H. & Heß, J. (2014). Effect of intercropping winter peas of differing leaf type and time of flowering on annual weed infestation in deep and shallow ploughed soils and on pea pests. <i>Landbauforschung - Applied Agricultural and Forestry Research</i> , 64(1), 31-44. https://doi.org/10.3220/LBF_2014_31-44	Germany Winter pea-triticale intercropping	+	NA	±	NA	Weeds: Intercropping clearly reduced weeds Insects: <i>Acyrtosiphon pisum</i> was reduced, while <i>Cydia nigricana</i> was not.
Cadoux, S., Sauzet, G., Valantin-Morison, M., Pontet, C., Champolivier, L., Robert, C., Lieven, J., Flénet, F., Mangenot, O., Fauvin, P. & Landé, N. (2015). Intercropping frost-sensitive legume crops with winter oilseed rape reduces weed competition, insect damage, and improves nitrogen use efficiency. <i>OCL</i> , 22(3), D302. https://doi.org/10.1051/ocl/2015014	France Winter oilseed rape intercropped with frost-sensitive legume mixtures	+	NA	+	Oilseed rape yield was maintained or increased. Nitrogen-use efficiency improved.	Weeds: Companion legumes reduced autumn weeds. Insects: Damage by rape winter stem weevil (<i>Ceutorhynchus picitarsis</i>) was reduced.
Costanzo, A. & Bärberi, P. (2016). Field scale functional agrobiodiversity in organic wheat: Effects on weed reduction, disease susceptibility and yield. <i>European Journal of Agronomy</i> , 76, 1-16. https://doi.org/10.1016/j.eja.2016.01.012	Italy Wheat genetic diversity combined with subterranean-clover living mulch	+	+	NA	Living mulch generally caused little yield penalty unless wheat establishment was poor; old cultivars suppressed weeds well but tended to yield less.	Weeds: Living mulch reduced dicot. weed abundance and biomass Fungi: Composite Cross Populations were less susceptible than pure lines to foliar diseases.
Kwiatkowski, C.A., Harasim, E. & Wesolowski, M. (2016). Effects of catch crops and tillage system on weed infestation and health of spring wheat. <i>Journal of Agricultural Science and Technology</i> , 18, 999-1012.	Poland Cover crops: white mustard, tansy phacelia, and a bean-spring vetch-oat mixture	+	+	NA	NA	Weeds: CC reduced weed density and biomass; white mustard and phacelia were strongest. Fungi: CC significantly reduced the spring-wheat stem-base fungal disease complex compared with no CC.
Kadžienė, G., Supronienė, S., Auškalnienė, O., Pranaitienė, S., Švegžda, P., Veršulienė, A., Češevičienė, J., Janušauskaitė, D. & Feiza, V. (2020). Tillage and cover crop influence on weed pressure and Fusarium infection in spring cereals. <i>Crop Protection</i> , 127, 104966. https://doi.org/10.1016/j.cropro.2019.104966	Lithuania Cover crops: White mustard and white clover cover crops under different tillage systems	+	+	NA	NA	Weeds: Strong weed suppression was reported for both cover crops, especially white clover. Fungi: White mustard reduced <i>Fusarium graminearum</i> in barley; white clover reduced <i>Fusarium culmorum</i> in wheat.
Jalli, M., Huusela, E., Jalli, H., Kauppi, K., Niemi, M., Himanen, S. & Jauhiainen, L. (2021). Effects of crop rotation on spring wheat yield and pest occurrence in different tillage systems: A multi-year experiment in Finnish growing conditions. <i>Frontiers in Sustainable Food Systems</i> , 5, 647335. https://doi.org/10.3389/fsufs.2021.647335	Finland Diversified crop rotations compared with continuous spring wheat	-	+	0	Diversified rotation increased wheat yield, especially under no-till.	Weeds: Weed density was generally highest in the four-year rotation. Fungi: Stem/root diseases and leaf blotch were lower in the most diverse rotation; <i>Pyrenophora tritici-repentis</i> was the main leaf blotch pathogen. Insects: Wheat midge (<i>Sitodiplosis mosellana</i>) response was neutral.
Emery, S.E., Anderson, P., Carlsson, G., Friberg, H., Larsson, M.C., Wallenhammar, A.-C. & Lundin, O. (2021). The potential of intercropping for multifunctional crop protection in oilseed rape (<i>Brassica napus</i> L.). <i>Frontiers in Agronomy</i> , 3, 782686. https://doi.org/10.3389/fragro.2021.782686	Sweden Winter oilseed rape intercropped with four legume companion crops	±	±	±	OSR yield was similar in most treatments but lower with winter pea.	Weeds: Weed control depended on companion species. Fungi: Sclerotinia spp. did not develop, so its response could not be evaluated; <i>Uromyces fabae</i> on winter faba bean was strongly reduced in intercropping. Insects: Cabbage stem flea beetle was reduced by some intercrops; pollen beetle was neutral.
Timaeus, J., Weedon, O.D. & Finckh, M.R. (2022). Harnessing the potential of wheat-pea species mixtures: Evaluation of multifunctional performance and wheat diversity. <i>Frontiers in Plant Science</i> , 13, 846237. https://doi.org/10.3389/fpls.2022.846237	Germany Wheat-pea mixtures combined with different wheat genotypes and heterogeneous populations	±	0	NA	Resource-use efficiency and total mixture performance were positive. Wheat yield was lower in intercropping because wheat was sown at reduced density.	Weeds: Mixtures strongly reduced weeds compared with pea monoculture but were almost unchanged compared with wheat monoculture, where weed pressure was already very low. Fungi: Disease pressure was low and no mixture effect was detected for foot diseases.
Boetzi, F.A., Douhan Sundahl, A., Friberg, H., Viketoft, M., Bergkvist, G. & Lundin, O. (2023). Undersowing oats with clovers supports pollinators and suppresses arable weeds without reducing yields. <i>Journal of Applied Ecology</i> , 60, 614-623. https://doi.org/10.1111/1365-2664.14361	Sweden Oats undersown with a mixture of three annual clovers	+	0	0	Oat yield was unchanged. Pollinators increased and root-feeding nematodes declined, but spider activity and grain N concentration decreased.	Weeds: Weed cover decreased by about 33% and weed biomass tended to decrease. Fungi: Root disease severity did not differ from the control. Insects: Cereal leaf beetle damage did not differ between treatments.
Tosti, G., Falcinelli, B. & Guiducci, M. (2023). Lentil-cereal intercropping in a Mediterranean area: Yield, pests and weeds. <i>Agronomy Journal</i> , 115, 2570-2578. https://doi.org/10.1002/agj2.21413	Italy Lentil-barley and lentil-triticale intercropping	+	NA	+	Lentil yield fell by about 59% because of cereal competition, while total land-use efficiency remained positive.	Weeds: Weed biomass fell by about 97%; <i>Chenopodium album</i> was dominant in 2020 and <i>Polygonum aviculare</i> in 2021. Insects: Bruchid grain loss was reduced (<i>Bruchus signaticornis</i>).

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Paper	Country / practice	Weeds	Fungal diseases	Insect pests	Yield / other outcomes	Pest-specific effects
Hatt, S. & Döring, T.F. (2025). The interplay of intercropping, wildflower strips and weeds in conservation biological control and productivity. <i>Journal of Pest Science</i> , 98, 159-174. https://doi.org/10.1007/s10340-024-01801-1	Germany Faba bean-wheat and breadseed poppy-barley intercropping, with or without wildflower strips	+	NA	+	Intercropped crop yields were lower, while LER remained > 1.	Weeds: Intercropping reduced weed biomass by about 60% compared with the sole flowering crop. Insects: Aphid colonisation was lower; <i>Acyrtosiphon pisum</i> was the main aphid on faba bean and <i>Aphis fabae</i> on breadseed poppy.
Tous-Fandos, A., Bragg, D., Blanco-Moreno, J.M., Chamorro-Lorenzo, L. & Sans, F.X. (2025). Wheat cultivar mixtures enhance the delivery of agroecosystem services compared to monocultures under contrasted tillage intensities and fertilization. <i>Agronomy for Sustainable Development</i> , 45, 2. https://doi.org/10.1007/s13593-024-00996-y	Spain Three-cultivar wheat mixture under contrasting tillage and fertilisation	±	NA	±	NA	Weeds: The mixture improved weed control mainly under reduced tillage and high weed pressure. Insects: The mixture strongly reduced aphids on the susceptible cultivar but had no effect on the two more resistant cultivars. Main aphids were <i>Sitobion avenae</i> , <i>Metopolophium dirhodum</i> and <i>Rhopalosiphum padi</i> .
Guy, M., Lorin, M., Boussetin, X. & Corre-Hellou, G. (2026). Intercropping chickpea with a competitive service plant and mowing the inter-rows controls weeds and ascochyta blight while mitigating interspecific competition. <i>European Journal of Agronomy</i> , 178, 128112. https://doi.org/10.1016/j.eja.2026.128112	France Chickpea intercropped with four service-plant species, with or without inter-row mowing	±	±	NA	Unmowed oat reduced chickpea yield by 72% in 2023; mowing reduced the penalty to 48%.	Weeds: Oat reduced weed biomass in both years; under high pressure, unmowed oat reduced weed biomass by 66% compared with sole chickpea. The other service plants were not consistently effective. Fungi: Under high disease pressure, unmowed oat reduced <i>ascochyta blight</i> by 56%; other intercrops were generally not different from sole chickpea.

Coding and colours: green (+) = significant improvement in pest regulation; yellow (±) = mixed (species, year or context dependent response); red (-) = increase in pest pressure; grey (0) = assessed but no significant effect; grey (NA) = not assessed.

The selected papers were strongly focused on weeds. 13 of the 14 studies included a weed response, while only Tratwal and Walczak (2010) examined fungal disease and insect pests without a weed component.

Several studies showed simultaneous benefits for more than one pest group. Clear examples include Cadoux et al. (2015),

Wojciechowski et al. (2016), Kadziene et al. (2020), Tosti et al. (2023), and Hatt and Döring (2025). Guy et al. (2026) also showed a strong weed-disease synergy, but only when chickpea was intercropped with a sufficiently competitive service plant, in this case oat. Jalli et al. (2021) provides the clearest direct pest-pest trade-off. A more diverse crop rotation reduced fungal disease severity and increased yield, but weed density was higher than in wheat monoculture and the insect response was neutral.

A second common pattern was a positive effect on one pest group combined with a neutral response in another. Boetzel et al. (2023) showed that undersown clovers reduced weeds without increasing root disease or cereal leaf beetle damage. Several studies showed strong context dependence. Gronle et al. (2014), Emery et al. (2021), Timaeus et al. (2022), Tous-Fandos et al. (2025) and Guy et al. (2026) showed that the effect of diversification depends on crop identity, cultivar traits, pest pressure, year or companion-species competitiveness.

Within the limited number of studies assessing more than one pest group, a few are especially useful for understanding how diversification can work under field conditions. These studies can be considered “lighthouse cases” because they do not simply report whether a practice was successful or not. They show how the same practice can affect several components of crop protection at the same time, sometimes in the same direction and sometimes not.

Cadoux et al. (2015) provides one of the clearest examples of a positive multi-pest response. The introduction of frost-sensitive legume companion crops in winter oilseed rape reduced weed competition and also reduced damage caused by rape winter stem weevil. Oilseed rape yield was maintained and, in some cases, increased. This is particularly relevant because two crop-protection services were obtained from the same preventive practice without a clear yield penalty. Jalli et al. (2021) gives a rather different result. Increasing crop-rotation diversity reduced fungal disease severity and improved wheat performance, but weed density increased, while insect pests were largely unaffected. This is the clearest pest-pest trade-off among the selected studies. Looking only at fungal diseases would have led to a clearly positive assessment of the diversified rotation. Once weeds are considered as well, the conclusion becomes less straightforward. This is a good example of what can be missed when preventive practices are evaluated against only one pest group. In Tosti et al. (2023), the main trade-off was not between pest groups but between crop protection and crop productivity. Lentil-cereal intercropping strongly reduced weed biomass and bruchid-related grain losses. At the same time, the cereal

component competed strongly with lentil and reduced lentil yield. The benefits for pest regulation were therefore clear, but they came with an agronomic cost. This points to the importance of managing crop density, spatial arrangement and competition between the component species. Boetzel et al. (2023) showed that undersowing oats with clovers reduced weed pressure, while root disease severity and cereal leaf beetle damage were not significantly affected. Other responses were also recorded: pollinators increased, spider activity decreased, crop yield remained stable and grain nitrogen concentration was slightly reduced. The study of Guy et al. (2026) also makes clear that increasing diversity per se is not enough. In chickpea, oat was the service plant that gave the clearest effects, reducing both weed biomass and *Ascochyta* blight under high pest pressure. The other service plants did not give the same response. However, oat also competed strongly with chickpea and reduced grain yield, although mowing partly reduced this effect.

4. Discussion

The main result of this targeted synthesis is the small number of studies that explicitly connect crop diversification with the response of several pest groups. This is remarkable because the individual practices such as diversified crop rotation, cover crops, intercropping, undersowing, living mulches and cultivar mixtures, have each been studied extensively. The gap is therefore not a lack of research on diversification itself. The gap is the lack of experiments that ask how the same practice changes the whole crop-protection problem. This distinction matters for the transition towards strong pesticide reduction or pesticide-free agriculture. A redesigned system cannot be judged only by its best single effect. A cover crop that suppresses weeds but increases disease risk may simply move pesticide dependence from one product to another. Conversely, a practice that gives moderate benefits against several pest groups, while maintaining yield and avoiding new problems, may be more useful for system redesign than a practice that is highly effective against only one target.

The core studies demonstrate that crop diversification can generate simultaneous benefits across multiple pest groups. Intercropping reduced both weed pressure and insect damage in winter oilseed rape, lentil, and other crop mixtures, cover and catch crops contributed to the suppression of both weeds and fungal diseases and cereal mixtures reduced the incidence of powdery mildew while also limiting insect pests. Overall, the choice of species or cultivars and the way they are managed strongly influence system performance. In Emery et al. (2021), different legumes gave different combinations of pest, disease, weed and yield responses. In Guy et al. (2026), oat was competitive enough to suppress weeds and reduce *ascochyta* blight, but this same competitiveness strongly reduced chickpea yield unless mowing was used. In Tous-Fandos et al. (2025), the value of cultivar mixtures was evident when a susceptible cultivar was combined with more resistant, taller cultivars and when pest pressure was high. Functional complementarity is therefore more important than diversification in itself.

Trade-offs should also be considered in a broader context. Jalli et al. (2021) gives a clear pest-pest trade-off, but other studies show that production and ecological trade-offs may be more common. Tosti et al. (2023) combined excellent weed and bruchid control with a large reduction in lentil yield, although land-use efficiency remained above one. Boetzel et al. (2023) reduced weeds and supported pollinators without reducing yield, but spider activity and grain nitrogen concentration decreased. Hatt and Döring (2025) reduced aphids even though predator colonisation and predation were often lower in intercropping. These findings show why a whole-system assessment is needed.

These lighthouse cases do not define complete holistic IPM strategies on their own. Rather, they identify preventive components that could be combined with other compatible measures in redesigned cropping systems. The next step is therefore to understand how rotations, cover crops, intercropping, cultivar diversity and targeted direct control can be assembled without losing the multi-pest benefits observed for individual practices.

Another important gap is the weak representation of temporal and landscape dimensions. Most core studies were short-term field experiments focused on intercropping or mixtures. However, several processes underlying pest regulation operate over longer time scales, including changes in weed seed banks, soil-borne

pathogens, host continuity, natural-enemy populations, and pest movement among fields. Short-term, plot-scale experiments may therefore capture only part of these dynamics.

The available evidence was largely focused on weed-related studies, with weeds included in 13 of the 14 selected experiments, whereas studies jointly addressing fungal diseases and insect pests were largely lacking. This imbalance highlights a substantial gap in experimental research explicitly assessing interactions among these pest groups under the same field conditions. Future studies should also broaden the range of target organisms beyond weeds, insect pests, and fungal diseases to include viruses, bacteria, nematodes, slugs, and other relevant antagonists according to the specific cropping system. A first priority is the development of more cross-cutting and multidisciplinary studies. Diversification affects different components of the agroecosystem at the same time, but weeds, diseases and insect pests are still often studied separately. Future work should bring together weed science, plant pathology, entomology, agronomy and agroecology within the same experiments, so that synergies and trade-offs can be assessed directly. Crop performance and other relevant ecosystem functions should also be considered in the same framework. A second priority is the need for longer-term experiments. Many effects of diversification become visible only over several years, especially changes in weed seed banks, soil-borne pathogens, pest carry-over and natural-enemy communities. Short-term trials can therefore provide only a partial view of the performance of redesigned cropping systems. Longer experiments are needed to understand whether the benefits of diversification are stable over time and whether new trade-offs emerge as the system develops.

Bibliography

- Boetzel FA, Douhan Sundahl A, Friberg H, et al (2023) Undersowing oats with clovers supports pollinators and suppresses arable weeds without reducing yields. *J Appl Ecol* 60:614–623. <https://doi.org/10.1111/1365-2664.14361>
- Cadoux S, Sauzet G, Valantin-Morison M, et al (2015) Intercropping frost-sensitive legume crops with winter oilseed rape reduces weed competition, insect damage, and improves nitrogen use efficiency. *OCL* 22:D302. <https://doi.org/10.1051/ocl/2015014>
- Emery SE, Anderson P, Carlsson G, et al (2021) The Potential of Intercropping for Multifunctional Crop Protection in Oilseed Rape (*Brassica napus* L.). *Front Agron* 3:782686. <https://doi.org/10.3389/fagro.2021.782686>
- Gronle A, Böhm H, Hess J (2014) Effect of intercropping winter peas of differing leaf type and time of flowering on annual weed infestation in deep and shallow ploughed soils and on pea pests. *Landbauforsch - Appl Agric For Res* 31–44. https://doi.org/10.3220/LBF_2014_31-44
- Guy M, Lorin M, Bousselin X, Corre-Hellou G (2026) Intercropping chickpea with a competitive service plant and mowing the inter-rows controls weeds and ascochyta blight while mitigating interspecific competition. *Eur J Agron* 178:128112. <https://doi.org/10.1016/j.eja.2026.128112>
- Hatt S, Döring TF (2025) The interplay of intercropping, wildflower strips and weeds in conservation biological control and productivity. *J Pest Sci* 98:159–174. <https://doi.org/10.1007/s10340-024-01801-1>
- Jalli M, Huusela E, Jalli H, et al (2021) Effects of Crop Rotation on Spring Wheat Yield and Pest Occurrence in Different Tillage Systems: A Multi-Year Experiment in Finnish Growing Conditions. *Front Sustain Food Syst* 5:647335. <https://doi.org/10.3389/fsufs.2021.647335>
- Kadziene G, Suproniene S, Auskalniene O, et al (2020) Tillage and cover crop influence on weed pressure and Fusarium infection in spring cereals. *Crop Prot* 127:104966. <https://doi.org/10.1016/j.cropro.2019.104966>
- Timaeus J, Weedon OD, Finckh MR (2022) Harnessing the Potential of Wheat-Pea Species Mixtures: Evaluation of Multifunctional Performance and Wheat Diversity. *Front Plant Sci* 13:846237. <https://doi.org/10.3389/fpls.2022.846237>
- Tosti G, Falcinelli B, Guiducci M (2023) Lentil–cereal intercropping in a Mediterranean area: Yield, pests and weeds. *Agron J* 115:2570–2578. <https://doi.org/10.1002/agj2.21413>

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Tous-Fandos A, Bragg D, Blanco-Moreno JM, et al (2025) Wheat cultivar mixtures enhance the delivery of agroecosystem services compared to monocultures under contrasted tillage intensities and fertilization. *Agron Sustain Dev* 45:2. <https://doi.org/10.1007/s13593-024-00996-y>

Wojciechowski W, Zawieja J, Lehmann A, Sekutowski TR (2016) The effect of catch crops cultivated in accordance with the agri-environment scheme on weed infestation of spring wheat stand. *Plant Soil Environ* 62:99–104. <https://doi.org/10.17221/533/2015-PSE>