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Green covers effectively increase arthropod biodiversity in orchards, even at high management intensity

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ABSTRACT

Agri-environmental measures such as wildflower strips and green covers are a key instrument to halt biodiversity loss and enhance the delivery of biodiversity-based ecosystem services in farmland. Agri-environmental measures produce mixed biodiversity benefits and it has been hypothesized that this is partly due to the moderating effects of farm management intensity. However, contrasting hypotheses exist suggesting both positive and negative effects of management intensity on the ecological effectiveness of agri-environmental measures. To improve our understanding of the relation between farm management and effects of measures under real-life scenarios, we established flowering green covers in 15 Spanish stone fruit orchards varying in management intensity. In paired green cover and conventionally managed plots within the same orchards, we sampled arthropod pollinators, predators, and parasitoids, as well as flowering plants. Abundance and species richness of all functional groups was consistently higher in green covers compared to control alleys. The effectiveness of establishing green covers increased with management intensity for pollinators and flowers, but not for predators and parasitoids. Our results suggest that, depending on the target species group, agri-environmental measures are at least equally effective, if not more effective, when farm management intensity is high. Therefore, the hypothesized negative impact of high-intensity farm management on agri-environmental measure effectiveness does not justify reallocating budgets away from more intensive farms. Implementing agri-environmental measures in highly intensive farmland is valuable, especially considering their potential to provide ecosystem services, and the urgent need for action in those areas where biodiversity is most severely degraded.

1. Introduction

Traditional low-intensity farming systems with a high nature value have dominated the European landscape until the rapid agricultural modernization that took place during the second half of the 20th century (Bignal and McCracken, 2000; Benton et al., 2003; Jepsen et al., 2015). To increase yields, complex agro-ecosystems were replaced by simplified farming systems, characterized by high levels of mechanization, use of external inputs such as agrochemicals, high-yielding crop varieties, and intensive water management (Matson et al., 1997; Bignal and McCracken, 2000; Foley et al., 2005; Tscharntke et al., 2005). These intensified farming systems succeeded in increasing food production, but this came at the expense of farmland biodiversity and the ecosystem services it provides (Foley et al., 2005; Henle et al., 2008; Potts et al., 2010; Hooper et al., 2012; Garibaldi et al., 2017). Paradoxically, these environmental impacts also negatively affect intensive farming systems themselves, for example as a result of decreased crop pollination and reduced natural pest control (Tscharntke et al., 2005; Klein et al., 2007; Hooper et al., 2012; Dainese et al., 2019). When ecosystem services are degraded, farming systems are more likely to be vulnerable to unpredictable events like pest infestations, droughts, and floods (Tscharntke et al., 2005; Kremen and Miles, 2012), leading to high economic and environmental costs (Altieri, 1999), and threatening food security (Garibaldi et al., 2017).

There is a growing call to prevent this undesirable scenario of farming systems causing substantial negative environmental impacts while facing high economic costs to artificially replace lost ecosystem services. A potential solution is an agricultural transition from systems that depend primarily on external inputs to systems that rely more on biodiversity-based ecosystem services (Bommarco et al., 2013; Garibaldi

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et al., 2017; Dainese et al., 2019). In Europe, the Common Agricultural Policy (CAP) is a key driver of agricultural practices and land-use change on farms. Environmental considerations and biodiversity conservation are taking an increasingly prominent place in discussions on the CAP reform, and the CAP 2023–27 is a key tool in reaching multiple goals of the European Green Deal (European Commission, 2020; Díaz et al., 2021). Agri-environmental schemes are currently the main CAP tool to restore and reinforce farmland biodiversity. Through this subsidy system, farmers are economically incentivized to adopt nature-friendly methods in their management and to set aside non-productive areas for biodiversity (Primdahl et al., 2003). Agri-environmental schemes prescribe a set of agri-environmental measures that are expected to enhance local farmland biodiversity. However, biodiversity benefits do not always materialize when implemented in the context of the daily activities of farm businesses (Batáry et al., 2015). The effects of agri-environmental schemes therefore remain variable (Kleijn and Sutherland, 2003; Tscharntke et al., 2005; Kleijn et al., 2011; Scheper et al., 2013) and despite substantial efforts and expenditures, the decline in farmland biodiversity continues (Cole et al., 2020; European Court of Auditors, 2020; Hasler et al., 2022).

The type of measure taken is a key factor explaining its effectiveness in increasing biodiversity (Batáry et al., 2010; Marja et al., 2019; Larkin and Stanley, 2021). For example, in orchards, green covers are one of the most applied agri-environmental measure aiming to protect the soil against erosion (Rodrigues and Arrobas, 2020), increase fertility and water retention capacity (Demestihas et al., 2017), increase biodiversity, and support ecosystem-services (Campbell et al., 2017; Luján Soto et al., 2021). However, how green covers are implemented and managed varies considerably across farms. For instance, green covers can be inert (pruning residues) or living (herbaceous plants, spontaneous vegetation, or a mix of sown herbaceous and flowering plants). Inert green covers are likely less effective in supporting beneficial arthropods like pollinators or natural enemies of pest species than living green covers, as they provide no structural vegetation complexity nor living plant or floral resources (Simon et al., 2010; Monzó et al., 2011; Garibaldi et al., 2017; Crézé and Horwath, 2021; Giacalone et al., 2021; Ji et al., 2022).

Effectiveness of agri-environmental measures is further expected to be moderated by two additional factors: landscape complexity and farm management intensity (Kleijn et al., 2011; Marja et al., 2019). The effect of landscape complexity is relatively well-studied. Agri-environmental measures taken in simple landscapes have a stronger positive effect on biodiversity than in complex or cleared landscapes, because in complex landscapes there is continuous spill-over of species from natural areas to farmland even without biodiversity measures, whereas in completely cleared landscapes, source populations are absent (Batáry et al., 2010; Scheper et al., 2013; Larkin and Stanley, 2021).

Although the influence of specific management practices is relatively well studied, it is less clear how field-level management intensity as a whole moderates the effectiveness of agri-environmental measures in enhancing biodiversity. According to Kleijn and Sutherland (2003) and Kleijn et al. (2009), restoring biodiversity in intensively managed farms takes relatively more effort, because biodiversity decreases exponentially with management intensity (Kleijn and Sutherland, 2003; Kleijn et al., 2009). We refer to this hypothesis as the management intensity inhibition hypothesis. However, a meta-analysis by Marja et al. (2019) provides indications that agri-environmental measures might be more effective in restoring pollinator populations when management intensity is high. This is potentially explained by the ecological contrast hypothesis, predicting that a bigger contrast is created by an agri-environmental measure in intensive farms, while in low-intensity farms it may be more difficult to make the same relative improvement (Kleijn et al., 2011; Hammers et al., 2015; Marja et al., 2019). Moreover, differences in the relationship between the effect of an agri-environmental measure and management intensity can also be caused by different species groups responding differently to both management intensity and agri-environmental measures (Batáry et al., 2010; Scheper et al., 2013). For instance, the success of a green cover to act as a food source for pollinators may be inhibited if intensive herbicide usage or frequent mowing is applied on farm. For the cost-effective allocation of the agri-environmental scheme budget, it is important to know if management intensity affects agri-environmental measure effectiveness in different farming system contexts.

Here we investigate if the effectiveness of living green covers to support biodiversity varies along a gradient of farm management intensity. For this purpose, a living green cover implementation was co-designed with farmers and landowners of 15 conventionally managed Mediterranean stone fruit orchards. In each farm, the abundance and species richness of a number of functionally important arthropod groups —pollinators, spiders, other predators, and parasitoids— was measured in alleys with and without living green covers. With this data, we then tested the two contrasting hypotheses that land use intensity either increases (Marja et al., 2019), or decreases (Kleijn et al., 2011) the relative effect on biodiversity that is realized by agri-environmental measures (Fig. 1). This knowledge may contribute to better decision making in the allocation of agri-environmental measures.

2. Materials and methods

2.1. Research area

Data collection took place in the Vega del Guadalquivir region, a river valley northeast of Sevilla, Southern Spain. The fertile and largely flat area is mainly used for intensive agriculture, including stone fruit orchards. Distributed over the area, 15 stone fruit orchards were selected, of which eight peach (*Prunus persicae*), three nectarine (*P. persicae nucipersica*), and four plum (*P. domestica*) orchards. Selected orchards were separated from each other by at least 700 m and ranged in size from 2.3 to 86 ha. In every orchard, trees were arranged in rows with an alley of at least tree meters wide in between the rows. By selecting farms across a range of land tenure types, from small landowners who generally practice less intensive farming to large companies that can invest in highly intensive operations, we ensured that our sample represented a gradient in management intensity.

2.2. Experimental design

In a co-design process with the farmers, it was decided to seed a mixture of five plant species (*Trifolium pratense*, *Trifolium repens*, *Vicia villosa*, *Brassica juncea* and *Secale cereale*) to establish a green cover with an expected combined flowering period from March to July. The seeds were hand-sown in the winter of 2021–2022, at a density of 1 kg per 100 m^2. Farmers were recommended to superficially till the soil before seeding, but as the project was designed in a collaborative approach, not all farmers agreed to that. Seeding occurred in the central 1.5 m of the alleys, extending along the entire length of at least four adjacent alleys and covering a minimum of 0.5 ha. Depending on farm management, the control alleys consisted of bare soil maintained by herbicides (6 orchards), a sown grass cover (3 orchards), or a cover of spontaneous vegetation (6 orchards). The farmers did not change their farm management, with the only exceptions that herbicides were not used in green cover alleys and that the green cover vegetation was not mown below 15 cm. The management of both control and green cover alleys varied substantially between farms, allowing us to test for the effect of management intensity on green cover effectiveness. In each orchard, a green cover plot and a control plot were selected where we collected our data. The green cover and control plots consisted of four adjacent alleys each, and were separated from each other by at least two control alleys and from the field border by at least one alley to limit edge and spillover effects.

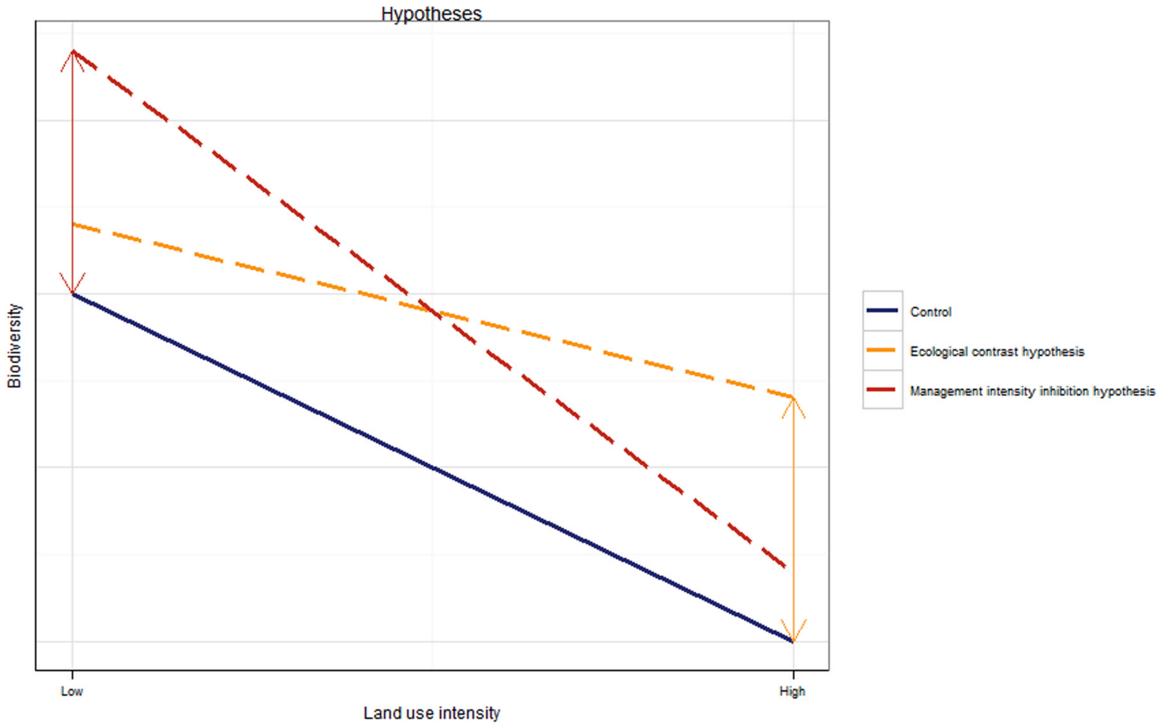

Fig. 1. The two main hypotheses predicting the effect of management intensity on effectiveness of agri-environmental measures. The dashed lines describe the effect of a measure compared to the baseline situation (blue line). The orange line describes the hypothesis that agri-environmental measures result in larger effects on biodiversity in intensive farms than in extensive farms (ecological contrast hypothesis). The red line describes the hypothesis that agri-environmental measures result in larger effects on biodiversity in extensive farms than in intensive farms (management intensity inhibition hypothesis). Arrows indicate the location of the biggest contrast in both cases.

2.3. *Management intensity index*

The farmers were asked to provide information on the amount of nitrogen fertilizer used (kg(N) ha^{-1} y^{-1}), the number of pesticide applications (the number of different pesticides used multiplied by the number of applications made per pesticide), the number of manual field operations (e.g., pruning and thinning), the number of mechanical field operations (e.g., mowing) and the number of trees per hectare. These measures are indicators of farm management intensity and their implementation shapes alley appearance, varying from bare soil under heavy herbicide application, to spontaneous vegetation under less intensive management practices (Herzog et al., 2006; Dennis et al., 2012; Carmona et al., 2020). The total number of field operations was defined as the sum of the number of pesticide applications, mechanical operations, and manual operations. Fertilization was not considered a field operation, because liquid fertilizers were continuously dispensed by drip-lines in all farms. The management data applies to the management of the whole farm during the 2022 calendar year.

Based on the above mentioned management variables, we defined an intensity index to be able to test how management intensity affects green cover effectiveness in enhancing biodiversity. Firstly, we performed an exploratory multivariate Correspondence Analysis (CA) with the management variables per orchard to test whether the management variables were interrelated. The first two CA-axes explained 95.3 % of the variation in management between farms. The first axis was most strongly correlated with nitrogen application (CA1: −0.25) and the number of manual field operations (CA1: −0.23), and the second axis with pesticide use (CA2: 0.31) and the total number of field operations (CA2: 0.23) (Figure A.1). These variables are also commonly used to assess management intensity (e.g., Blüthgen et al., 2012; Carmona et al., 2020). We decided to define a management intensity index using nitrogen application and number of field operations, because both variables together include information on all important management variables and explain a large proportion of the variation in management between farms. Based on the method of Herzog et al. (2006) and Blüthgen et al. (2012), management intensity M for a given farm i is defined as $M_i = \frac{N_i}{N} + \frac{F_i}{F}$, where N is the mineral nitrogen use (kg(N) ha^{-1} y^{-1}) and F the number of field operations (the sum of pesticide applications, mechanical, and manual field operations). Subsequently, the index was standardized to zero mean and unit variance. The management intensity index is strongly correlated with the sum of the first two CA-axes (Pearson's correlation: $r = 0.791$, $t(14) = 4.832$, $p = 0.0003$), supporting that it explains a significant part of the variation in management intensity. The index values range from −2.1 in the orchard that is managed least intensively, to 1.6 in the orchard with highest management intensity.

2.4. *Biodiversity assessments*

2.4.1. *Pollinators and flowers*

To get a measure of pollinator abundance and species richness, we sampled bees (wild and managed), hoverflies, and butterflies. We carried out two sampling rounds during spring 2022, when green covers were flowering. Sampling was done by walking 50 * 1.5 m transects for 7.5 minutes (excluding time used for collecting and writing) in each of the four control and green cover alleys (Vincent et al., 2022). This resulted in a total effort of 30 minutes (4 *7.5) and 300 m^2 (4 *50 m*1.5 m) per plot per sample round. To avoid field margin effects, transects were placed 20 m from the end of the alley. All pollinators encountered within the transect were counted and, when possible, identified to species level. Unidentifiable specimens were collected for later identification, using the literature listed in Table A.1. The first sampling round was carried out between 18–03–2022 and 20–04–2022, and the second round between 19–04–2022 and 29–04–2022 (Table A.2). Due to weather conditions, there was a one-day overlap between the two rounds, but the two sampling rounds on a farm were always separated by at least eleven days. The fieldwork was conducted during days with clear skies, low wind speed, and warm (>15°C) and dry weather.

As pollinator abundance and species richness is strongly influenced by the availability of flowers, we also counted all inflorescences per plant species (see Table A.1 for identification literature) within each pollinator transect (Scheper et al., 2015). Flower counts were done directly after the pollinator sampling. Only entomophilous flowers were counted. When flowers of a species were too abundant to count individually, they were counted in hundreds or thousands.

2.4.2. Spiders

We collected data on spider abundance and species richness using suction sampling, following Schmidt et al. (2005). In each of the four plot alleys, five 20-second suction samples were taken with a modified vacuum shredder, covering a delimited area of 0.1 m^2. The five samples were pooled per alley. Suction samples within an alley were taken with a distance of 20 m from each other and from the end of the alley. In all farms, samples were taken during two sampling rounds, the first between 18–03–2022 and 18–04–2022 and the second between 19–04–2022 and 29–04–2022 (Table A.2). Two sample rounds on a farm were separated by 18 days on average (11 − 40), and sampling only took place during dry and warm weather. Suction samples were stored in the freezer, and after cleaning the samples manually, spiders were stored in a 70 % alcohol solution. Spiders were identified to the family or genus level in case of juveniles and to species level in case of adults, using the identification literature listed in Table A.1.

2.4.3. Predators and parasitoids

We used yellow sticky traps to collect abundance data of a wider taxonomic range of potential natural pest enemies. In each plot, seven sticky traps were hung, spread over the four alleys. The sticky traps were hung on the tree branches, between one and two meters high, and 20 m separated from each other and from the end of the alley. The sticky traps were placed between 18–03–2022 and 31–03–2022 and collected between 28–03–2022 and 11–04–2022 (Table A.2). There were 8–14 days between hanging and collecting the sticky traps. Sticky traps in paired control and green cover plots were always hung and collected simultaneously. The sticky traps were stored in a freezer. All arthropods were counted and identified to at least order level, but in most cases to family level. Taxonomic groups of which all members have a predatory or parasitoid lifestyle, were classified as such. Identification and classification into guilds was done using the identification literature listed in Table A.1.

2.5. Data analysis

We calculated the total number of individuals of pollinators, flowers and spiders on the transect level and the number of predators and parasitoids on the sticky trap level, pooling the two sample rounds. Honey bees were omitted from the pollinator counts as their abundance is influenced by hive placement rather than the ecological mechanisms of interest. In the case of pollinators, flowers, and spiders, we also counted the number of unique species per transect. Individuals that were only identified up to the genus or family level, were only counted as an additional species if no other individuals from this taxonomic group were found in the transect. The abundance of pollinators, flowers, spiders, predators and parasitoids and the species richness of pollinators, flowers, and spiders was modeled using Generalized Linear Mixed Models (Brooks et al., 2017). The management intensity index, treatment (control or green cover), and their interaction effect were included as fixed effects, and farm id as a random effect to account for the paired study design. In the case of the predator and parasitoid models, the natural logarithm of the number of days the sticky trap was outside, was used as an offset. The spider models and the predator model were fitted using a negative binomial distribution with variance increasing quadratically with the mean, and the parasitoid model and pollinator models were fitted using a generalized poisson distribution. Significance of the fixed effects was tested with a Likelihood Ratio Test, using a backward selection procedure. In the case of a significant interaction between management intensity and treatment, we additionally examined whether the coefficients for the individual slopes with management intensity for control and green cover were significantly different from zero. This was done by running the model once with control as the contrast reference level (default) and once with green cover as the contrast reference level. Models were validated by visual inspection of the residuals using the package *DHARMa* (Hartig, 2022), and conditional (variance explained by entire model, i.e. both fixed and random effects) and marginal (variance explained by fixed effects only) R^2 values were calculated using the package *report* (Makowski et al., 2023)

All data analysis was done in R (R Core Team, 2022), using the packages *DHARMa* (Hartig, 2022), *ggplot2* (Kassambara, 2023), *ggrepel* (Slowikowski, 2023), *glmmTMB* (Brooks et al., 2017), *INBOtheme* (Onkelinx, 2023), *kableExtra* (Zhu, 2021), *knitr* (Xie, 2014), *lsmeans* (Lenth, 2016), *lubridate* (Spinu et al., 2023), *patchwork* (Pedersen, 2022), *readxl* (Wickham and Bryan, 2023), *report* (Makowski et al., 2023), *scales* (Wickham and Seidel, 2022), *tidyverse* (Wickham, 2023), and *vegan* (Oksanen et al., 2022).

3. Results

3.1. Pollinators

In total, 3860 pollinators representing 52 species were found (Table A.3). Excluding honey bees, 2046 pollinator individuals were counted, of which 57 % were bees, 36 % hoverflies, and 7 % butterflies. Only 3 species were uniquely found in control plots, while 35 species were unique to green cover alleys. Pollinator abundance and species richness were significantly higher in green cover alleys compared to control alleys. This difference increased with management intensity, because of divergent trends of pollinators with management intensity in green covers compared to control alleys (Fig. 2; Table 1). Pollinator abundance in green covers was even showing a significant and positive correlation with management intensity (estimate = 0.395, SE = 0.194, p = 0.042). Relative to the control, green covers led to an estimated 2-fold increase in pollinator abundance when management intensity was at its minimum, and a 40-fold increase at maximum management intensity. Pollinator species richness in green covers was 2.4 times higher compared to the control when management intensity was at its lowest, and 6.2 times higher at maximum management intensity. In the fitted models for pollinator abundance and species richness, 68 % and 64 % of the variation, respectively, was explained by the fixed effects only (Table 1, R^2_{cond} & R^2_{marg}).

3.2. Flowers

In total, 647,678 flowers from 45 species were counted (Table A.4). Pooled across all farms, most species were found in control alleys. 16 species were only found in control alleys, while 11 species were uniquely found in green covers. Of the four sown flower species in green cover alleys, only one species, *Brassica juncea*, was found flowering. Both flower abundance and species richness were significantly higher in green cover alleys compared to control alleys, and this difference increased with management intensity because of opposite trends in green cover and control alleys (Fig. 3; Table 1). Relative to the control situation, green covers led to an estimated 5-fold increase in flower abundance at lowest management intensity, and a 248-fold increase at the maximum management intensity within our study. Flower species richness in green covers was 1.1 times higher compared to the control when management intensity was at its lowest, and 2.2 times higher at maximum management intensity. In the fitted models for flower abundance and species richness, 74 % and 24 % of the variation, respectively,

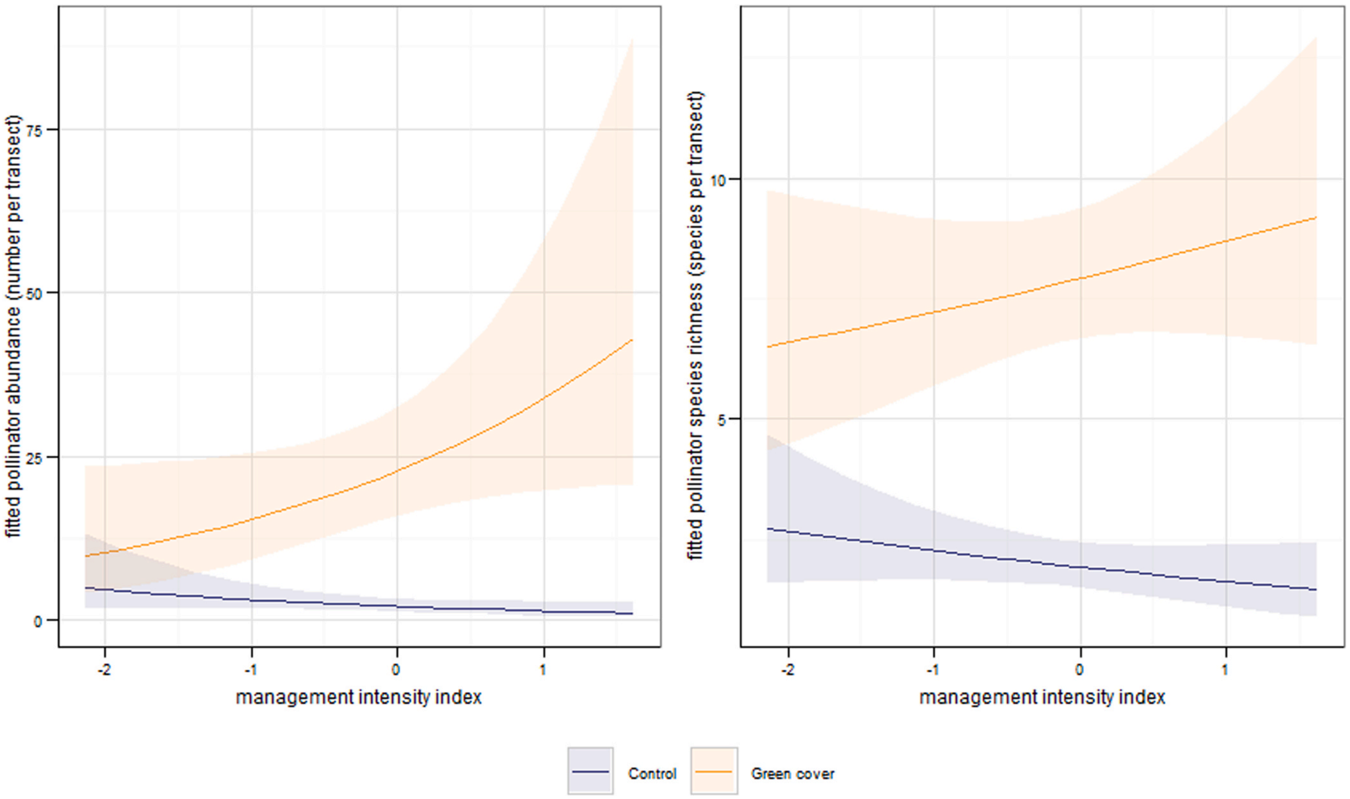

Fig. 2. Response of pollinator abundance and species richness to management intensity in green cover and control plots. Shaded areas represent 95 % confidence intervals.

Table 1
Results from GLMM models for each group, with control as the contrast reference level. Significant p-values at the 0.05 level are indicated in bold. Genpois = generalized poisson, nbinom = negative binomial.

			Treatment		Intensity		Interaction		R^2	
Group	Response	Family	Chi2(df)	p	Chi2(df)	p	Chi2(df)	p	cond	marg
Pollinators	Abundance	genpois	118.45(1)	**< 0.001**	1.82(1)	0.177	24.91(1)	**< 0.001**	0.90	0.70
Pollinators	Richness	genpois	123.35(1)	**< 0.001**	0.19(1)	0.664	4.96(1)	**0.026**	0.44	0.39
Flowers	Abundance	nbinom	116.51(1)	**< 0.001**	1.13(1)	0.287	33.27(1)	**< 0.001**	1.00	0.77
Flowers	Richness	genpois	34.11(1)	**< 0.001**	0.08(1)	0.771	5.01(1)	**0.025**	0.11	0.05
Spiders	Abundance	nbinom	5.18(1)	**0.023**	0.57(1)	0.452	0.11(1)	0.735	0.65	0.05
Spiders	Richness	nbinom	4.2(1)	**0.040**	1.17(1)	0.279	0.01(1)	0.934	0.58	0.07
Predators	Abundance	nbinom	50.92(1)	**< 0.001**	0.26(1)	0.611	0(1)	0.987	0.51	0.13
Parasitoids	Abundance	genpois	26.05(1)	**< 0.001**	0.16(1)	0.687	0.12(1)	0.724	0.56	0.06

was explained by the fixed effects (Table 1, R^2_{cond} & R^2_{marg}).

3.3. Spiders

In total, 506 spiders comprising of 49 unique species were collected and identified (Table A.5). Sixteen species were only found in control plots and 23 species only in green cover plots. Spider abundance in green cover alleys was on average 1.5 times higher compared to control alleys and spider species richness was 1.3 times higher in green cover compared to control alleys (Fig. 4). Both effects are significant and independent of management intensity (Table 1). Management intensity had no significant effect on spider abundance, nor species richness. The fitted model for spider abundance explained 62 % of the variation, but only 5 % was explained by the fixed effects. In the model for spider species richness, 54 % of the variation was explained, and 7 % by the fixed effects only (Table 1, R^2_{cond} & R^2_{marg}).

3.4. Predators and parasitoids

The sticky traps yielded a total of 123771 arthropods, distributed over 74 identified taxonomic groups (Table A.6). Of these, 12 taxonomic groups representing 10,611 individuals could be classified as predators and 12 taxonomic groups representing 10,212 individuals could be classified as parasitoids (Table A.6). Predator and parasitoid abundances in green cover alleys were 1.9 and 1.4 times higher, respectively, compared to control alleys (Fig. 5). For both functional groups, this effect was significant and independent of management intensity (Table 1). Management intensity had no significant effect on predator nor parasitoid abundance (Table 1). The fitted models for predator and parasitoid abundance explained 51 % and 56 % of the total variation, respectively. However, only 13 % and 6 % of the variation was exclusively explained by the fixed effects (Table 1, R^2_{cond} & R^2_{marg}).

4. Discussion

Flowering green covers in stone fruit orchards increase the

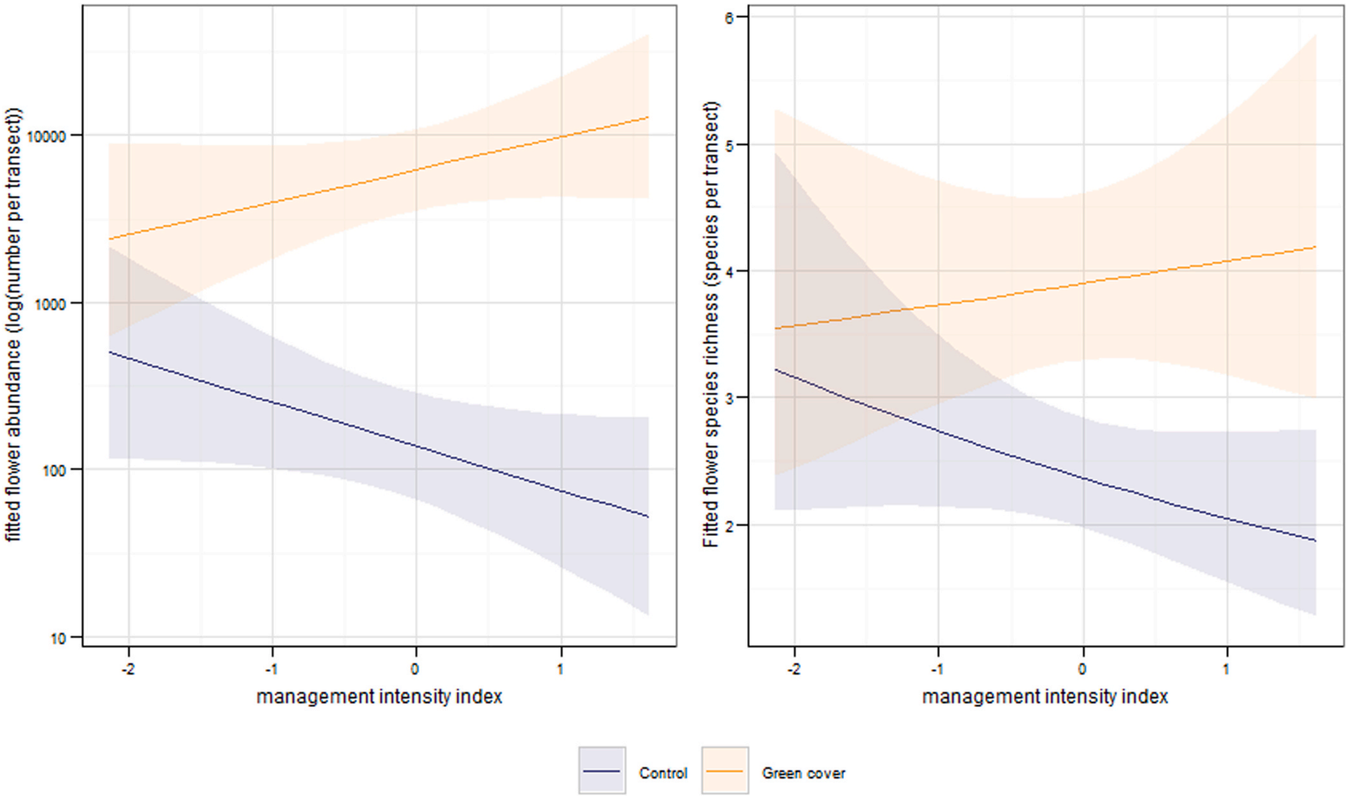

Fig. 3. Response of flower abundance (log scale for visualization) and species richness to management intensity in green cover and control plots. Shaded areas represent 95 % confidence intervals.

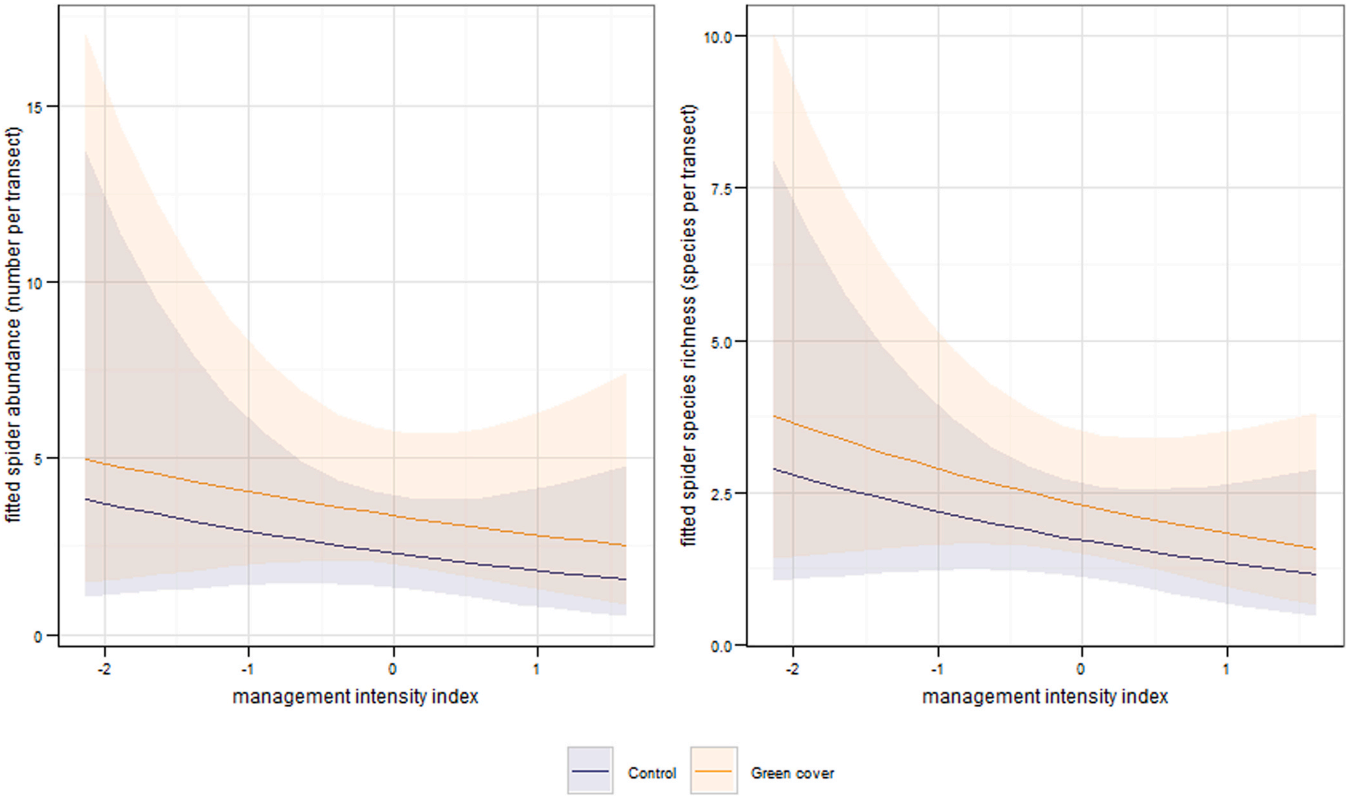

Fig. 4. Response of spider abundance and species richness to management intensity in green cover and control plots. Shaded areas represent 95 % confidence intervals.

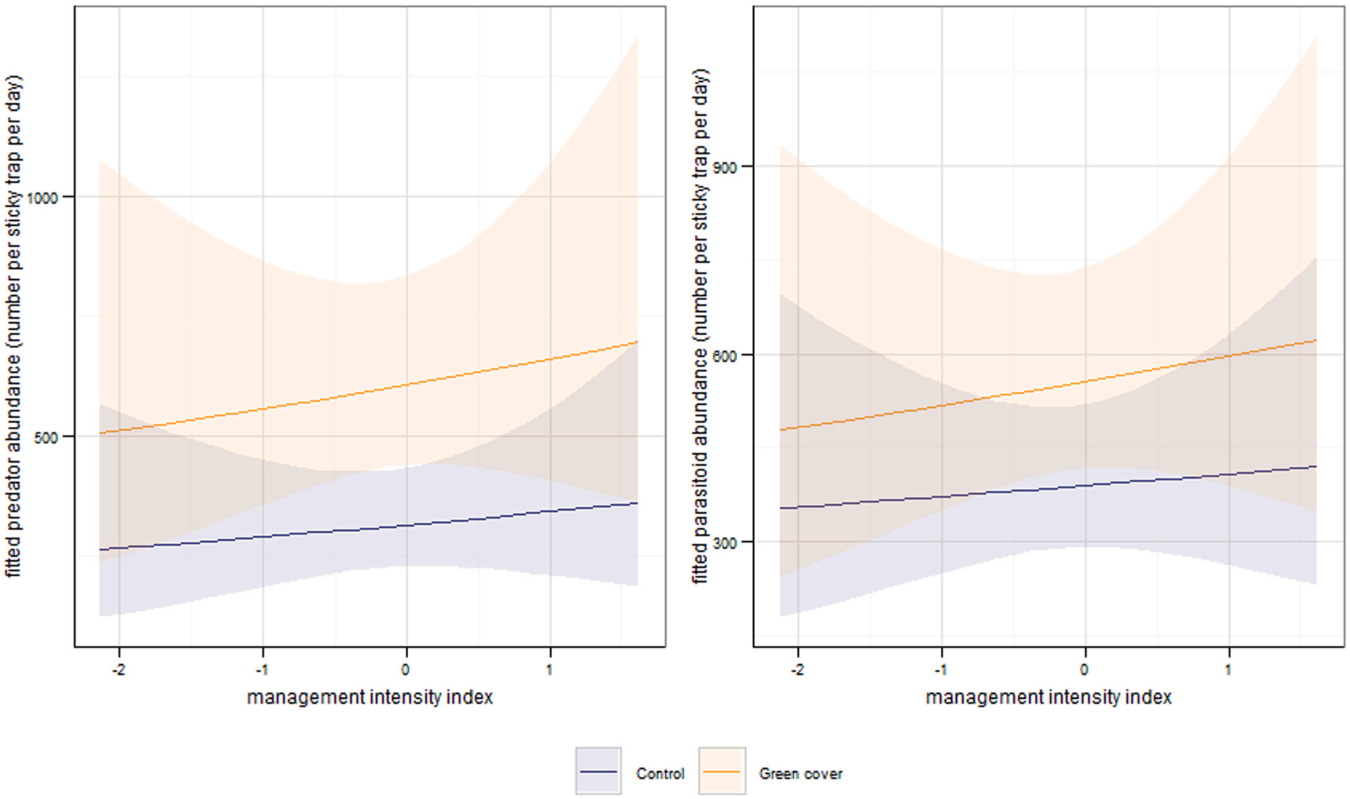

Fig. 5. Response of predator and parasitoid abundance to management intensity in green cover and control plots. Shaded areas represent 95 % confidence intervals.

abundance and species richness of several beneficial arthropods irrespective of the intensity of farm management. This implies that those measures are effective even in intensively managed farms. In fact, for pollinator and flower abundance and species richness, the effectiveness of green covers even increased with management intensity. Although we acknowledge the regional limitations of our study, we believe these findings may have important implications for the allocation of agri-environmental measures.

4.1. Pollinators correlated positively with management intensity mediated by green cover establishment success

The results for pollinators are in line with the ecological contrast hypothesis that effectiveness of agri-environmental measures increases with management intensity (Marja et al., 2019). Lower numbers of pollinators in control alleys as a result of higher management intensity could cause the higher relative effect of green covers. Orchards with high management intensity tended to have bare soil in the control situation as a result of herbicide use, creating a larger contrast with the flowering green cover. However, the higher effectiveness is not only the result of a larger relative effect compared to the lower number of pollinators in the baseline situation. Also in absolute terms, the number of pollinators in green covers increased with management intensity. This exceeds our expectations, because an increase in management intensity is generally related to biodiversity loss (Kleijn et al., 2009; Le Féon, 2010). The positive trend of pollinators in green covers with management intensity is most likely explained by the similar patterns in flower abundance and species richness, as pollinator abundances are known to be directly driven by floral resources (Scheper et al., 2015). Just like for pollinators, flower abundance and species richness increased with management intensity in green covers, while decreasing in control alleys.

The positive correlation between management intensity and flowers in green cover alleys indicates that the establishment success of green covers was higher when management intensity was high. Possibly, more intensive orchards provide better germination and growing conditions for the sown species because of higher levels of fertilization and irrigation (Scheper et al., 2021; Stroot et al., 2022). In our study region, water availability is expected to be an important limiting factor for plant growth, considering the dry and hot climatic conditions and the severe droughts during and prior to our study (AEMET, 2022, 2023). As a result, the level of irrigation might be a key factor determining green cover establishment. Even though all orchards were irrigated with drip lines, a precision method designed to minimize water loss, occasional spillover of water into the alleys was visible. Additionally, herbicide application in the years prior to green cover seeding might have positively affected green cover establishment by limiting competition with herbs and grasses naturally present in the alleys (see example from Bakker et al., 2003 in semiarid areas).

While the positive effect of green covers on pollinators is a promising result, a question that remains is whether this is reflecting an actual growth in population size, or merely a spatial redistribution of pollinators. To test for this, a different research approach would be needed, including measurements on a larger spatial scale and across several years (Kleijn et al., 2018). However, considering the short time span between green cover seeding and pollinator monitoring, the positive effect is most likely reflecting a spatial concentration effect of pollinators in green cover alleys (Kremen et al., 2019; Albrecht et al., 2020). Only a few butterfly and hoverfly species in our study have generation times short enough to show a population level response to green covers within this short period in spring (Geusen-Pfister, 1987; Hasan and Ansari, 2011; Lillo et al., 2021). A spatial concentration can also be an additional factor explaining the positive effect of management intensity on pollinators in green covers, complementary to the explanation that this is a response to improved green cover establishment. When flower availability in the surroundings is low as a result of high management intensity, the concentration effect is expected to be stronger, while pollinators will remain more evenly distributed over the area when flowers are also present in the control alleys (Scheper et al., 2015; Kleijn et al., 2011, 2018).

4.2. *Green covers, but not management intensity, affect predators and parasitoids*

Spiders and predatory and parasitoid insects were also positively influenced by green covers. However, the effect size was smaller than in pollinators, and the predictors explain only a small fraction of the variation in abundance and species richness. Green covers may directly benefit predators and parasitoids, for example, by providing flowers as a food source for parasitoid wasps (Denis et al., 2021; Wackers, 2004), or by increasing vegetation complexity thus providing structures for web-building spiders (Woodcock et al., 2009; Diehl et al., 2013). However, compared to pollinators, predators and parasitoids are generally to a lesser extent and more indirectly dependent on vegetation and flowers (Scherber et al., 2010), which may explain the weaker response of these groups to green covers. The positive effect of green covers on spiders and predatory and parasitoid insects was independent of management intensity. No significant trend with management intensity was found for spiders nor predators or parasitoids. Other studies show that spiders are highly sensitive to farm management practices like mowing, tillage, and insecticide use (Prieto-Benítez and Méndez, 2011; Herzog et al., 2012; Diehl et al., 2013). The limited effect of management intensity on spiders in our study may be attributed to the presence of relatively stable habitat in the tree rows of orchards, where practices that cause a lot of disturbance like mowing and tillage are not implemented. This could serve as a refuge allowing the alleys to be quickly recolonized after disturbing field operations. (Sunderland and Samu, 2000; Monzó et al., 2011; Diehl et al., 2013). This effect might be even stronger in the largely flying predatory and parasitoid insects in our study, because they are more mobile than spiders (Sunderland and Samu, 2000; Burel et al., 2004; Dauber et al., 2005). Mobile species are more strongly affected by large-scale landscape features and colonize newly created habitats like green covers more easily. Local management intensity is of less importance for these species because they can more easily escape and recolonize the alley during management practices that cause disturbance. (Billeter et al., 2008). Possibly, the time span between green cover seeding and spider sampling was too short (3–4 months) for some spiders to colonize the green cover from nearby semi-natural habitat, as the effect of the green cover could still increase over time (Lessard-Therrien et al., 2018).

4.3. *Potential effects of beneficials on ecosystem service delivery*

Conventional stone fruit orchards rely heavily on pesticide use and managed pollinators for fruit production (Simon et al., 2010; Herrera et al., 2021). The positive effect of green covers on wild pollinators and natural enemies of pest species might partly replace or complement these external inputs. Wild bee species contribute to food production complementary to managed honey bees (Kleijn et al., 2015; Koh et al., 2018), and simultaneously provide an insurance in unforeseen circumstances like poor weather conditions or honey bee losses (Winfree et al., 2007; Osterman et al., 2021; Karbassioon et al., 2023). The interspersed design of green covers in between the tree rows likely maximizes the spill-over of beneficial arthropods into the crop (Woodcock et al., 2016; Fountain, 2022). However, studies investigating the relation between agri-environmental measures, beneficial arthropods, and yield, show mixed results (Fountain, 2022; Jacobsen et al., 2022; Judt et al., 2023; Kleijn et al., 2019; Scheper et al., 2023; Simon et al., 2010). Increased numbers of beneficial arthropods can even be associated with negative effects on yield, because of parallel increases in pest populations (Meagher and Meyer, 1990; Markó et al., 2013). Agri-environmental measures like green covers should therefore be carefully designed and tested in different contexts, to not only enhance the value for biodiversity, but also for pest control and crop pollination (Wackers, 2004; Simon et al., 2010).

5. Conclusion

Regardless of management intensity, green cover application was effective in increasing the abundance and species richness across a variety of beneficial functional groups. In the case of pollinators and flowers, numbers even increased with management intensity in green covers, while they decreased with management intensity in conventionally managed alleys. Likely, better growing conditions in intensively managed farms improved green cover establishment, leading to a spatial concentration of pollinators in an otherwise flower-poor orchard. To test whether the enhanced flower availability also leads to an actual growth in pollinator population size, long-term monitoring is needed at a larger spatial scale. In predatory and parasitoid arthropods, the positive effect of green covers was less pronounced and unaffected by management intensity, potentially because of their higher trophic distance to flowers. Our results show that relatively simple agri-environmental schemes can be effective in enhancing biodiversity, even in highly intensive farming systems. These results suggest that subsidizing living green covers on intensive farmlands could serve as an effective measure, supporting multiple taxonomic groups. Further research should lead to a better understanding of the generalizability of our results to other regions, crop types, and agri-environmental measures, and to the subsequent effects on crop yield and other ecosystem services.

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CRediT authorship contribution statement

Remco Ploeg: Writing – original draft, Visualization, Formal analysis. **Alberto Rodriguez Ballesteros:** Writing – original draft, Visualization, Formal analysis. **Jeroen Scheper:** Writing – review & editing, Supervision, Methodology. **Elena Velado Alonso:** Writing – review & editing, Supervision, Project administration, Methodology, Investigation, Data curation, Conceptualization. **Ignasi Bartomeus:** Writing – review & editing, Supervision, Resources, Project administration, Methodology, Funding acquisition, Conceptualization. **David Kleijn:** Writing – review & editing, Supervision, Methodology, Funding acquisition.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.agee.2024.109436.

Data availability

Data will be made available on request.

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