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Farmers' attitudes towards biodiversity shape the effectiveness of biodiversity-friendly management practices for wild bees, but not plants and spiders

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ABSTRACT

Biodiversity continues to decline in European agricultural landscapes despite policies that promote biodiversity-friendly farming. While the ecological drivers of the effectiveness of biodiversity-friendly practices are well-studied, less is known about how farmers' attitudes influence biodiversity outcomes. We examined, in eight European countries, whether positive farmer attitudes towards biodiversity are related to higher on-field biodiversity levels and effectiveness of biodiversity-friendly practices. We combined farmer attitude surveys with field inventories of wild plants, bees and spiders in biodiversity-friendly managed and control fields. We found that, in control fields, none of the examined taxa were associated with farmers' biodiversity attitudes. However, in biodiversity-friendly managed fields, both wild bee abundance and species richness increased with a more positive attitude, resulting in a positive relation between farmers' attitude and the effectiveness of biodiversity-friendly management. This relationship was mainly driven by farmers' perceived necessity of considering biodiversity in their farm management, rather than by general biodiversity attitudes. For wild plants and spiders, no relationship between attitude and effectiveness was observed, possibly because these taxa are less

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conspicuous and less positively perceived. We additionally found that farmers' attitude was positively related to the diversity of biodiversity-friendly practices implemented on farms. Our results suggest that, while agronomical and economic motivations predominate in conventionally managed fields, farmers' biodiversity attitudes can play a role in both the uptake and the effectiveness of biodiversity-friendly practices, although the latter is taxon-dependent. To improve the effectiveness of biodiversity-friendly practices, our findings stress the importance of addressing the social and motivational drivers of farmers.

1. Introduction

In Europe, traditional extensive farming practices supported high levels of biodiversity in agricultural landscapes up until the mid-20th century (Bignal and McCracken, 1996). However, after the Second World War, the European Common Agricultural Policy (CAP) stimulated intensification and industrialization of agriculture to boost agricultural production and farmer income (Emmerson et al., 2016). The associated increased use of agrochemical inputs, mechanization, irrigation, monocultures and land consolidation have resulted in severe declines in farmland biodiversity through the loss, degradation and pollution of habitats (Stoate et al., 2009; Beckmann et al., 2019; Rigal et al., 2023). As an unintended consequence, the intensification of agriculture thereby also negatively impacts the delivery of ecosystem services that support agricultural production, such as natural pest regulation, soil health and pollination (Deguines et al., 2014; Dainese et al., 2019; Burian et al., 2024). In response to growing concerns about the loss of farmland biodiversity, since the early 1990s the EU's agricultural and environmental policies have increasingly aimed at promoting the implementation of agri-environmental and biodiversity-friendly farming practices (such as reduced agrochemical inputs or the establishment of flower strips and hedgerows), culminating in the current European Green Deal and greening of the CAP. Nevertheless, while these practices often result in (modest) local biodiversity enhancements (Batáry et al., 2015) and sometimes even halt or reverse population declines (Redhead et al., 2022), species associated with farmland continue to decline across Europe (EEA, 2020). This raises doubt about the effectiveness of these practices, or the quantity and quality of their implementation (Kleijn et al., 2001).

The impact of biodiversity-friendly practices is basically determined by the product of their ecological effectiveness (i.e. the extent to which these practices support biodiversity, depending on the type of measure and the quality of implementation) and their uptake (i.e. the extent to which these practices are implemented by farmers) (Batáry et al., 2015; Bishop et al., 2025). There is a substantial body of conceptual, empirical and synthesis studies that have examined the ecological and farm management factors that influence farmland biodiversity and determine the ecological effectiveness of biodiversity-friendly practices (e.g. Hendrickx et al., 2007; Kleijn et al., 2011; Pywell et al., 2012; Tscharntke et al., 2012; Scheper et al., 2013; Martin et al., 2019; Sánchez et al., 2022). Consequently, we currently have a reasonably good understanding of how the interplay among ecological and agricultural factors like type of biodiversity-friendly practice, landscape context, land use intensity and farmland type impact the effectiveness of biodiversity-friendly management.

Likewise, many studies have shown how the adoption of biodiversity-friendly farming practices relates to farm structure, farm economics and farmer socio-demographical characteristics (e.g. Ahnström et al., 2009; Brown et al., 2021; Canessa et al., 2024; Klebl et al., 2024a). However, in addition to farm structure and socioeconomic factors, farmers' socio-psychological characteristics such as their motivations and attitudes towards biodiversity and nature conservation also play a critical role in whether and how farmers implement biodiversity-friendly practices (Klebl et al., 2024b). According to the Theory of Planned Behavior, farmers' attitude is one of the main determinants of their intention to implement practices that support biodiversity (Ajzen, 1991). It is well established that a positive attitude towards biodiversity is positively related to the intention or willingness of farmers to adopt biodiversity-friendly practices (Herzon and Mikk, 2007; Wauters et al., 2017) and to the uptake of biodiversity-friendly practices (Brown et al., 2021; Klebl et al., 2024a), although attitude is usually more strongly related to intention than actual adoption of practices (Lu et al., 2022; Swart et al., 2023).

By contrast, whether and how farmers' attitudes towards biodiversity relate to actual on-field biodiversity or the ecological effectiveness of biodiversity-friendly practices is less known. A few studies have shown that on-farm biodiversity is positively related to farmers' attitudes (Schmitzberger et al., 2005; Ahnström et al., 2013; Power et al., 2013; Fig. 1 red lines), possibly because farmers with a more positive attitude are more intrinsically motivated to manage their farm in a more biodiversity-friendly way, even without agri-environment subsidies incentivizing this (Mills et al., 2018). It stands to reason that the ecological quality of implemented biodiversity-enhancing practices is positively related to attitude as well (Fig. 1 blue lines) because the ecological quality ultimately depends on farmers' decisions and behavior on what type of practices are implemented where, how, and on what share of land. Furthermore, biodiversity-minded farmers may be more dedicated to and have more experience with biodiversity-friendly management practices (Power et al., 2013; McCracken et al., 2015).

Ironically, more positive farmer attitudes may reduce the absolute ecological effectiveness of biodiversity-friendly practices (i.e. the net difference between managed and control sites; black arrows in Fig. 1), even if the practices still improve biodiversity. This situation could arise if baseline biodiversity levels are already higher on farms of biodiversity-minded farmers than on those of less biodiversity-minded ones (as suggested by Ahnström et al., 2013). The ecological effectiveness of biodiversity-friendly practices often decreases with the amount of biodiversity already present on a farm, simply because it is often easier to enhance biodiversity when initial levels are relatively low (Tscharntke et al., 2012). The extent to which farmer attitude influences the effectiveness of biodiversity-friendly farming practices thus critically depends on the relative strength of the relationships (i.e. the slopes) between farmer attitude and biodiversity in sites with biodiversity-friendly practices and in conventionally managed control sites. If this relationship is stronger in biodiversity-friendly sites than in controls, the ecological effectiveness increases with increasingly biodiversity-positive farmer attitudes (Fig. 1a). In contrast, if biodiversity increases less strongly with farmer attitude in sites under biodiversity-friendly management than in control sites, the effectiveness of biodiversity-friendly farming practices may instead decrease as attitudes become more positive (Fig. 1b). Whether and how the effectiveness of biodiversity-friendly practices is related to farmers' attitudes towards biodiversity is, however, largely unknown.

Here, taking an individual-behavioral perspective, we address this knowledge gap by linking survey data on farmers' attitudes with biodiversity data collected in fields with and without biodiversity-friendly practices across eight European countries. Focusing on wild plants, wild bees and spiders as indicators for biodiversity, we examine 1) whether and how farmers' attitudes towards biodiversity are related to overall levels of biodiversity in the study fields, and 2) whether their attitude affects the effectiveness of biodiversity-friendly practices. We furthermore account for other factors that may influence these relationships by exploring the direct and indirect effects of farm and farmer characteristics and landscape context. Covering a variety of biogeographic regions, farmland types and biodiversity-friendly management practices, our analyses will provide a general picture on the relationship between farmer attitude and biodiversity in European farmland.

2. Methods

2.1. Study areas

We collected data on biodiversity and farmer attitudes in eight study areas across Europe, in France, Hungary, the Netherlands, Portugal, Spain, Sweden, Switzerland and the United Kingdom (Fig. 2). These study areas are ecological and socioeconomic experimental sites as part of the H2020 SHOWCASE research project (Kleijn et al., 2022), which, among other things, aims to empirically evaluate the effectiveness of biodiversity-friendly management in enhancing farmland biodiversity. To this end, in each study area biodiversity-friendly farming practices, such as reducing external inputs or sowing wildflowers, were implemented in experimental agricultural plots or fields and compared with conventionally managed ones (business-as-usual production practices). In total, the eight study areas provided data on 68 farmers and 173 agricultural plots/fields, covering a variety of biogeographical regions (Fig. 2), farmland types, biodiversity-friendly management practices and study designs (Table 1). The experimental biodiversity-friendly practices varied in the extent to which they targeted intrinsic biodiversity values (e.g. the Netherlands) or functional and agronomic aspects of biodiversity (e.g. the United Kingdom). All biodiversity-friendly treatments were implemented on-field; however, in the Swiss study area the on-field treatment (no pesticides) was combined with an off-field treatment as well (annual wildflower strip).

In the United Kingdom, three different biodiversity-friendly treatments were applied: a mixture of four winter-sensitive cover crop plant species, a mixture of four winter-hardy plant species, and mixture combining the eight plant species. We selected the eight-species treatment for inclusion in the analyses because this treatment may be expected to result in the largest ecological contrast (sensu Kleijn et al., 2011). Furthermore, the Dutch study was originally designed as a correlative study examining biodiversity along a gradient of grassland management intensity, quantified as annual nitrogen fertilizer input per hectare per year (range: 0–332 kg effective nitrogen ha^{-1} yr^{-1}). Nitrogen input generally correlates with other farming intensity measures (e.g. pesticide use, livestock density, productivity) and is often used as indicator for land-use intensity (Herzog et al., 2006; Kleijn et al., 2009). For our analyses we therefore categorized the grasslands as either extensive or intensive based on nitrogen input. Grasslands receiving less than 100 kg N ha^{-1} yr^{-1} were classified as extensively managed biodiversity-friendly sites (mean ± se = 28.4 ± 6.8 kg N ha^{-1} yr^{-1}); grasslands receiving more than 100 kg N ha^{-1} yr^{-1} were classified as conventionally managed control sites (234.6 ± 27.6 kg N ha^{-1} yr^{-1}) (De Vries et al., 2012; Hudewenz et al., 2012). In the other countries, the study design consisted of a single treatment versus control contrast.

2.2. Biodiversity indicators

Three biodiversity indicators were sampled: wild vascular plants, wild bees and spiders. These species groups represent different trophic levels and play important roles in the functioning of agroecosystems and the delivery of ecosystem services (Ebeling et al., 2018; Artamendi et al., 2025; Cardoso et al., 2025). Not all species groups were sampled in each study area, and the exact method and sampling effort varied slightly across study areas as well (Table 1).

Wild vascular plants were surveyed in each study area. Vegetation surveys were performed once during the growing season using four to ten quadrats (Table 1). In general, arable fields (where plant diversity is low) were surveyed using 1 m × 1 m quadrats, while the more diverse wildflower strips and grassland vegetations were surveyed using 0.5 m × 0.5 m quadrats. The old field grasslands in the Hungarian study area were surveyed using 2 m × 2 m quadrats. Quadrats were regularly placed along the bee transects (see below). In each quadrat, cover of all vascular plant species was visually estimated to the nearest percentage. Species with negligibly low cover (i.e. <0.5%) were given a cover of 0.01%.

Wild bees were surveyed in each study area except the United Kingdom, where the cover crop implementation did not coincide with the main activity period of bees. Wild bees were surveyed using standard transect walks. The number of transects per field, the transect area, the net sampling time per transect and the number of survey rounds varied across study areas (Table 1). Transects in study areas that used a single transect per field were located in a representative part of the field perpendicular to the field edge, running from the edge towards the

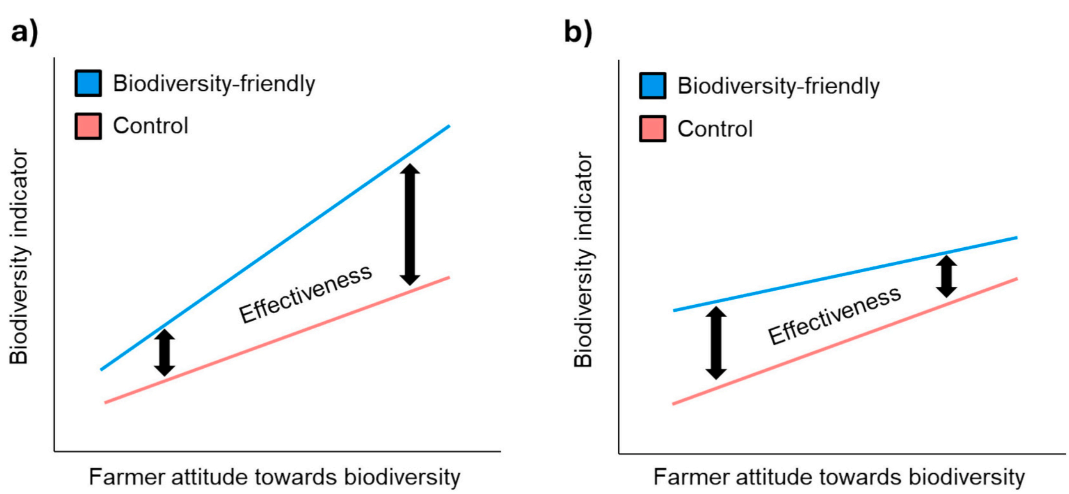

Fig. 1. Two scenarios of how farmer attitudes (larger values indicate more positive attitude towards biodiversity) may influence the effectiveness of biodiversity-friendly farming practices. Here, effectiveness is the difference in biodiversity levels between fields with biodiversity-friendly farming practices (blue lines) and conventionally managed control fields (red lines). In both examples farmland biodiversity is expected to be positively related to farmer's attitude towards biodiversity. **a)** The effectiveness of biodiversity-friendly farming practices may increase with farmer attitude if biodiversity increases more strongly with attitude in biodiversity-friendly than in control fields. **b)** The effectiveness of biodiversity-friendly farming practices may decrease with farmer attitude if biodiversity increases less strongly with attitude in biodiversity-friendly than in control fields. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

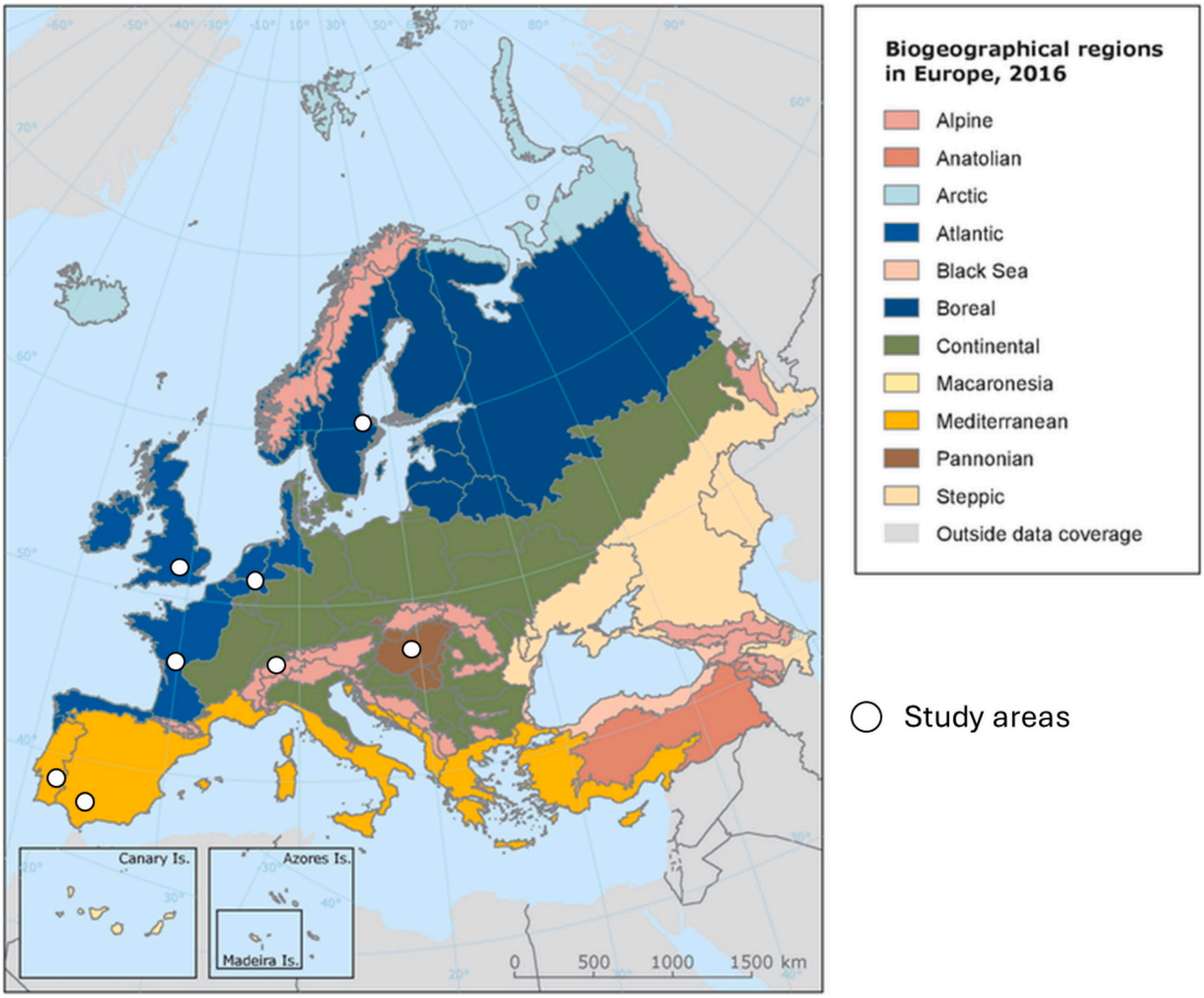

Fig. 2. Overview of the study areas in the eight European countries. Map: European Environment Agency (www.eea.europa.eu).

center of the field. Transects in study areas that deployed multiple transects per field were located parallel to the field edge, at different distances from the field edge. In the Swiss study area, four transects were located in the agricultural field and one or two transects were located in the annual wildflower strip or control field boundary. Bees were surveyed on days with dry weather, low wind speeds and temperatures of >13 °C under >60% clear sky conditions or >17 °C under <60% clear sky conditions.

Spiders were sampled in all study areas except the Hungarian study area. Spiders were collected in each bee transect using a modified leaf blower. Five suction sub-samples (eight in Portugal) were taken within sample rings of 0.357 m internal diameter (covering 0.1 m^2 each) that were evenly distributed over the bee transects. Subsamples were pooled per transect. In the Netherlands, spiders were not sampled through suction sampling but by sweep netting (210 single sweeps) along the bee transect. Spiders were sampled during one sampling round in Portugal, three rounds in the Netherlands and two rounds in the other study areas (Table 1).

2.3. Landscape context

Local biodiversity levels (Liira et al., 2008; Marja et al., 2022; Mei et al., 2023) and the effectiveness of biodiversity-friendly management (Concepción et al., 2012; Scheper et al., 2013; Sánchez et al., 2022) have been shown to be affected by landscape context. We therefore determined landscape composition around the center of the focal fields within radii of 250 m, 500 m and 1000 m using R version 4.4.1 (R Core Team, 2024) and 10 m resolution raster land use data obtained from ESA WorldCover (Zanaga et al., 2022). We then characterized landscape context for each of the three radii using the percentage of cropland in the surrounding landscape, a metric of landscape simplification (Dainese et al., 2019).

2.4. Farm characteristics and farmer attitude

Within the SHOWCASE project, a large-scale online farm survey was performed across the different study areas to examine farmers' viewpoints and willingness to implement biodiversity-friendly management in agriculture (Häfner et al., 2025). For the purpose of the present study, the survey aimed to collect data on farmers' attitudes towards biodiversity. Designed from an individual-behavioral perspective based on the Theory of Planned Behavior (Ajzen, 1991), these survey questions focused on individual attitudes and values of farmers regarding biodiversity and biodiversity management on their farms. Specifically, farmers were asked to rate their agreement with several statements about (farmland) biodiversity on a 1–10 Likert scale (1 = I don't agree at all; 10 = I fully agree). This included statements such as “Biodiversity in general is very important to me” (see Appendix S1 for the full survey). The survey also collected basic information on farm structure, farm management and farmer characteristics. These variables were included in the present study as well since farm and farmer attributes, such as age, education, farm size, economic size, farming system, and previous participation in agri-environment schemes, have been shown to be correlated with farmer attitudes towards biodiversity and the adoption

Table 1
Overview of farmland types, biodiversity-friendly management practices, study designs and measured biodiversity indicators in the study areas in the different countries.

Country	Farmland type	Biodiversity-friendly mangement	Study design	Year	Number of valid farmer survey responses	Number of experimental plots/fields		Sampled biodiversity indicators (and method)		
						Biodiversity-friendly	*Control*	*Plants*	*Bees*	*Spiders*
France	Arable	On-field: reduction of fertilizers, pesticides and/or tillage	Mix of plot and field scale, paired and unpaired	2022, 2023	11	27	26	Yes (10×1 m^2 quadrats)	Yes (4×75 m^2 transect surveys; 7.5 min; 2 rounds)	Yes (4×5 suction samples; 30 s each; 0.357 m diam; 2 rounds)
Hungary	Grassland	On-field: overseeding old fields with native legume-rich seed mixture	Plot scale (0.5 ha), paired within fields	2022, 2023	3	4	4	Yes (6×4 m^2 quadrats)	Yes (2×150 m^2 transect surveys; 20 min; 3 rounds)	No
Netherlands	Grassland	On-field: extensive grassland management (< 100 kg N ha^{-1} yr^{-1})	Field scale, unpaired	2021, 2022	17	14	10	Yes (10×0.25 m^2 quadrats)	Yes (1×150 m^2 transect survey; 15 min; 3 rounds)	Yes (1×150 m^2 sweepnetting; 3 rounds; only in 2022)
Portugal	Orchard	On-field: wildflower green cover in orchard alleys	Plot scale (seven 70 m $\times$ 1.5 m alleys), unpaired	2023	10	6	19	Yes (4×0.25 m^2 quadrats)	Yes (1×150 m^2 transect survey; 15 min; 1 round)	Yes (1×8 suction samples; 30 s each; 0.357 m diam; 1 round)
Spain	Orchard	On-field: wildflower green cover in orchard alleys	Plot scale (0.5 ha), paired within orchards	2022, 2023	8	10	10	Yes (8×0.25 m^2 quadrats)	Yes (4×75 m^2 transect surveys; 7.5 min; 2 rounds)	Yes (4×5 suction samples; 30 s each; 0.357 m diam; 2 rounds)
Sweden	Arable	On-field: inter-cropping cereal with leguminous crop	Mix of plot and field scale, paired	2022, 2023	6	10	7	Yes (10×1 m^2 quadrats)	Yes (4–5 $\times$ 75 m^2 transect surveys; 7.5 min; 3 rounds)	Yes (4–5 $\times$ 5 suction samples; 30 s each; 0.357 m diam; 1 round 2022, 2 rounds 2023)
Switzerland	Arable	On-field and off-field: reduction of pesticides and establishment of annual wildflowers strip	Field scale, paired	2022, 2023	8	8	8	Yes (8×1 m^2 and 8×0.25 m^2 quadrats)	Yes (5–6 $\times$ 75 m^2 transect surveys; 7.5 min; 2 rounds)	Yes (5×5 suction samples; 30 s each; 0.357 m diam; 2 rounds)
United Kingdom	Arable	On-field: winter cover crops (three different treatment seed mixtures)	Plot scale (0.5–0.9 ha), paired within fields (randomized complete blocks)	2022–2023	5	5	5	Yes (10×1 m^2 quadrats)	No	Yes (4×5 suction samples; 30 s each; 0.357 m diam; 2 rounds)

of biodiversity-friendly farming practices (Featherstone and Goodwin, 1993; Schmitzberger et al., 2005; Hammes et al., 2016; Klebl et al., 2024a; Canessa et al., 2024).

The survey ran from December 2022 to November 2023. The farmers that participated in the field study (i.e. farmers that owned/managed biodiversity-friendly and/or control fields in the field study) were invited to the survey through a personal link. For each field-study-farmer a pseudonym was created to ensure data protection. Farmer identities are not published anywhere and are not part of the published data set. The surveys of the field-study-farmers were mostly conducted online but were complemented by hard copy questionnaires or face-to-face interviews when necessary. In line with the EU General Data Protection Regulations, all farmers were informed of and declared their consent to data collection and processing. The online questionnaires were implemented in the survey platform Qualtrics DesignXM Cloud.

2.5. Analysis

2.5.1. Data processing

For each biodiversity indicator, data on species richness and abundance (for bees and spiders) was averaged per sampling unit (plants: quadrat; bees: transect; spiders: pooled suction sample / sweep net transect), per field and treatment, and averaged over survey rounds and years. The main questions addressed in this study are operating at the level of the farmer (i.e. relationship farmer attitude – biodiversity). Since several farmers managed multiple treatment and/or control fields, we therefore subsequently averaged the biodiversity indicator and landscape context data per farmer and treatment.

We checked the farmer survey for consistency of farmers' responses and removed the data of two farmers (one from the Dutch study area and one from the Swedish study area) because of inconsistent responses to the attitude questions (i.e. fully agreeing to both positive and negative phrasing of the same questions). A total of 68 valid farmer responses remained (Table 1). We recoded Likert scores for negatively phrased attitude questions (Appendix S1) so that the score 10 represented the most positive attitude for all questions. We checked for internal consistency of the scales for the different attitude questions using Cronbach's alpha, which showed high reliability (Cronbach's $\alpha = 0.92$). We subsequently calculated for each farmer an average score across all attitude questions to get the farmer's overall attitude towards biodiversity, ranging from 1 (negative attitude) to 10 (positive attitude). We furthermore obtained basic farmer and farm structure data from the survey, including farmer age, education, farming system (organic, conventional low-input, conventional), farm size (ha), economic size (farm output in € yr^{-1}), whether farmers have ever participated in agri-environmental or conservation schemes, and how many different types of biodiversity-friendly measures they have currently implemented. Farm size was calculated as the sum of the area of arable land, permanent crop, grassland and other agricultural land. The number of implemented different types of biodiversity-friendly measures ranged from zero to four, and included flower strips, hedgerows, extensive grassland management, or the category “other measures”. Exploration of the basic farmer and farm data revealed that the variables education, farming system, economic size and experience with agri-environmental or conservation schemes were incomplete and/or hardly varied within study areas (e.g. all Hungarian and British farmers had experience with agri-environmental schemes and none of the Spanish and British farms were organic). These variables were therefore not further considered in the analyses.

2.5.2. Statistical analysis

We used piecewise Structural Equation Models (SEM) to examine direct and indirect effects of farmer attitude on local biodiversity and the effectiveness of biodiversity-friendly management, while taking into account other factors that may affect farmer attitude and biodiversity (see conceptual SEM in Fig. 3). We expected farmer age (Schmitzberger et al., 2005) and farm size (Buttel and Gillespie Jr., 1988) to be negatively related to farmers' attitude towards biodiversity. In turn, a positive farmer attitude was hypothesized to be positively related to on-field biodiversity (Ahnström et al., 2013) and the number of implemented types of biodiversity-friendly practices on a farm (Klebl et al., 2024a), which in turn was expected to be positively related to local biodiversity as well (Marja et al., 2021). Biodiversity was furthermore expected to be positively affected by the biodiversity-friendly farming treatment (Marja et al., 2022) and negatively related to landscape context quantified as the proportion of cropland (Dainese et al., 2019). Finally, we hypothesized that the effectiveness of biodiversity-friendly farming treatment was influenced by farmer attitude, the diversity of implemented

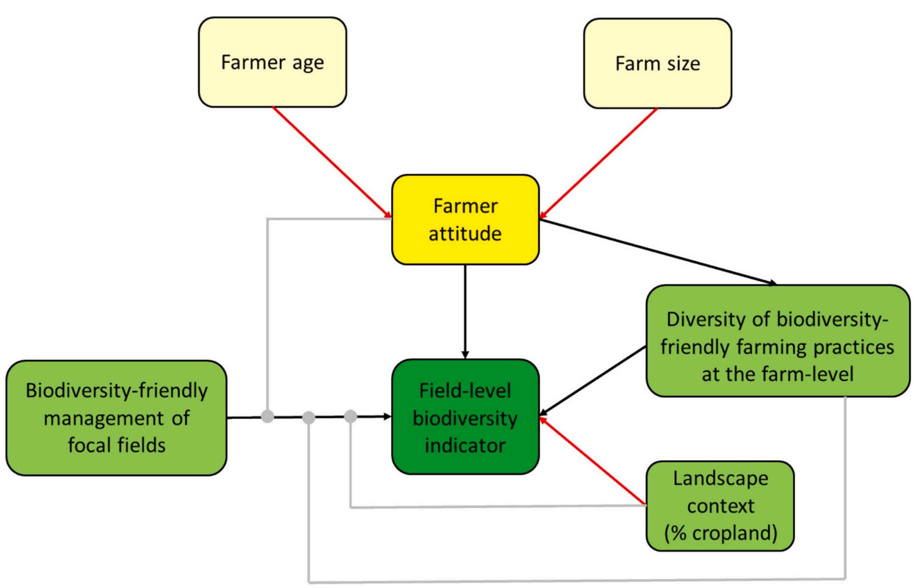

Fig. 3. Conceptual causal diagram of the examined hypothesized paths in the piecewise SEMs explaining biodiversity on farmland. Red arrows indicate hypothesized negative relationships and black arrows indicate hypothesized positive relationships. Grey arrows indicate two-way interaction effects. The arrow for biodiversity-friendly management of the focal fields represents the effect size compared to conventionally managed control fields. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

biodiversity-friendly practices (Image et al., 2023), and landscape context (Scheper et al., 2013) (i.e. two-way interactions with treatment).

Effects of landscape context may be taxon and scale-dependent (Steffan-Dewenter et al., 2002). Furthermore, the influence of landscape on the effectiveness of biodiversity-friendly management may be non-linear, with highest effectiveness at intermediate landscape complexity (Scheper et al., 2013). In a set of preliminary analyses we therefore used linear mixed models (LMMs) and an Information Theoretic approach (i.e. AIC_c, Burnham et al., 2011) to examine, for each biodiversity indicator, which shape (linear or hump-shaped) and what scale (250 m, 500 m or 1000 m radius) best explained interactive effects of percentage of cropland in the surrounding landscape and biodiversity-friendly management on local biodiversity levels. The LMMs included percentage cropland, biodiversity-friendly management and their interaction as fixed effects, country-specific FarmerID as random factor, and random slopes within country for percentage cropland. These preliminary analyses showed that the model containing a linear effect of percentage cropland at 500 m radius was the best performing model explaining species richness of plants and wild bees, and species richness and abundance of spiders (Table S1). For wild bee abundance, the model containing a linear effect of percentage cropland at 250 m radius was the highest ranked model. However, this model hardly performed better than the second-best model which included the percentage cropland within a 500 m radius (Δ $AIC_c = 0.12$). For consistency, we therefore included the percentage cropland within a 500 m radius in all further analyses.

We built piecewise SEMs for each biodiversity indicator separately, and in the case of wild bees and spiders, for both abundance and species richness. We examined the hypothesized paths by combining several LMMs within the piecewise SEMs. The LMMs with farmer attitude and the number of biodiversity-friendly practices as response variables included random slopes within study area for the explanatory variables. The LMMs explaining the biodiversity indicators additionally included random intercepts for country-specific FarmerID to account for cases where the same farmer managed both treatment and control fields (which was the case for 40 out of 68 farmers). These LMMs furthermore included weights for the number of fields that farmers managed, since farmers differed in the number of treatment and control fields that they managed and the biodiversity indicator variables were aggregated at the level of farmer and treatment (see section *Data processing*). The biodiversity indicator variables were standardized by mean-centering and scaling (divided by 1 standard deviation, i.e. z-scores) within study areas because the sampling methodology and/or sampling effort differed across study areas. All explanatory variables were mean-centered within study areas (as we were interested in the generality of within-study area patterns; Van de Pol and Wright, 2009), and subsequently scaled across all study areas. This preserved the within-study variable ranges while aiding model convergence and comparison of effect sizes. Prior to standardization, the left-skewed variable attitude and right-skewed variable farm size were square- and log-transformed, respectively. In addition, wild bee abundance and richness were square-root-transformed and spider abundance was log-transformed (x + smallest non-zero value) to improve normality and homogeneity of model residuals.

Relying on a single metric to assess the fit of piecewise SEMs may result in misspecified SEMs (underspecified or overly complex SEMs) (Herzog, 2019; Garrido et al., 2022). We therefore assessed the fit of the SEMs using a combination of Shipley's test of d-separation (Fisher's C statistic, Shipley, 2009) and AIC_c. In a first step, to avoid potentially spurious results originating from overly complex SEMs, we created a set of different SEMs to examine the support for (the combinations of) the two-way interactions in our hypothesized SEM (Fig. 3). Interactions were only maintained in the SEM if they improved SEM model fit with at least 2 AIC_c units. Next, we further examined the fit of the selected SEM resulting from the first step using Shipley's test of d-separation. In case of any missing paths indicated by Fisher's C-statistic, we added the missing paths sequentially, but only if their addition resulted in a lower AIC_c for the SEM (Δ $AIC_c > 2$).

If the SEM analysis revealed significant main or interaction effects of farmer attitude on the biodiversity indicators, we performed a follow-up analysis to explore which attitude component was mainly driving the observed pattern. To this end, we compared the fit of the LMM in the SEM, which included farmer attitude based on the overall average attitude score (see 2.5.1), to the fit of LMMs that instead included the separate attitude components that made up the overall average attitude score. These LMMs included farmers' attitude scores 1) on the importance and value of biodiversity in general (the average of the scores on the first, third and fifth attitude question in Appendix S1), 2) on the importance and value of biodiversity in agricultural landscapes (the average of the scores on the second, fourth and sixth attitude question in Appendix S1), or 3) on the necessity of considering biodiversity management in farm management (the score on the seventh attitude question in Appendix S1). The relative performance of the different attitude components in explaining local biodiversity was then assessed by ranking the different LMMs based on AIC_c.

All analyses were performed using R version 4.2.1 (R Core Team, 2022) and the packages lme4 (Bates et al., 2015), DHARMa (Hartig, 2022), MuMIn (Bartoń, 2023) and piecewiseSEM (Lefcheck, 2016).

3. Results

3.1. Effects of farmer attitude on on-field biodiversity and the effectiveness of biodiversity-friendly management

We found no significant main effect of farmers' biodiversity attitude on any of the biodiversity indicators (Fig. 4), indicating that there was no general relationship between farmer attitude and biodiversity on agricultural fields. However, for wild bee species richness and abundance, the relationship with farmers' attitude towards biodiversity depended on management type (Fig. 4b,c), as supported by the inclusion of this interaction effect in their highest ranked SEMs (Table S2). Although there was no such relationship for bees in control fields, wild bee abundance and species richness did increase with a positive farmer attitude in biodiversity-friendly managed fields (Fig. 5b,c). Consequently, the effectiveness of biodiversity-friendly management increased with a more positive attitude of farmers towards biodiversity. In the case of plant richness and spider richness there was no support for an interactive effect of management type and farmers' biodiversity attitude (Table S2). For spider abundance, we did find that the highest ranked SEM was the model including all hypothesized two-way interactions, but this model did not substantially perform better than a model not including any interactions (Δ AICc = 1.00).

3.2. Relative importance of different attitude components

Our follow-up analysis for wild bee abundance and species richness showed that the observed interaction effect of management type and farmers' overall attitude score were mainly driven by farmers' attitudes towards the necessity of considering biodiversity in their farm management, rather than by their attitudes towards the importance of biodiversity in general or biodiversity in agricultural landscapes in particular. The LMMs containing the interaction between biodiversity-friendly management and the attitude score on the necessity of biodiversity management clearly outperformed the LMMs based on the overall average attitude score (wild bee abundance: Δ AICc = 6.63; wild bee species richness: Δ AICc = 12.69), while the LMMs based on the attitude towards biodiversity in general or in agricultural landscapes had considerably less support (Tables S3-S4).

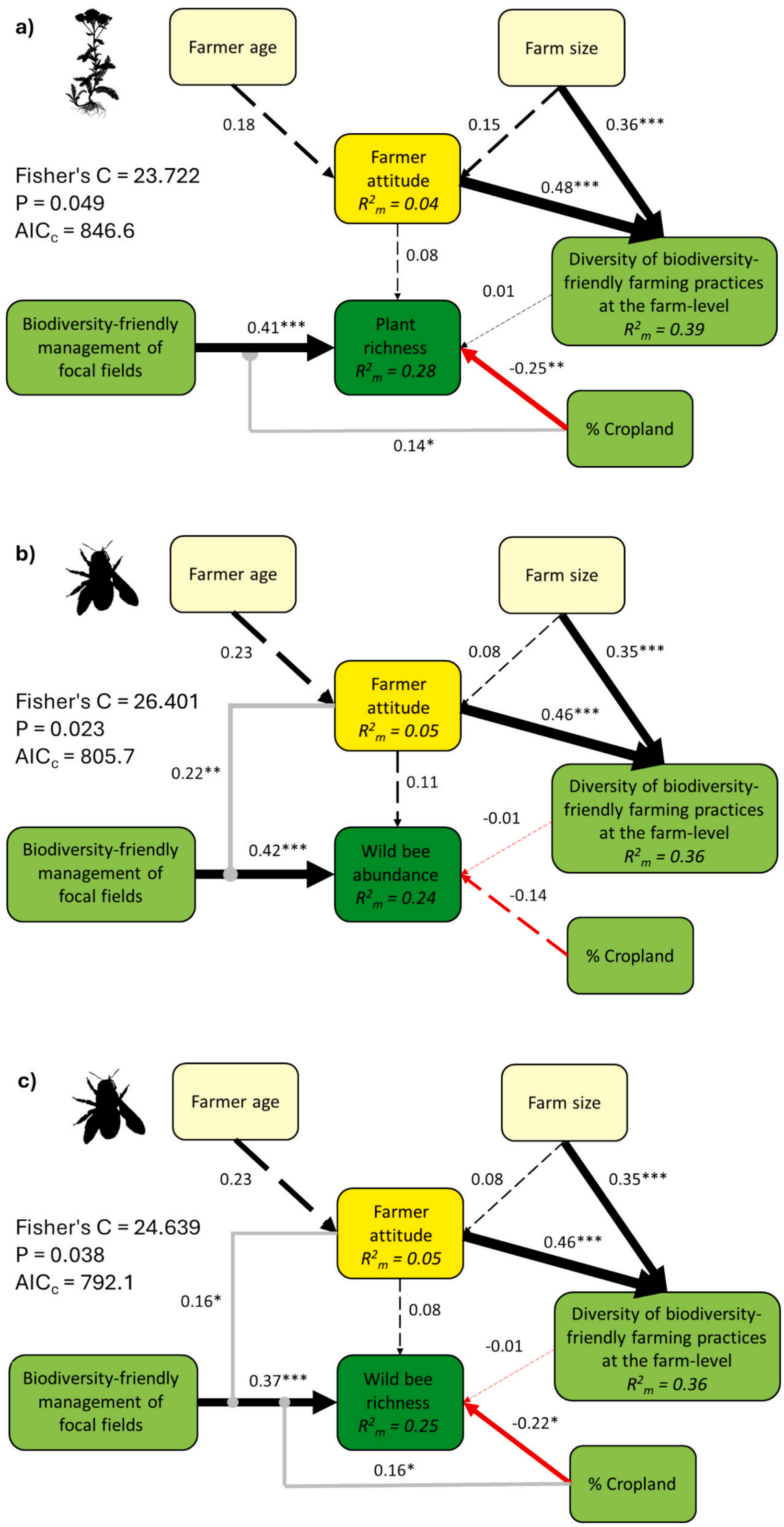

Fig. 4. Results of piecewise Structural Equation Models (SEMs) for **a)** plant species richness, **b)** wild bee abundance, **c)** wild bee species richness, **d)** spider abundance and **e)** spider species richness. Solid arrows and asterisks indicate (level of) statistical significance (*P < 0.05; **P < 0.01; ***P < 0.001). Red arrows represent negative and black arrows represent positive relationships between examined variables. Grey arrows indicate interaction effects. The numbers indicate the standardized path coefficients, also indicated by the proportional thickness of lines. The arrow and coefficient for biodiversity-friendly management of the focal fields represents the effect size compared to conventionally managed control fields. Marginal R^2 values are displayed in the boxes of response variables. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

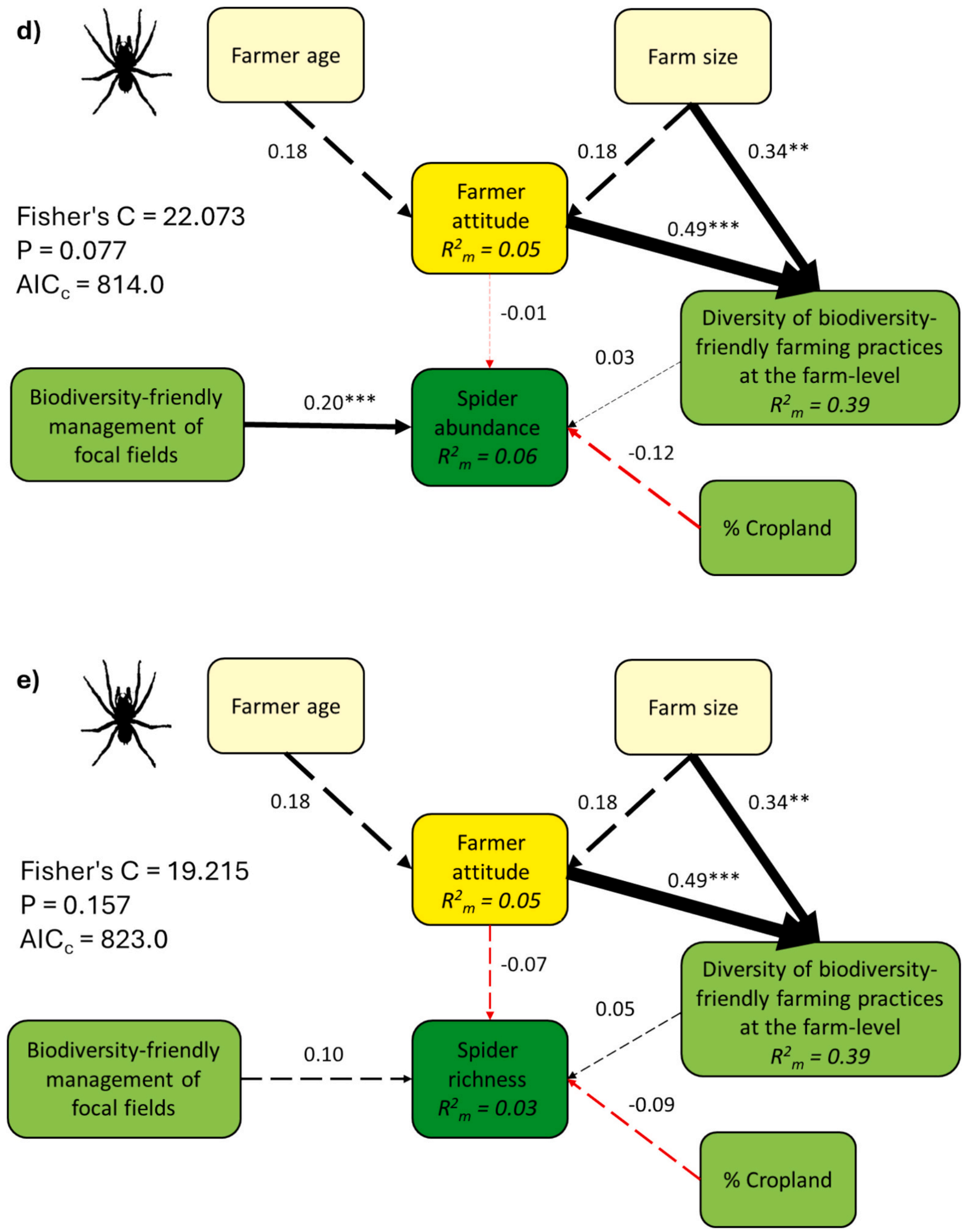

Fig. 4. (*continued*).

3.3. *Other factors influencing biodiversity and the effectiveness of management*

Plant species richness responded positively to biodiversity-friendly management but the magnitude of this effect was moderated by landscape context (Fig. 4a). Specifically, plant richness was negatively related to the percentage of cropland in the surrounding landscape, but this was more pronounced in control fields than in biodiversity-friendly managed fields (Fig. 5a). For plant richness, this resulted in a higher effectiveness of biodiversity-friendly management in more simplified, cropland-dominated landscapes. A similar pattern was found for wild bee richness, in addition to the observed interaction between management type and farmer attitude (Fig. 4c; Fig. 5d). However, although the SEM that additionally included the interaction between management type and percentage cropland was the highest ranked model for wild bee species richness, there was some model selection uncertainty (Table S2): the candidate set within Δ AICc < 2 also included SEMs that only contained the interaction between biodiversity-friendly management and farmer attitude (Δ AICc = 0.86), or only the interaction between biodiversity-friendly management and percentage cropland (Δ AICc = 1.68). Spider abundance was positively affected by biodiversity-friendly management (Fig. 5e), but the variance explained was low (Fig. 4d). Spider richness was not significantly explained by any of the hypothesized paths (Fig. 4e). None of the biodiversity indicators was significantly related to the diversity of implemented biodiversity-friendly practices on farms.

3.4. *Farm and farmer characteristics*

The diversity of biodiversity-friendly practices on farms was positively related to farmer attitude in all SEMs (Fig. 4; Fig. S1a). In addition, in all SEMs, Shipley's tests of d-separation revealed missing paths for the

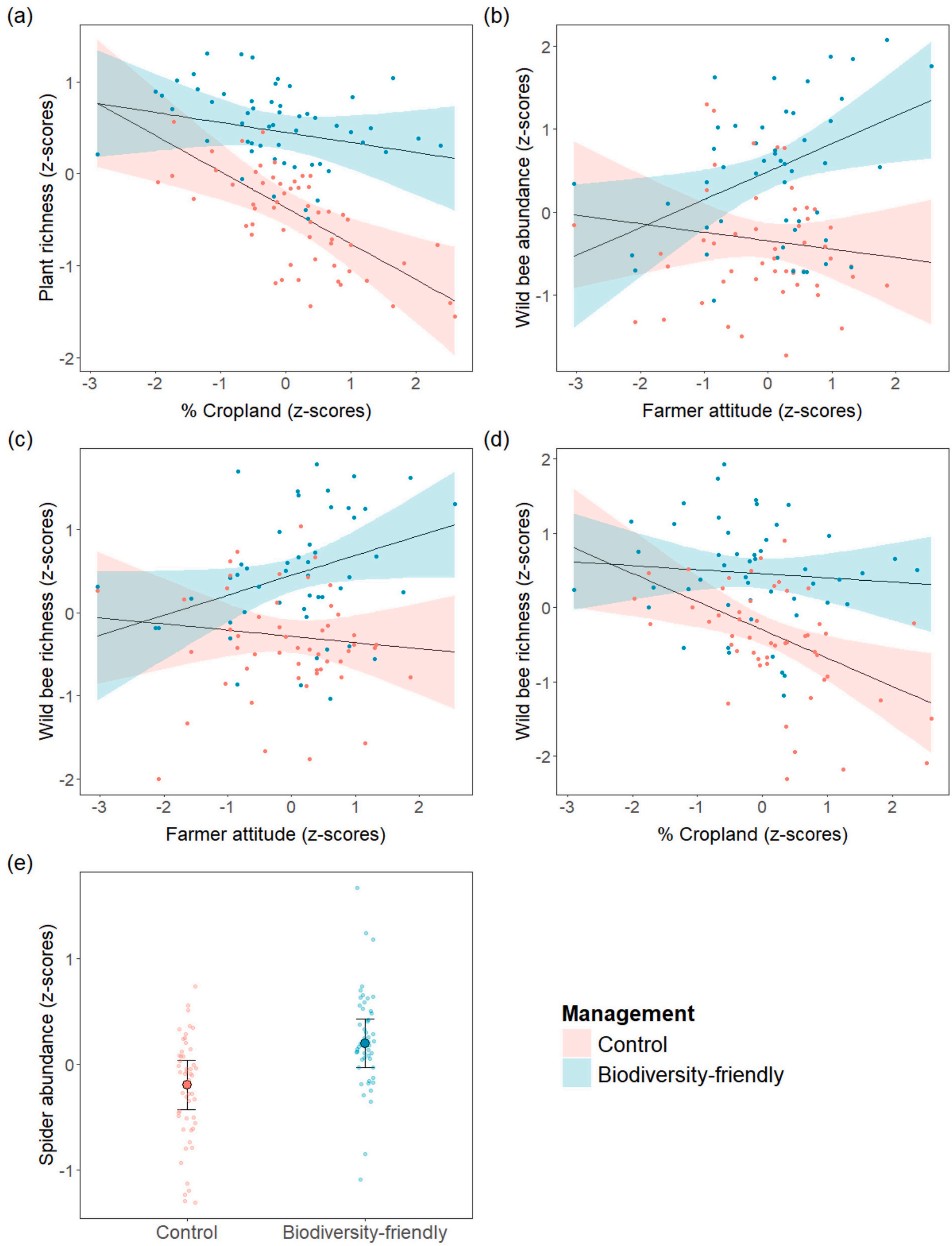

Fig. 5. Conditional partial regression plots for the SEM paths significantly explaining variation in the examined biodiversity indicators: **a)** the interactive effect of percentage cropland and biodiversity-friendly management on plant species richness; **b)** the interactive effect of farmer attitude and biodiversity-friendly management on wild bee abundance; **c)** the interactive effect of farmer attitude and biodiversity-friendly management on wild bee species richness, **d)** the interactive effect of percentage cropland and biodiversity-friendly management on wild bee species richness; and **e)** the effect of biodiversity-friendly management on spider abundance. Wild bee abundance and species richness were square-root-transformed, spider abundance was log-transformed and farmer attitude was square transformed prior to standardization to z-scores. Plotted points represent partial residuals; shaded areas and error bars indicate 95% confidence intervals.

significant positive relationship between farm size and the number of different implemented types of biodiversity-friendly practices (Table S5). Inclusion of this path improved model fit for all SEMs, as indicated by AIC_c (Fig. 4, Table S6; Fig. S1b). For plants and bees an additional missing path for the correlation between the diversity of implemented biodiversity-friendly practices and the percentage of cropland was indicated (Table S5), but inclusion of this path resulted in higher AIC_c values (Table S6). Farmer attitude was not correlated with farmer age or farm size in any of the SEMs (Fig. 4).

4. Discussion

A vast knowledge base exists on the ecological factors that affect the effectiveness of biodiversity-friendly farming practices (e.g. Scheper et al., 2013; Marja et al., 2019; Sánchez et al., 2022) but very little is known about how the biodiversity outcomes of these practices are related to farmers' socio-psychological characteristics. Here we show that farmers with a more positive attitude towards biodiversity are associated with higher wild bee abundance and species richness in biodiversity-friendly managed fields, but not in conventionally managed ones. As a result, at least for bees, the effectiveness of biodiversity-friendly practices increased with a more positive farmer attitude, which is consistent with the hypothesized scenario shown in Fig. 1a. For wild plants and spiders we found no relationship with farmer attitude, in either biodiversity-friendly or control fields. However, plant species richness and spider abundance, but not spider species richness, were generally enhanced by biodiversity-friendly management, regardless of farmer attitude.

In contrast to our expectations (Fig. 1), we found no overall positive relationship between farmer attitude and on-farm biodiversity levels, as would be indicated by observed positive relationships for both biodiversity-friendly and conventionally managed control fields. The few studies that have to date examined this relationship have found that farmers' interest in nature and pro-environmental attitudes were positively related to overall biodiversity (total biodiversity of vascular plants, carabid beetles, bumblebees, solitary bees, and birds) on arable fields (Ahnström et al., 2013), vascular plant diversity in organic permanent grasslands (Power et al., 2013), and more floral resources in sown agri-environment scheme field margins (McCracken et al., 2015). Conversely, more production-oriented attitudes have been shown to be negatively related to vascular plant diversity on both arable and livestock farms (Schmitzberger et al., 2005). Yet, in our study, the diversity of plants, bees (in control fields) and spiders was not related to farmers' biodiversity attitudes across the variety of regions and farmland types. This might suggest that, among the farmers included in our study, there was a significant discrepancy between farmers' attitudes towards biodiversity and their actual behavior in managing their (control) fields, as is often the case (De Rito et al., 2022; Swart et al., 2023; Byfuglien et al., 2025). Yet, our analyses revealed a consistently strong and positive relationship between farmers' attitude and the different types of biodiversity-friendly practices implemented on their farms (Fig. 4), which could indicate that the disparity between attitude and actual behavior was limited. Alternatively, the farmers in our study with a more positive attitude may have actually managed their control fields less intensively than farmers with a more negative attitude, but the reduction in land use intensity (i.e. the ecological contrast; Kleijn et al., 2011) might have been insufficient to result in measurable differences in biodiversity levels in control fields. However, because land use intensity could not be included in our analyses due to lack of data, this remains speculative.

Although for wild bees we did not find a relationship with farmer attitude in control fields, we did find that bee abundance and species richness increased with attitude in biodiversity-friendly managed ones. The hypothesis that a more positive attitude would result in a higher effectiveness of biodiversity-friendly practices (Fig. 1a) was thereby supported for bees. Increased effectiveness was mainly driven by the extent to which farmers believed that active biodiversity management on their farm is necessary, while the opinion that biodiversity is important (whether in general or in agricultural landscapes specifically) did not necessarily translate into higher effectiveness. Power et al. (2013) studied the effectiveness of organic farming in enhancing vascular plant diversity and found similar patterns as we found for bees: plant diversity increased with a positive environmental attitude on organic but not on conventional farms, so that the effectiveness increased with attitude. This suggests that attitude only becomes important once the decision to implement biodiversity-friendly management has been made. This is possibly because agronomical and economic motivations take precedence in conventionally managed fields, while farmers at the same time often have a low perception of the importance of biodiversity and ecological processes for agricultural production (Cartailler et al., 2024). Participation in biodiversity-friendly practices, such as agri-environment schemes, can positively affect these perceptions, albeit to a limited extent (Cartailler et al., 2024). Once biodiversity-friendly management is implemented, farmers with a more positive attitude may be more motivated and knowledgeable, thereby positively affecting the ecological quality of the implemented practices and their outcomes (Power et al., 2013; McCracken et al., 2015). The species richness and abundance of wild bees, which depend on floral resources in both their larval and adult life stages, are mainly determined by local flower cover and species richness (Scheper et al., 2015; Neumüller et al., 2020; Bishop et al., 2024). Although we could not include floral resource availability in our analyses due to lack of data, the ecological quality for bees therefore most probably meant increased availability of floral resources. For example, in the Spanish study area, farmers were allowed to mow the sown flowering green covers when necessary, but farmers differed in the frequency and timing of mowing, thereby influencing the beneficial effects of the biodiversity-friendly practice on wild bees (Ploeg et al., 2025). These management decisions may have been driven, at least partly, by the farmers' underlying attitude towards biodiversity.

In contrast to the results for bees, we found no relationship between farmers' attitudes towards biodiversity and the observed number of wild plant species in biodiversity-friendly managed fields. This suggests that while the effectiveness of biodiversity-friendly management for wild plants was higher in more simplified landscapes, as previously found by Roschewitz et al. (2005), it was not affected by farmer attitude. Local land-use intensity has been shown to affect the local diversity of plants, which occupy the lowest trophic level, more strongly than the diversity of higher trophic levels (Gossner et al., 2016). Any variation in the extent of biodiversity-friendly management potentially driven by farmer attitude, such as the level of fertilizer or herbicide reduction, may therefore be expected to impact wild plants most directly. It is therefore surprising that we found that the effectiveness of biodiversity-friendly management increased with attitude for bees, but not for plants. This may reflect that, while bees and pollination services are almost invariably perceived positively by farmers (Osterman et al., 2021; Faure et al., 2024), their perception of plant diversity is more ambivalent because of concerns about weeds and potential loss of productivity (Moroder and Kernecker, 2022).

Alternatively, the lack of a relationship between farmer attitude and plants in fields with biodiversity-friendly practices may be because, for example, once implemented, any further reduction in agrochemical inputs is accompanied by increased mechanical weeding (Masson et al., 2024). Furthermore, past intensive management may have impoverished the soil seed bank (Gaba et al., 2018), both of which may dampen further positive effects on plant diversity. Therefore, even if farmers with a more positive attitude more strongly reduced their management intensity in biodiversity-friendly fields, these actions may not necessarily translate into larger positive effects on plant diversity. This may seem at odds with the speculated increased floral resource availability mentioned above, because plant diversity is often correlated with flower cover and species richness (Ebeling et al., 2008). However, reductions in mowing or grazing intensity, for example, may readily enhance flower cover and bees without benefitting total plant species richness (Kleijn et al., 2001; Davidson et al., 2020; Horstmann et al., 2024), and sown low-diversity flower seed-mixes may abundantly flower despite not increasing total plant species richness (Carvell et al., 2007; Ploeg et al., 2025). In fact, wildflower seed mixtures were sown in four of the eight study areas. Wildflower strips are known to readily enhance wild bees (Scheper et al., 2015) while at the same time their effectiveness is strongly affected by quality of ongoing management (Piqueray et al., 2019) and, by extension, farmer attitude (McCracken et al., 2015). The prevalence of this practice in our study may therefore additionally explain the discrepancy between the relationship of farmer attitude with wild bees on the one hand, and with plant species richness on the other.

For spiders, the absence of a relationship between farmer attitude and effectiveness of biodiversity-friendly practices was less surprising, because spiders and their ecosystem services are generally less positively perceived (Martínez-Sastre et al., 2020; Cardoso et al., 2025) than bees (Faure et al., 2024). Furthermore, factors other than plant diversity or floral resources, such as vegetation structure, disturbance and the availability of prey, are more direct drivers of spider abundance and richness (Nentwig, 1982; Baines et al., 1998; Diehl et al., 2013; Kovács-Hostyánszki et al., 2013). In fact, regardless of farmer attitude, spiders were hardly affected by the implemented biodiversity-friendly practices.

We found a consistent positive relationship between farmers' attitude and the number of different biodiversity-friendly practices on their farms (Fig. 4). This is in line with findings of previous studies on the relationship between farmer attitude and the adoption of biodiversity-friendly management (Brown et al., 2021; Lu et al., 2022; Swart et al., 2023; Klebl et al., 2024a). Attitude, in turn, was not related to farm size or farmer age, in contrast to previous findings (Buttel and Gillespie Jr., 1988; Featherstone and Goodwin, 1993; Schmitzberger et al., 2005; Peterson et al., 2012). However, attitudes have been shown to be associated with a wide variety of factors that were not part of our analyses, such as education, self-identity and social group influence (Sulemana and James, 2014; Maas et al., 2021; Barnes et al., 2022), and our hypothesized SEM (Fig. 3) was therefore probably too simplified to adequately explain variation in attitude. Furthermore, more broadly, farmer behavior is also influenced by socio-cultural aspects outside of our individual-behavioral perspective, such as societal social norms, public discourses surrounding biodiversity loss, relational values of nature and landscape, and institutional agricultural education and training (Bartkowski et al., 2023; Klebl et al., 2024a; Strauser and Stewart, 2024). We additionally found that the diversity of biodiversity-friendly practices was positively related to farm size. A positive link between farm size and adoption of biodiversity-friendly practices has been found before (Hammes et al., 2016; Cullen et al., 2020; Lu et al., 2022; Klebl et al., 2024a), and may be explained by larger farms having more low-opportunity-cost areas available for implementing such practices (Canessa et al., 2024) and more capacity to handle the administrative burden of subsidized practices (Bartkowski et al., 2023). The number of different types of biodiversity-friendly practices implemented at the farm-level was not related to any of the biodiversity indicators measured at the field-level (Fig. 4). This is likely because information on the number of different practices does not give any insight into their effectiveness, quality of implementation, spatial extent or configuration, or how long they have been in place. Nevertheless, our study corroborates that farmers with a more positive attitude towards biodiversity are more likely to adopt biodiversity-friendly management on their farms.

Based on a pooled dataset of 68 farmers and 173 fields that cover a variety European agricultural contexts, our study provides an overall picture of the relationships between farm and farmer characteristics, biodiversity attitude, and uptake and ecological outcomes of biodiversity-friendly practices. It would have been informative to examine how these relationships vary across specific countries as well. However, limitations on sample sizes within individual countries (ranging from 3 to 17 farmers) prevented us from performing cross-national comparisons or evaluate country-specific socio-cultural drivers. Furthermore, in our study, country-specific differences in the influence of farmer attitude cannot be disentangled from differences in e.g. farming system and type of implemented biodiversity-friendly practice. Future research incorporating larger, stratified national surveys would be valuable to explore how national socio-cultural contexts influence the relationship between individual attitudes and biodiversity outcomes.

5. Conclusion

The EU's CAP allocates billions of euros annually to measures intended to support farmland biodiversity (ECA, 2020). Nevertheless, although positive impacts have been demonstrated, biodiversity loss on farmland has so far been neither halted nor reversed. This makes it imperative to enhance both the uptake and ecological effectiveness of biodiversity-friendly practices. Our results suggest that farmers' attitudes towards biodiversity can, across a variety of farmland types and practices, play an important role in driving the effectiveness of biodiversity-friendly practices. This relationship appeared to be taxon-dependent, however, being only restricted to wild bee abundance and species richness. Notably, the observed overall lack of a relationship between biodiversity indicators and farmers' attitudes in conventionally managed control fields suggests that, without financial compensation policies, a positive attitude towards biodiversity does not necessarily result in higher biodiversity in mainstream farming. Our study further supports previous findings that farmer attitude is an important factor associated with the uptake of biodiversity-friendly management. Taken together, our results suggest that significant progress could be made if farmers' perceptions, awareness and motivations regarding biodiversity conservation on farmland could be improved. While the factors shaping farmers' attitudes are complex and changing attitudes is not an easy task (Kaplan and Kaplan, 2008), several pathways may help shift attitudes in a more positive direction. These include awareness-raising, formal training, and peer-to-peer learning, as well as the provision of high-quality advice from farm advisors, scientists, and environmental NGOs. Furthermore, fostering a societal shift that recognizes and supports farmers as the primary custodians of biodiversity in agricultural landscapes would further support these efforts. Ultimately, our study indicates that, without addressing the social and motivational drivers of farmers, solely focusing on financial, agronomic, and ecological aspects will likely not be sufficient to improve the effectiveness of biodiversity-friendly practices.

CRediT authorship contribution statement

Jeroen Scheper: Writing – original draft, Visualization, Methodology, Formal analysis, Data curation, Conceptualization. **David Kleijn:** Writing – review & editing, Project administration, Funding acquisition, Conceptualization. **Fabian Klebl:** Writing – review & editing, Methodology, Conceptualization. **Anneli Adler:** Writing – review & editing, Investigation. **András Báldi:** Writing – review & editing, Methodology, Funding acquisition. **Ignasi Bartomeus:** Writing – review & editing, Methodology, Funding acquisition. **Vincent Bretagnolle:** Writing – review & editing, Methodology, Funding acquisition. **J.P. Reinier De Vries:** Writing – review & editing, Investigation. **Sabrina Gaba:** Writing – review & editing, Methodology, Investigation. **Maura Ganz:** Writing – review & editing, Investigation. **José M. Herrera:** Writing – review & editing, Methodology, Funding acquisition. **Felix Herzog:** Writing – review & editing, Methodology, Funding acquisition. **Amelia S.C. Hood:** Writing – review & editing, Investigation. **Philippe Jeanneret:** Writing – review & editing, Methodology, Funding acquisition. **Maria Kernecker:** Writing – review & editing, Methodology. **Klara Leander Oh:** Writing – review & editing, Formal analysis. **Francisco P. Molina:**

Writing – review & editing, Investigation. **Vasco S. Mendes:** Writing – review & editing, Investigation. **Csaba Molnár:** Writing – review & editing, Investigation. **Erik Öckinger:** Writing – review & editing, Methodology, Funding acquisition. **Álvaro Pérez-Gómez:** Writing – review & editing, Investigation. **Simon G. Potts:** Writing – review & editing, Methodology, Funding acquisition. **Vanesa Rivera:** Writing – review & editing, Investigation. **Gyula Szabó:** Writing – review & editing, Investigation. **José Van Paassen:** Writing – review & editing, Investigation. **Flóra Vajna:** Writing – review & editing, Investigation. **Elena Velado-Alonso:** Writing – review & editing, Investigation. **Kati Häfner:** Writing – review & editing, Methodology, Conceptualization.

Declaration of competing interest

The authors declare no competing interests.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.biocon.2026.112049.

Data availability

Data and code are available from Zenodo at https://doi.org/10.5281/zenodo.22010718 (Scheper et al., 2026).

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