

RESEARCH ARTICLE

Comparing ecological and economic benefits of organic farming and annual flower strips

Péter Batáry^{1,2}  | Costanza Geppert³  | Rita Földesi⁴  | Róbert Gallé¹  |
 Katalin Sztár¹  | Edina Török¹  | Christina Fischer²  | Oliver Musshoff⁵  |
 Teja Tscharnke⁴ 

¹'Lendület' Landscape and Conservation Ecology, Institute of Ecology and Botany, MTA-HUN-REN Centre for Ecological Research, Budapest, Hungary

²Faunistics and Wildlife Conservation, Department of Agriculture, Ecotrophology, and Landscape Development, Anhalt University of Applied Sciences, Bernburg, Germany

³DAFNAE, University of Padova, Padova, Italy

⁴Functional Agrobiodiversity & Agroecology, University of Göttingen, Göttingen, Germany

⁵Department of Agricultural Economics and Rural Development, University of Göttingen, Göttingen, Germany

Correspondence

Péter Batáry
 Email: batary.peter@ecolres.hu

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Abstract

1. Across the EU, common agri-environment schemes (AES) comprise measures such as organic farming, which prohibits synthetic agrochemicals, and wildflower strips.
2. We evaluated the ecological and economic effectiveness of non-productive annual wildflower strips adjacent to conventional wheat fields and productive organic wheat fields. Our study spanned nine landscapes, each containing three types of winter wheat fields: conventional with a wildflower strip, conventional without strip as a control (no AES) and organic field. Over 2 years, we surveyed plants and sampled carabids, spiders and rove beetles using pitfall traps, and wild bees and hoverflies via transect walks and sweep netting along field edges. Farmers provided revenue, cost and profit data.
3. Organic farming harboured the highest number of wild arable plant species, even though flower strips achieved similar species richness when including sown plant species. Flower strips were visited by three times more bee species than organic fields, while both AES exceeded controls. Carabids, spiders and hoverflies showed higher species richness under both AES, with 20%–30% more species than controls, whereas rove beetles showed no significant differences among management types. Both AES enhanced farmland biodiversity, with partly distinct plant and arthropod community compositions. Flower strips, organic fields and conventional fields had 28%, 12% and 3% unique species, respectively.
4. Economically, organic fields were the most profitable, with profits over 150% higher than those of conventional control fields, despite 50% lower wheat yields, due to better marketing opportunities and AES subsidies (234 €/ha). Profit of flower strip fields was only slightly lower than that of the control when flower strip subsidies (875 €/ha) were included. We also compared the profits solely for the wheat-growing area, excluding flower strips. Profits from control fields were

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21% higher, prompting suspicion that farmers implemented flower strips selectively on more marginal, less productive land.

5. *Synthesis and applications.* Integrating agri-environment schemes such as organic farming and wildflower strips offers complementary effects on biodiversity conservation. Implementing these schemes enhanced biodiversity by 20%–30%, while maintaining economic viability and similar profits/ha through premium pricing and subsidies. Their combined implementation could be a valuable future step for achieving multifunctional agricultural landscapes.

KEYWORDS

agri-environment scheme, arthropods, landscape structure, plants, pollinators, profit, subsidies, yield

1 | INTRODUCTION

Agriculture covers roughly 40% of the terrestrial surface, making it the primary driver of land cover change and the associated decline in biodiversity (Raven & Wagner, 2021). Prior to industrialization, land cover changes were not coupled with the industrialized and intensive conventional farming practices found in most countries of the Global North today. These intensified land-use practices endanger farmland biodiversity and vital ecosystem services, such as natural pest control, pollination and soil services (Wittwer et al., 2021). Despite ongoing intensification, a wealth of various low-intensity management approaches are employed, including local and landscape-scale diversification (Rosa-Schleich et al., 2019). For example, in Europe, the agri-environment schemes (AES) are government programs aimed at counteracting the negative effects of agricultural intensification, including measures applied to productive land and those taking land out of production (Batáry et al., 2015).

Vanbergen et al. (2020) classified farming approaches into three major sets of farm management systems with different levels of ecological intensification. The ecological intensification should promote functional biodiversity and associated ecosystem services (de la Riva et al., 2023). The first set of approaches focusses on increasing farming efficiency through sustainable intensification or precision farming by optimizing agrochemical inputs based on agrotechnological solutions, thereby minimizing externalities (Vanbergen et al., 2020). The second set of approaches emphasizes the benefits of substituting external inputs or environmentally harmful procedures (Vanbergen et al., 2020). For example, integrated pest management reduces the use of environmentally harmful pesticides by choosing less toxic products or substituting chemical control with biocontrol, while organic farming prohibits most synthetic inputs and genetically modified crops. The third and most diverse set involves the redesign of farming systems and nature-based approaches, emphasizing spatial and temporal heterogeneity of agricultural land use, while also leveraging productive and non-productive semi-natural landscape elements (Vanbergen et al., 2020).

Increasing landscape-scale crop heterogeneity through smaller field sizes (configurational heterogeneity) is a promising approach

to boosting farmland biodiversity without considerably altering agricultural area. A European-wide study showed that farmland biodiversity can be largely enhanced by increasing crop configurational heterogeneity on a landscape scale (Sirami et al., 2019). Although organic farming is gaining traction in Europe, increasing field sizes remains a crucial factor in constraining biodiversity (Tscharntke et al., 2021). Decreasing field sizes and thereby increasing edge habitats have significant positive effects on farmland biodiversity, comparable to those of organic farming practices (Batáry et al., 2017). Overall, enhancing configurational heterogeneities through smaller fields is expected to foster biodiversity and support ecosystems, with the benefits from ecosystem services potentially compensating for the associated yield losses (Batáry & Tscharntke, 2022).

Organic agriculture is widely regarded as a sustainable alternative to conventional farming, primarily due to its reliance on soil fertility, besides the prohibition of synthetic pesticides and fertilizers. Despite its benefits, organic farming typically yields 10–34% less than conventional agriculture, causing significant yield gaps in intensive agricultural regions, such as 50% for wheat in Western Europe (e.g. Batáry et al., 2017; Gabriel et al., 2010). Biodiversity benefits are notable, with around 30% more species and 50% higher abundance compared to conventional systems (Tuck et al., 2014), although these advantages are more pronounced in simpler farmland landscapes (Batáry et al., 2011). However, when accounting for lower yields in organic farming, these advantages are smaller when expressed per unit output or when additional land is required to meet demand (Batáry & Tscharntke, 2022; Gabriel et al., 2013). Economically, price premiums for organic products can offset yield gaps, with profits reaching up to double those of conventional farming per hectare (Batáry et al., 2017). To effectively enhance biodiversity at a landscape scale requires more than just organic certification; it involves implementing strategies such as cropland diversification and reducing field size, which are applicable in both conventional and organic systems.

Whereas organic farming reduces input intensity within cropped fields, sown wildflower strips or fields are set-aside habitats established to enhance biodiversity, particularly benefiting pollinators (Cooke et al., 2025) by temporarily taking land out of agricultural

production (González et al., 2026). These mostly annual landscape elements have gained popularity among conventional farmers in Western Europe, serving as magnets for pollinating bees and other flower-visiting insects (González et al., 2026). However, they also provide habitat for other species groups, such as ground-dwelling arthropods (Gallé et al., 2020), bats (Krings et al., 2022) and birds (Schmidt, Fartmann, et al., 2022). The effectiveness of flower strips depends on factors such as age and plant composition (Schmidt, Kirmer, et al., 2022), as well as their spatial and temporal placement within agricultural fields and landscapes (Eccard, 2022). They may provide habitats, offer overwintering sites and additional food resources for various organism groups, and contribute to ecosystem services—such as pollination and biological control (Török et al., 2021)—unless these benefits are directly undermined by conventional, intensive agricultural management (Tscharntke et al., 2016). Additionally, when integrated into agricultural landscapes, flower strips can enhance landscape connectivity, serving as corridors or stepping stones between semi-natural habitats, thereby facilitating movement and genetic exchange among populations of insects and other wildlife.

Although there is a vast and growing literature on the biodiversity effects of AES (Batáry et al., 2015), most studies do not assess the ecosystem service outcome most important to farmers: crop yield (Marja et al., 2024). This hampers demonstrating, especially to farmers, that AES can maintain yields comparable to conventional farming, which is a central aim of ecological intensification (Bommarco et al., 2013). Cost-benefit analyses are even rarer in farmland biodiversity studies, even though such evidence strongly influences farmers' management decisions, including participation in AES (Woodcock et al., 2025).

In this study, we addressed the research gap concerning the potential complementary effects of two different AES on farmland biodiversity and economic viability, which remains underexplored. Specifically, we evaluated the ecological and economic effectiveness of (i) organic farming, an in-production AES, (ii) annual flower strips along conventional wheat fields as an out-of-production AES, and (iii) compared these AES measures with conventional wheat fields as a control. Additionally, (iv) we examined the effect of local field size and whether it moderates these AES effects. We tested effects on wild arable plants and five arthropod groups (carabids, spiders, rove beetles, wild bees and hoverflies). Over 2 years, we sampled plants and arthropods at the margins of winter wheat fields or, in the case of flower strips, within the strips. We analysed species richness and community composition, and we conducted detailed agro-economic surveys with the farmers to assess the economic performance of the AES. We anticipated higher species diversity in both AES types compared to the control, but with each measure supporting different plant and arthropod communities. Regarding agro-economic valuations, we hypothesized that organic farming would incur lower costs and yield higher revenues due to its good market position and premium prices compared to conventional methods (Batáry et al., 2017). Additionally, we expected flower strips to perform

similarly to conventional controls since the AES subsidies compensate for the lost yield due to land being taken out of production.

2 | MATERIALS AND METHODS

2.1 | Study area and study design

The study area was located in Germany, in and around the Leinebergland region, adjacent to the southern foothills of the Harz Mountains. This region is characterized by forested hilltops and fertile, small-scale farmlands with crop fields and meadows in the valleys, interspersed with villages. It spans the administrative districts of the cities of Göttingen, Northeim and Osterode in Lower Saxony. The soils in this area are predominantly loamy, providing good fertility and drainage, which supports diverse agricultural practices. According to the German Weather Service (measuring point ID: 1691), the mean annual temperature and total annual precipitation in the study area were 9.81°C and 543 mm in 2016, and 9.86°C and 776 mm in 2017, respectively. The mean elevation of the study sites was 75 m. Within this area, we first identified candidate landscapes by locating villages with at least one certified organic arable farmer and confirming the availability of an organic winter wheat field. Landscapes were defined as 1000-m-radius buffers around the sampled field margins. We then selected nine landscapes, each containing a triplet of winter wheat fields (with harvesting time around the end of July and early August): one organic field managed by an organic farmer, and two conventional fields (one as control and one with an annual flower strip; the latter one hereafter flower strip field), the latter two managed by the same conventional farmer in each landscape. Given that double subsidies from these two AES are prohibited in Lower Saxony, there were no organic fields with flower strips available, preventing us from directly testing this combination. We selected fields of similar size that were close to each other, but preferably not adjacent, on similar soil and under the same climatic conditions, and situated within the farmland matrix, away from built-up areas and forests (distances between study fields within a landscape: 1585 ± 132 m, mean $\pm$ SEM). All farmers gave permission for the field sampling on their land. These relatively small-scale agricultural landscapes are characterized by a mixture of fields where neighbouring fields often belong to different farmers. Farmers typically own or rent fields that are interspersed throughout the landscape, which may partly hinder the gradual merging of farms and fields. An additional site selection criterion was that the landscapes, with a 1000-m-radius buffer around the sampled field margins (as defined later), represented a gradient of field sizes, ranging from 1.2 to 6.5 ha (see Table 1, for landscape and study field size data per management type).

All biodiversity and agronomic surveys were conducted in the growing season of 2016 and repeated in 2017. Due to crop rotation, most fields were changed between 2016 and 2017, with the exception of two fields with flower strips. Moreover, since there is

	Organic field	Conventional control field	Flower strip field
Landscape structure			
Field size (ha)	3.2±0.3	3.3±0.3	3.4±0.2
Agricultural area (%)	71.2±3.0	73.3±2.7	68.2±3.1
Management intensity			
Fertilizer (kg N/ha)	52.8±17.2	181.3±10.3	186.9±9.0
Pesticide application (#)	0.0±0.0	4.4±0.2	4.4±0.2
Study field size (ha)	4.6±0.8	5.0±0.6	5.6±1.2

TABLE 1 Landscape structure (in 1000 m buffer) around and local management intensity of study fields (mean±SEM) in 2016 and 2017 (N=54 fields, data on management intensity only from 2016).

typically one organic farmer per village and one or two conventional farmers with fields containing flower strips, we had to completely change four landscapes to meet the study site selection criteria, leading to the involvement of new farmers. In two original landscapes, we engaged two new conventional farmers in 2017. This resulted in 2 years×9 landscapes×3 fields=54 study fields managed by 12 organic farmers and 16 conventional farmers (for a map, see [Appendix S1](#) in Supporting Information). Landscape layers were compiled from official digital topographic maps (ATKIS DTK50, 2015) and updated by on-screen digitisation of ArcGIS World Imagery and field verification; from these, we derived field size and arable land cover. We documented key experimental details in alignment with standardized reporting guidelines for agroecology, underscoring our comprehensive approach to data collection in agroecological studies (Daykin et al., 2023).

To standardize the comparison among the management types, all selected fields were adjacent to a grassy margin adjoining a dirt road. In the case of fields with flower strips, the strip was located between the grassy margin and the field edge. In Lower Saxony, flower strips typically range from 6 to 30 m in width, but may also include flower areas up to 2 hectares, as specified in the AES rules of Lower Saxony 2014 ([Appendix S2](#)). In our study, the average width was 22±3 m, with a minimum of five flowering species listed in the AES requirements. The studied flower strips averaged a size of 0.57±0.08 ha, covering approximately 15% of the conventional fields. Organic fields were fertilized with approximately 50 kg of nitrogen per hectare and no pesticides were used, whereas both types of conventional fields received over 180 kg of nitrogen per hectare and were treated with pesticides more than four times per year ([Table 1](#)).

2.2 | Biodiversity survey

To avoid interference from trees and hedgerows, we established 50-m-long survey transects along the grassy margins within 1 m from the edge of the wheat field. In fields with flower strips, transects were similarly set up within 1 m from the edge of the flower strip ([Figure S1](#)). In June and July of 2016 and 2017, we surveyed all plants in the wheat fields or flower strips by estimating the cover per species in four plots (each 5×1 m in size, with a 10 m distance between them) per transect (N=216 plots; for further

details, see Szitár et al. (2022)). We collected arthropods (carabids, spiders and rove beetles) using two pitfall traps per transect (situated 30 m apart and placed at the interface of the wheat field and grassy margin) over two 1-week periods from May to June each year (N=216 pitfall traps; for further methodological details, see Gallé et al. (2020)). Finally, we surveyed wild bees and hoverflies three times in June and July each year using 50 m long and 2 m wide transects (100 m²) along the field border, with 1 m in the grassy margin and 1 m into the field (N=54 transects; for further details see Geppert et al. (2020)). We conducted two different surveys for pollinators: first, a 15-min transect walk was used to survey wild bees and hoverflies; second, we performed sweep-net sampling to complement the transect surveys, standardizing it to 60 sweeps per transect (one sweep per footstep). All plants were identified to the species level. Most arthropods were also identified to the species level, while few specimens in carabids, spiders, rove beetles, and hoverflies remained unidentified or classified to a higher taxonomic level only (e.g. *Trochosa* sp.). No ethical approval was required for this study.

2.3 | Economic comparison

We conducted a detailed economic survey of our study fields based on approximately 2-h-long interviews with farmers, using a pre-prepared questionnaire, as outlined in Batáry et al. (2017) (N=54, for further details, see [Appendix S3](#)). Total costs included expenses for mechanical field management, seeds for the crop and flower strip plants, soil analyses, chemical plant protection, chemical growth regulators, synthetic and organic fertilizers, agricultural wage enterprises, working time and crop hail insurance. Total revenues encompassed income from grain and straw, as well as all types of subsidies, including those for organic agriculture (234 €/ha) and flower strip AES (875 €/ha). We calculated all costs and revenues per hectare for each field. In the case of the flower strip field, the flower strip itself was considered part of the conventional field, and thus costs and revenues for the flower strip and wheat were allocated per hectare. To obtain the total profit per field (€/ha), we subtracted the aggregated costs from the overall revenues. Finally, we also collected data on the yield from the farmer interviews; for the flower strip field, this refers only to the wheat-growing area, excluding the flower strip.

2.4 | Data analysis

Prior to analysing the biodiversity data (Batáry, 2026), we pooled the data per transect and per round within year, resulting in a sample size of 54 for all statistical analyses. The same sample size of 54 was also used for economic comparisons. We tested the effects of the two main design variables—management type (organic, conventional control and flower strip) and mean field size in the landscape as a measure of landscape configurational heterogeneity—as well as their interaction, using general or generalized mixed-effects models. These models were applied to species richness of plants, carabids, spiders, rove beetles, bees and hoverflies with a Poisson distribution, costs, revenue and profit with a negative binomial distribution, and yield with a normal distribution (using the lmerTest package, Kuznetsova et al. (2017)). To account for our nested design, we used the following random structure: ‘farmer’ nested within ‘village’ and crossed with ‘year’. Additionally, we included agricultural cover percentage as a landscape compositional heterogeneity covariate in all full models. The full model in R syntax was “y ~ mean field size × management type + agricultural cover % + (1|year) + (1|village/farmer)”. Before model simplification, we checked the normality of the residuals and heteroscedasticity, which did not show any signs of bias. We also calculated the overdispersion factor for Poisson and negative binomial models, which was always between 0.8 and 1.3, indicating no signs of overdispersion (using the blmeco package; Korner-Nievergelt et al. (2015)). Additionally, to address collinearity, we calculated the variance inflation factor for the above models without interaction terms (using the car package; Fox and Weisberg (2019)), which was always below 1.1, suggesting no collinearity. To simplify the full models, we applied a single fixed-effect deletion using the drop1 function of the lme4 package to identify the minimal adequate model (MAM) with the lowest AIC value. The contrasts between different management types in the MAMs was investigated by re-ordering factor levels. Finally, we also calculated the marginal and conditional R^2 values for the MAMs (using the MuMIn package; Bartoń (2024)).

To further explore the economics of flower strip establishment and wheat production in fields with flower strips, we conducted additional analyses comparing costs, revenues, and profits between the wheat-only portion of flower strip fields (i.e. excluding the strip area) and conventional control fields. We used the same model setup as described above, with management type as the sole fixed effect.

We performed redundancy analyses (RDA) to test the effects of management type, mean field size and agricultural cover percentage on the community composition of plants, carabids, spiders, rove beetles, bees and hoverflies using the vegan package (Oksanen et al., 2025). To characterize the community composition of plants, we used the percentage relative cover of each species, whereas for arthropods, we used their abundances. The species matrices were constrained by the aforementioned predictor variables, with year, village and farmer included as conditional variables to account for nesting. Prior to the analyses, the species matrices were transformed using the Hellinger transformation (Legendre & Gallagher, 2001). In

addition to testing the general effect of management type, we conducted multiple comparisons for all contrasts using the BiodiversityR package (Kindt & Coe, 2005). Finally, we plotted Venn diagrams to visualize how species were shared among the three management types using the ggvenn (Yan, 2023) and ggplot2 (Wickham, 2016) packages. All analyses were conducted in the R environment (R Development Core Team, 2025).

3 | RESULTS

3.1 | Farmland biodiversity

We identified a total of 139 plant species, including 16 species from the annual flower strip seed mixtures. *Phacelia tanacetifolia* was present in all flower strips ($N=18$) and was often dominant, with *Raphanus sativus* and *Fagopyrum esculentum* also frequently present. In organic fields, the most frequently occurring plant species were *Myosotis arvensis*, *Geranium pusillum*, *Apera spica-venti*, and *Veronica persica*, whereas in conventional fields, *Elymus repens* was most frequent. When testing the effects of field size and management on plant species richness, we found that richness in flower strips was 198% higher, and in organic fields, 180% higher compared to conventional fields (Table S1, Figure 1A). This translated to an average of around 25 species in flower strips, partly due to the approximately seven sown flower strip species (Figure S2). Furthermore, we observed a weak negative effect of field size on plant species richness. Testing local and landscape effects on plant community composition, we found distinct differences between flower strips and organic fields, as well as between organic and conventional fields (Table S2, Figure 2a). The Venn diagram supports this latter difference and highlights that the flora of conventional fields was largely encompassed by both AES types (Figure 3).

We captured 4348 carabid beetles belonging to 78 species, with 80 specimens unidentified. The most common species were *Pterostichus melanarius* (26.2% of all individuals), *Anchomenus dorsalis* (22.6%) and *Metallina lampros* (9.6%). We found that both AES field types contained significantly more species, with flower strips having 33% and organic fields 23% more than the control conventional fields (Table S1, Figure 1B). The community composition analysis showed that the three management types differed from each other, with organic fields situated in-between conventional fields and flower strips in the ordination biplot (Table S2, Figure 2b). The Venn diagram of carabids indicated that flower strips had the most distinct fauna, with 23% unique species (Figure 3).

We captured 3010 spiders belonging to 96 species, with 22 specimens remaining unidentified. The most common species were *Lycosidae* sp. (18.9%), *Oedothorax apicatus* (13.3%) and *Pardosa palustris* (8.0%). Spider species richness displayed a similar pattern to the carabids, with flower strips having 29% and organic fields 23% more species compared to conventional fields, although there were no differences between organic and conventional fields (Table S1, Figure 1C). Regarding community composition, the three

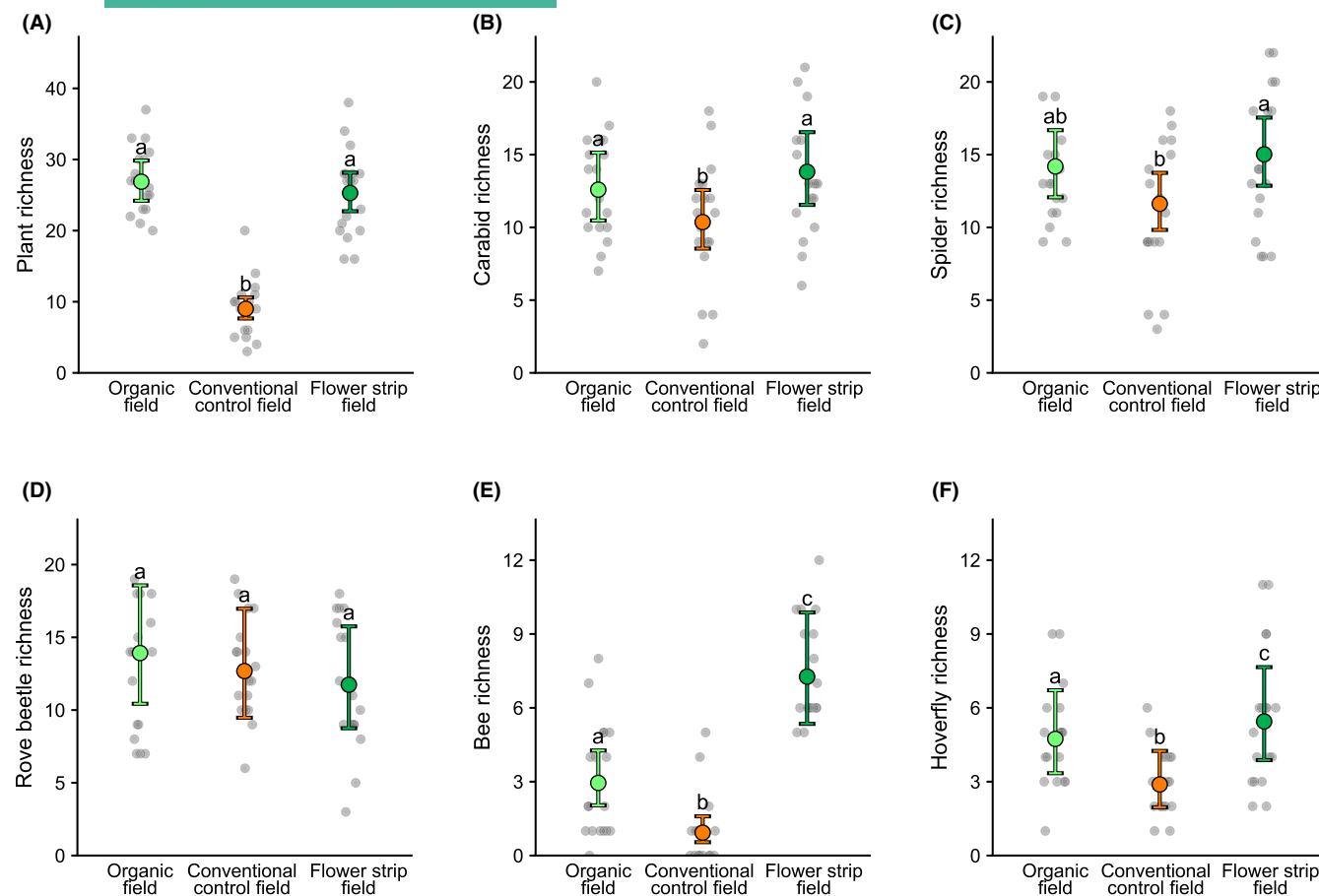


FIGURE 1 Model-predicted mean of plant (A), carabid (B), spider (C), rove beetle (D), bee (E), and hoverfly (F) species richness in relation to management type (organic field, conventional field, or flower strip field; $N=54$). Letters above the error bars indicate significant differences at $p < 0.05$. Error bars represent 95% confidence intervals calculated on the response scale.

management types differed from each other, with organic fields positioned centrally between conventional fields and flower strips in the ordination biplot (Table S2, Figure 2c). The Venn diagram showed that each management type, including conventional fields, had about 10%–15% unique species (Figure 3).

We captured 5235 rove beetles belonging to 93 species, with 23 specimens remaining unidentified. The most common species were *Drusilla canaliculata* (35.7%), *Falagium thoracica* (15.7%) and *Tachinus rufipes* (12.9%). We did not find an effect of field size or management type on either species richness or community composition of rove beetles (Tables S1 and S2; Figures 1D and 2d). However, the Venn diagram showed a high ratio of unique species for organic fields (20%) and flower strips (25%), with no unique species for conventional fields.

We registered 993 wild bees belonging to 41 species. The most common species were: *Bombus terrestris* (50.2%), *Bombus lapidarius* (18.7%) and *Bombus pascuorum* (5.3%). In flower strips, we found 682% more species compared to organic fields, and organic fields had 218% more than conventional fields, which were by far the poorest in species richness (Table S1; Figure 1E). The community composition was also significantly different among the management types (Table S2; Figure 2e). The Venn diagram showed the

highest proportion of unique species in flower strips (49%), with some unique species also present in organic fields (15%) (Figure 3).

We registered 1091 hoverflies belonging to 39 species, with 175 individuals remaining unidentified. The most common species had all aphidophagous larvae: *Melanostoma mellinum* (25.8%), *Episyrphus balteatus* (23.0%) and *Sphaerophoria scripta* (10.3%). We found 89% more species in flower strips and 64% more in organic fields compared to conventional fields (Table S1; Figure 1F). The community composition differed significantly among the management types and was also influenced by field size (Table S2, Figure 2f). The Venn diagram showed that unique species appeared only in the flower strips (33%) (Figure 3).

Across all six study taxa, we registered a total of 486 species. When averaging the unique species per management type, we found that flower strips had, on average, 28% unique species, organic fields had 12%, while conventional control fields had only 3%.

3.2 | Economic comparison

When we analysed the wheat yield, we found that the yield in conventional fields, both with and without flower strips, was twice as

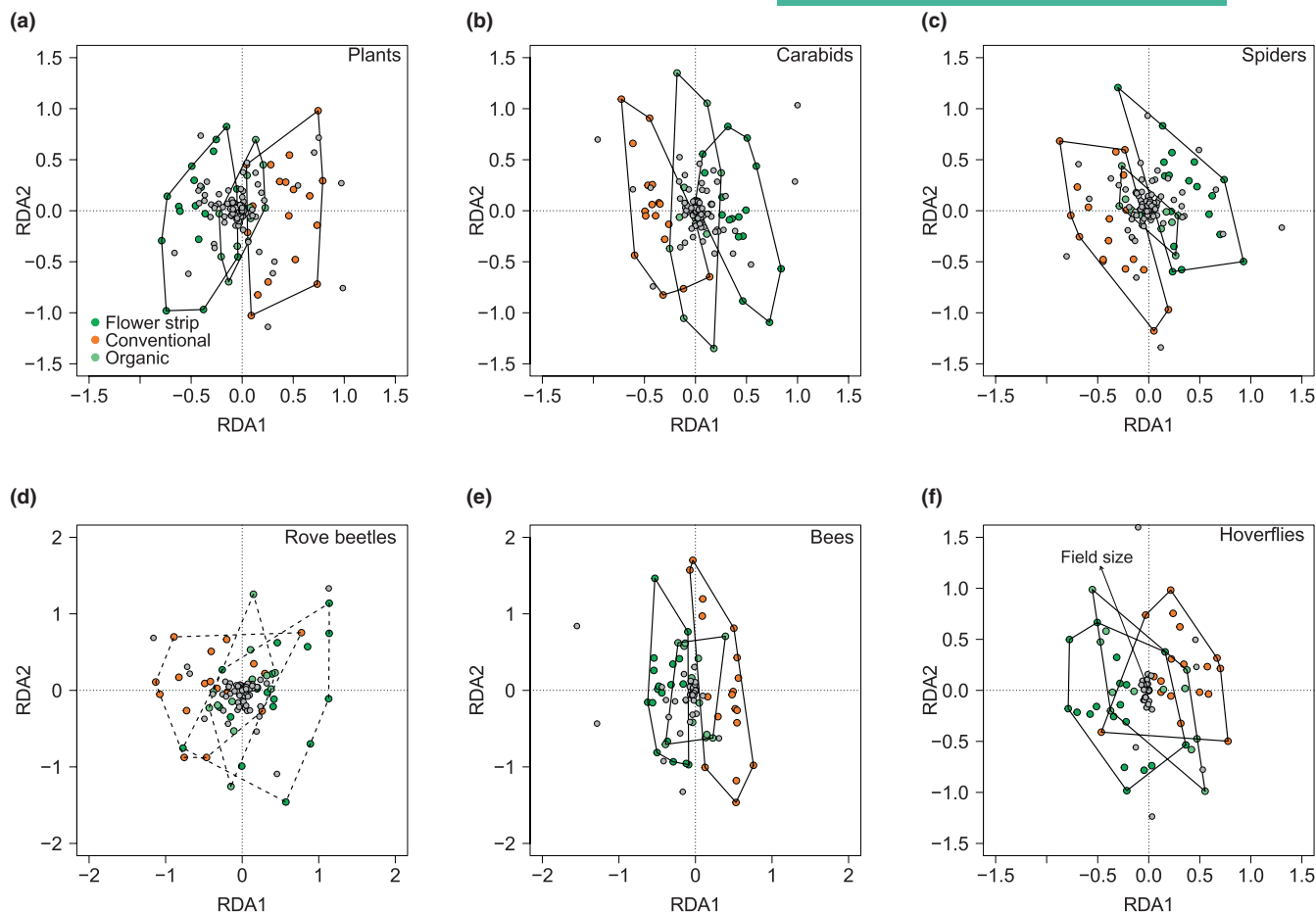


FIGURE 2 RDA biplots for plants (a), carabids (b), spiders (c), rove beetles (d), bees (e), and hoverflies (f) showing species in grey circles against site Figure 2a with minimum convex polygons according to field management type (organic, conventional or flower strip; $N = 54$). Non-significant management effect is shown by dashed convex polygon line. Arrow indicates significant effect of field size.

high as in organic fields (Table S3, Figure 4A). There was no statistically significant difference in yield between flower strip fields and conventional control fields, but yield was still 4.4% lower (3.8 dt/ha) in the former. The cost of field management was similar across all management types, though slightly lower in fields with flower strips (Table S3, Figure 4A). Nonetheless, these fields with flower strips generated the lowest revenues, even lower than conventional fields without flower strips, whereas organic farming achieved roughly double the revenue of conventional fields due to premium pricing (Table S3, Figure 4A). This led to a similar pattern in profit, where the difference between organic fields and conventional ones further increased, with organic fields achieving over 150% higher profits than conventional controls (Table S3, Figure 4A). The difference in profit between conventional fields with and without flower strips remained significant, with profits 19% lower in fields with AES. Additionally, profit per unit area tended to increase with increasing field size.

Furthermore, when comparing costs, revenues and profits between the wheat only portion of flower strip fields (i.e. excluding the strip) and conventional control fields (Table 2), we found similar wheat production costs (only 29 €/ha, i.e. 3% lower in the former). However, revenues were statistically significantly higher in the

control fields by 165 €/ha (10% higher), and accordingly profits were higher by 136 €/ha (21%). Finally, we also calculated the share of subsidies of revenues for the two studied AES based on our economic surveys, which were 7% for flower strip fields and 8% for organic fields.

4 | DISCUSSION

In this study, we compared the ecological and economic effectiveness of two contrasting AES: flower strips implemented by conventional farmers, where land is taken out of production, and organic farming, where land is managed without agrochemical inputs. Both AES enhanced the target taxa—wild arable plants, pollinator insects and ground-dwelling arthropods—compared to the conventional control, although some differences were observed based on taxon identity. Flower strips attracted bees more than organic fields due to their higher abundance of flowers, while other taxa benefited similarly from both AESs in terms of species richness. Notably, community composition among the studied taxa differed considerably, indicating that the two AES encompassed partly distinct species, with the conventional control often being a subset of the other two.

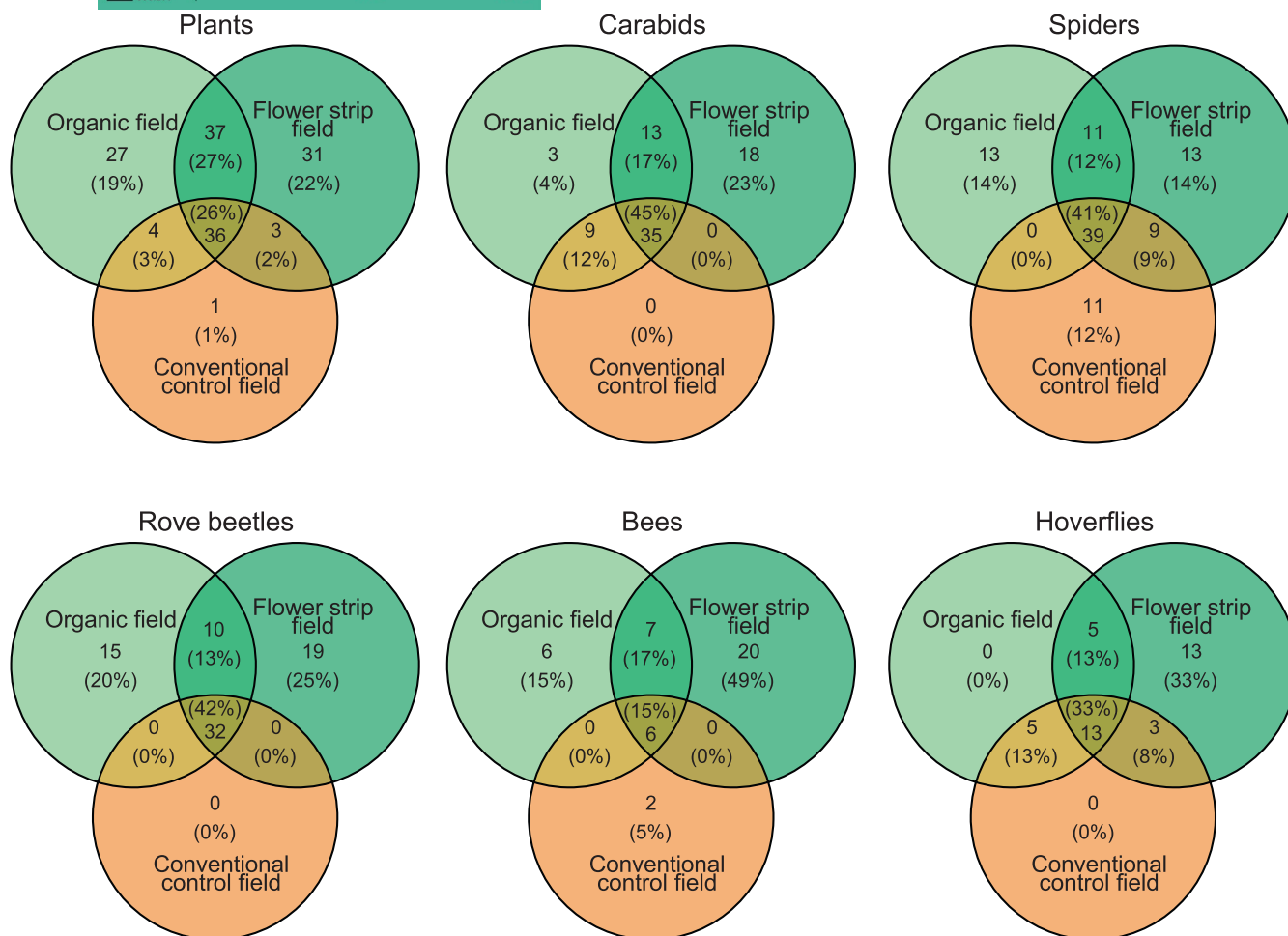


FIGURE 3 Venn diagrams representing the number of species and their percentage of overlap and difference among the three management types in the study taxa.

Lastly, the agro-economic comparison showed different profitability across the two AES and the conventional control due to markedly different wheat yields and revenues between conventional and organic farming.

4.1 | Farmland biodiversity

When we analysed the effects of AES on plant species richness, we found that both schemes roughly tripled the number of species compared to conventional controls. However, when we excluded the plant species sown from the seed mix in the flower strips, we observed that organic farming had a higher species richness of wild arable plants than the strips themselves. Nonetheless, the species richness in the flower strips still doubled that of the control fields. This indicates that the high richness of wild arable plants in the flower strips is supported by the soil seed and bud bank beneath the one-year-old flower strips, and by seed rain from the adjacent grassy margins, if the area is set aside from intensive conventional management (Wietzke et al., 2020). However, it cannot immediately reach the diversity levels found in organic farming, which benefits

from a species-rich soil seed bank as it was found in the assessment of Roschewitz et al. (2005) for the same region. Furthermore, it should be noted that the two AES sustain somewhat different plant communities due to their markedly different management practices, whereas the rather impoverished flora of the conventional control fields was a subset of both (Carrié et al., 2022).

Regarding the ground-dwelling arthropods, we found that both schemes increased the species richness of carabids and spiders by approximately 20%–30%. This suggests that flower strips not only attract and nourish pollinator insects but also benefit other arthropod groups (Raderschall et al., 2022). However, we did not observe a similar relationship for rove beetles, which might be less sensitive to farmland management and are a very mobile group among the studied ground-dwelling arthropods (Batáry et al., 2017). This aligns with the observation that the community composition of this species group was the only one showing no variation by management type. Nonetheless, Venn diagrams revealed a similar pattern to that of the plants, where the conventional control sites had nearly no unique species and were a subset of the combination of the two AES. In the case of carabids and spiders, community composition varied by management (Batáry et al., 2012), albeit with different patterns of

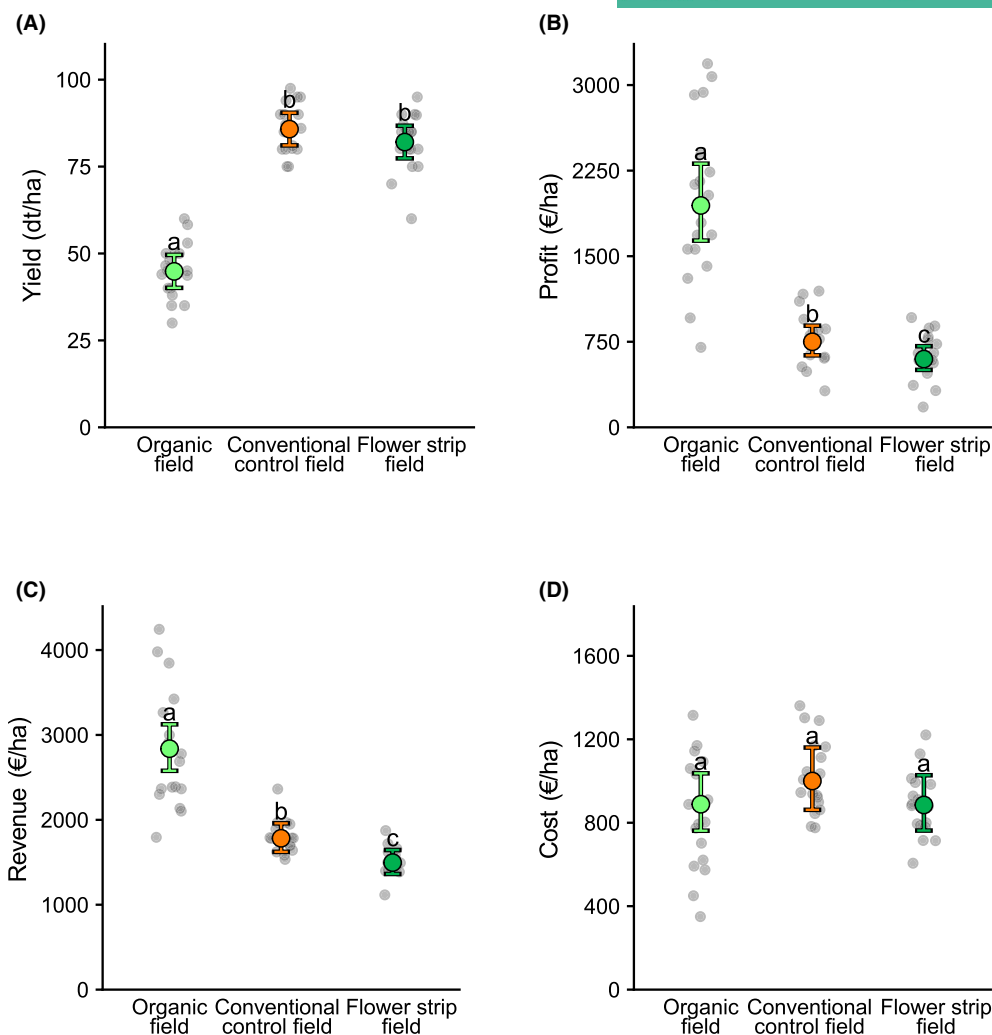


FIGURE 4 Model-predicted mean of yield (A), profit (B), revenue (C) and cost (D) in relation to field management type (organic field, conventional field, or flower strip field; $N = 54$). Letters above the error bars indicate significant differences at $p < 0.05$. Error bars are 95% confidence intervals calculated on the response scale.

TABLE 2 Cost, revenue and profit in wheat part of flower strip fields versus control conventional wheat field (mean $\pm$ SEM) in 2016 and 2017 ($N = 36$ fields).

	Wheat part of flower strip field	Conventional control field
Cost (€/ha)	992 $\pm$ 42 (a)	1021 $\pm$ 42 (a)
Revenue (€/ha)	1634 $\pm$ 40 (a)	1799 $\pm$ 44 (b)
Profit (€/ha)	642 $\pm$ 56 (a)	778 $\pm$ 48 (b)

Note: Significant differences at $p < 0.05$ are marked by different letters in parentheses based on generalized mixed-effects models.

unique and shared species. For carabids, flower strips hosted more than 20% unique species compared with the other management options, highlighting that this habitat can attract diverse farmland species, especially granivorous species, likely due to a greater amount and diversity of plant seeds (Gayer et al., 2019). In contrast, the distribution pattern for spiders based on the Venn diagram was rather balanced across all management types, with more than 10% unique

species in each, showing that the different management practices influence their community structure only slightly.

Concerning pollinator insects, we found that both schemes sustained hoverfly species richness well, doubling the species compared to the control. However, for bees, as expected, the abundance of flowers in the flower strips acted as a magnet (Batáry & Tscharntke, 2022), resulting in twice the richness compared to organic farming, which was still statistically significantly higher than the control. In addition, the diversity and temporal continuity of floral resources provided by flower strips may also enhance pollinator health by offering a more balanced diet throughout the season (Filipiak et al., 2023). This largely confirms findings in the literature (Buhk et al., 2018). However, the well-known strong local positive association between annual flower strips and arthropods may come with risks due to pesticide use in adjacent fields, residual pesticides in the soil and annual rotations destroying the overwintering habitats (Ganser et al., 2019). In both pollinator groups, community composition was associated with management type. For wild bees, the flower strips particularly enhanced bumblebees (Geppert

et al., 2020), and both bees and hoverflies were characterized by a high number of unique species within these strips. The composition of hoverfly communities may be further influenced by their life cycle, as larval stages often depend on non-floral resources, such as aphid colonies or decaying matter (Moquet et al., 2018).

These shifts in pollinator richness and community composition may cascade to higher trophic levels by increasing prey availability and foraging opportunities for insectivores. In our study region, organic wheat harboured twice the bird abundance than in conventional fields, with most species being insectivores or omnivores (Batáry et al., 2010). In the same region, the activity of narrow-space foraging bats was threefold higher over annual flower fields than over wheat (Krings et al., 2022), consistent with a bottom-up pathway. However, whether such activity responses translate into demographic benefits and increasing population densities remains unclear and may depend on landscape context, pesticide spillover from adjacent fields and the temporal stability of resources. Targeted studies that couple insect monitoring with acoustic/telemetry tracking and diet, reproduction, and survival of insectivores in relation to AES are therefore needed.

We found no relationship between agricultural area percentage and species richness for any taxa, as the study was designed to maintain a high level of agricultural area, minimizing the influence of semi-natural areas (Batáry et al., 2011). Field size (1.2–6.5 ha) did not explain additional variation after accounting for treatment and the random effect of village, suggesting any effect, if present, was small within this study system. The moderate gradient and between-village structure may also have reduced power. A negative trend was observed with increasing field size on plant species richness, and field size also significantly changed the structure of hoverfly community composition. Interestingly, a related study found that smaller field sizes were positively associated with wild bee abundance (Hass et al., 2018). This suggests that increasing field border density might influence AES effectiveness, similar to the intermediate landscape-complexity hypothesis (Tschamntke et al., 2012).

4.2 | Economic comparison

We found that the harvested yield on the cropped area of conventional fields, with or without flower strips, was roughly twice as high as on organic fields, which was already high compared to most parts of the continent (Van Eynde et al., 2025). This substantial yield gap likely reflects the high yield potential of the region, which conventional management could realize through mineral fertilizer and chemical crop protection, while organic yields were constrained mainly by nitrogen supply and weed/disease pressures. In our study, yields were calculated only for the cropped wheat area (i.e. not accounting for the land taken out for the flower strip), whereas Pywell et al. (2015), in a long-term randomized block experiment on a 900-ha farm in central England, included the habitat area and showed that allocating less productive land to wildlife habitat can offset field-scale yield losses. This suggests that targeting habitat to marginal areas and concentrating cropping on higher-productivity land can maintain overall

field-level output while delivering environmental benefits (Batáry and Tschamntke (2022)). During site selection, we also observed that farmers often placed annual flower strips on north-facing areas adjacent to forest edges—locations likely less productive.

Although there were no considerable differences in management costs among the three management types, revenues in organic fields were about doubled compared to conventional ones due to better marketability and premium pricing (Smith et al., 2020). Ultimately, profits were also much higher in organic fields (Heinrichs et al., 2021), where farms were roughly half the size of conventional ones, possibly resulting in similar economic outcomes for both farm types on a household level. Furthermore, we found lower revenues and profits in flower strip fields compared to conventional control fields. When we further explored the potential causes behind these patterns by comparing only the wheat portion of flower strip fields with conventional control fields, we found that wheat production costs were very similar. However, revenues were higher in the control fields by 165 €/ha (10% higher) and profits by 136 €/ha (21%), likely due to somewhat lower yield and possibly lower grain quality in the flower strip fields. The overall profit of the flower strip fields, including the land taken out for the flower strips (626 €/ha), was only slightly lower than the profit without considering the strips (642 €/ha), showing that the subsidy for flower strips nearly compensates the foregone margin from taking land out of wheat production. Thus, we think that the higher profit of the conventional control fields (778 €/ha) is due to the higher revenues there, which is possibly linked to farmers choosing less fertile and less productive fields for establishing flower strips. Establishing flower strips in more productive areas of fields, that is not simply at the margins but inside fields, as tested by Woodcock et al. (2025), can maximize yields in the cropped areas by supporting multiple ecosystem services. However, they also found that AES subsidies did not financially compensate for the land taken out for in-field strips; compensation was sufficient only when strips were placed at field margins. This suggests that payment schemes should be aligned with spatial placement. However, this should be interpreted cautiously, as the number of conventional farms was relatively low in our study. Finally, we observed a tendency for increasing profit with increasing field size, which might be attributed to economies of scale (Batáry et al., 2017).

5 | CONCLUSIONS

Our results demonstrate that both AESs, organic farming and flower strips, enhance farmland biodiversity by increasing the species richness of plants and various arthropod groups, while also maintaining distinctly different communities. This suggests that their combination could yield the highest biodiversity benefits. Given that spillover of beneficial organisms and their services from flower strips into conventional fields is often constrained by higher local land-use intensity (Rodenwald et al., 2023; Zamorano et al., 2020), organic agroecosystems may be better able to realize these benefits. Applying both schemes locally, organic fields with flower strips may be less

economically viable due to limited farm area of individual organic farms, coupled with high prices. However, spatially combining them and joint planning by farmers at the landscape level could enhance farmland biodiversity and associated ecosystem services (Boinot et al., 2025; Tschardt et al., 2024), creating multifunctional land sharing-sparing mosaic landscapes (Grass et al., 2021). This approach is critical in the face of rapidly accelerating global changes and aligns with the EU's 2030 goal of halving pesticide use. While some yield loss might occur due to less intensive management of organic farming and land being taken out of production for flower strips (Batáry & Tschardt, 2022), substantial losses from weather hazards, pest outbreaks, or limited soil and pollination services can be mitigated through landscape-scale diversification and the combined benefits they offer (Nelson et al., 2022; Tamburini et al., 2020). Thus, in our study region and crop system, the combination of two widely used German AES—organic farming and annual flower strips—can provide complementary biodiversity enhancement. However, effectiveness is context dependent, and AES should be selected and integrated to fit regional landscape context, farm objectives and locally available management options (Batáry et al., 2015).

AUTHOR CONTRIBUTIONS

Péter Batáry conceived the conceptualization, led the data curation and performed the formal analysis and methodology development. Costanza Geppert and Rita Földesi contributed to the data curation and writing of the original draft, with critical revisions and editing support. Róbert Gallé, Katalin Sztár, Edina Török, Christina Fischer and Oliver Musshoff provided original draft contributions and participated in review and editing. Teja Tschardt contributed to the conceptualization and participated in both the writing of the original draft and the review and editing process. All authors critically contributed to the drafts and gave their final approval.

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CONFLICT OF INTEREST STATEMENT

The authors declare that the research was conducted without any commercial or financial relationships that could be construed as a potential conflict of interest. Péter Batáry is an Associate Editor of the *Journal of Applied Ecology* but took no part in the peer review and decision-making processes for this paper.

DATA AVAILABILITY STATEMENT

Economic, landscape and species community data are available in the Zenodo Digital Repository <https://doi.org/10.5281/zenodo.21567304> (Batáry, 2026).

ORCID

Péter Batáry  <https://orcid.org/0000-0002-1017-6996>
 Costanza Geppert  <https://orcid.org/0000-0003-1970-4131>
 Rita Földesi  <https://orcid.org/0000-0002-3500-981X>
 Róbert Gallé  <https://orcid.org/0000-0002-5516-8623>
 Katalin Sztár  <https://orcid.org/0000-0002-8810-540X>
 Edina Török  <https://orcid.org/0000-0001-5982-7078>
 Christina Fischer  <https://orcid.org/0000-0001-7784-1105>
 Oliver Musshoff  <https://orcid.org/0000-0002-3746-623X>
 Teja Tschardt  <https://orcid.org/0000-0002-4482-3178>

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SUPPORTING INFORMATION

Additional supporting information can be found online in the Supporting Information section at the end of this article.

Appendix S1. 2LS_2016-17_Batary.kml. Location of 54 winter wheat fields around the city of Göttingen, Lower Saxony, Germany. The village name is shortened to the first three letters and means one landscape. Organic fields are marked in yellow and coded with 'Org', conventional fields are marked in red and coded with 'Con', and conventional fields with flower strips are marked in green and coded with 'CFS'. The year is coded as 2016 and 2017.

Appendix S2. Flower strip plant composition.

Appendix S3. Economic survey methodology.

Figure S1. Within-field study design.

Figure S2. Mean of plant species richness without planted flower mixture species in relation to management type (organic, conventional or flower strip; $n=54$). Letters above the bars show significant differences at $p < 0.05$. Error bars represent SEM.

Table S1. Summary table for GLMM results after model simplification showing the effects (ES: effect size, with 95 % confidence intervals) of field size and management on plant and arthropod species richness ($N=54$).

Table S2. Results of RDA presenting variance, F and p -values of ordination models on plant and arthropod communities ($N=54$).

Table S3. Summary table for GLMM results after model simplification showing the effects (ES: effect size with 95 % confidence intervals)

of field size and management on yield (dt/ha), profit (€/ha), revenue (€/ha) and cost (€/ha) ($N=54$).

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