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Determining the ecological value and farmers' perceptions of set-aside land

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Abstract

Set-aside fields are widely considered effective measures for maintaining biodiversity and ecosystem services in agricultural landscapes, although their ecological value depends on specific management and landscape context. Here, we assessed a multidimensional index of the ecological value of plant communities in 16 set-aside fields representing four different management types in northwest Saxony, Germany. Moreover, we used interview data to explore how farmers in the same study region perceive the ecological, economic, and social aspects of set-aside fields. Annual and perennial self-vegetated fallows had a higher ecological value than annual or perennial sown flowering areas. In most cases, perennial set-asides (self-vegetated or sown) had higher species richness, greater species diversity, and higher total abundance than the corresponding annual set-asides. Differences in soil parameters or landscape diversity were small, and differences in the ecological value were primarily driven by the management type and not by the landscape context. Farmers highlighted the value of perennial set-asides as habitat for wildlife and acknowledged their economic and social value, especially in areas with low soil productivity. However, farmers' overall confidence in the broader ecological value of set-asides remained limited. Our case study illustrates the inherent complexity of evaluating the success of conservation measures, which depends not only on the biodiversity outcomes but also on farmers' perceptions of these measures and thus their willingness to implement them and their ways of managing them.

KEYWORDS

arable weeds, biodiversity, conservation success, fallows, knowledge integration, values

INTRODUCTION

Decades of land use intensification and landscape homogenization have substantially reduced farmland biodiversity. This includes species adapted to traditional farming practices that create or maintain open but complex agricultural landscapes, such as farmland birds (Karp et al., 2012), small mammals (Pelletier-Guittier et al., 2020), insects (Hallmann et al., 2017; Seibold et al., 2019), and flowering plants (Eichenberg et al., 2021; Holz et al., 2022). Within the framework of the Common Agricultural Policy (CAP), the European Union (EU) promotes and finances measures to conserve and potentially enhance biodiversity and related ecosystem functions in agricultural landscapes.

One group of conservation measures that European farmers implement widely is set-aside fields, including self-vegetated fallows and sown flowering fields (see Kovács-Hostyánszki et al., 2021; Tarjuelo et al., 2020). Set-aside fields are "arable fields withdrawn from crop production for one or a few years, left for natural regeneration or sown by a seed mixture" (Kovács-Hostyánszki et al., 2021). In recent years, they have gained increasing political and public attention when, in response to the war in Ukraine and the resulting concerns for global food supply chains, the EU decided to suspend the obligation to set aside at least 4% of arable land to meet cross-compliance standards and receive basic income support from the CAP (Morales et al., 2022). Researchers and conservationists criticize this decision as the importance of set-aside fields for different taxonomic groups is fairly clear (e.g., Conservation Evidence Project, Dicks et al., 2020). Farmland birds profit particularly from set-asides (Staggenborg & Anthes, 2022; Traba & Morales, 2019), but positive effects have also been observed for insects (Kovács-Hostyánszki et al., 2011; Threadgill et al., 2020) and plants (Kovács-Hostyánszki et al., 2011; Ma & Herzon, 2014). Simultaneously, set-asides enhance ecosystem functions and services in a landscape, such as carbon sequestration, pollination, landscape aesthetics, and soil fertility (Van Buskirk & Willi, 2004).

The conservation success of set-asides depends mainly on their specific management (see Sanz-Pérez et al., 2019, 2021) and the duration of implementation (Kovács-Hostyánszki et al., 2011; Staggenborg & Anthes, 2022). In general, species and functional diversity of plant communities increase in the first years after implementation and are highest in extensively managed set-aside fields that are more than 3 years old. If set-aside land is not managed, it can become overgrown and plant diversity decreases (Albrecht et al., 2016; Tscharntke et al., 2011). Such set-asides also contain fewer flower heads, thus providing less food for pollinating insects and insectivorous birds (Threadgill et al., 2020). Factors over which farmers have no control, but which also influence the success of set-aside fields, include weather, soil parameters, land use history, or landscape complexity (Ma & Herzon, 2014; Tscharntke et al., 2011).

The conservation success of set-asides and thus their willingness to implement them are related to farmers' distinct but interrelated perceptions of the ecological, economic, and social values of these areas (Burton & Paragahawewa, 2011). Such perceptions are intertwined with cultural values and norms defining what it means to be a "good farmer" (Burton, 2004). Some farmers associate conservation more strongly with their roles as landscape stewards, while others may associate production more strongly with their roles as farmers (Moroder & Kernecker, 2022). Farmers' perceptions of particular conservation measures influence when and how these measures are implemented, which consequently determines their lands' ecological value. Taking farmers' perceptions and associated values into account is therefore important for improving biodiversity conservation efforts (Kelemen et al., 2013).

Here, we aim to contribute to the discourse on the conservation success of different set-aside measures by considering their ecological, economic, and social dimensions. To do so, we assessed species richness, species diversity, total abundances, and a multidimensional index of the ecological value of arable plant communities on set-aside fields in northwestern Saxony, Germany. We focused on arable plant species (i.e., segetal flora) as they represent an endangered species group in agricultural landscapes (Albrecht et al., 2016; Eichenberg et al., 2021; Meyer et al., 2013). They provide multiple ecosystem functions and services (Blaix et al., 2018; Yvoz et al., 2021) and serve as an important food source for insects and granivorous birds (Holland et al., 2006). We also interviewed 15 farmers in the study region to show how they perceive set-aside fields, shedding light on the multiple reasons for farmers to implement them. Insights from the interviews complement ecological findings to inform and discuss recommendations for set-aside fields. Our research questions are as follows: (1) How does species richness, species diversity, total abundances, and the ecological value of plant communities differ between four types of set-aside measures? (2) How do farmers perceive these conservation measures economically, ecologically, and socially?

First of all, we expect large differences between annually and perennially plowed set-aside fields in terms of their species richness, species diversity, and total abundance. Annual plowing presents a repeated disturbance that favors a limited number of ruderal species, whereas less disturbance in perennial fields allows a wider range of species to establish and survive (Tscharntke et al., 2011; Van Buskirk & Willi, 2004). We also expect large differences between sown flowering fields and self-vegetated fallows, especially regarding their ecological value. Here, we hypothesize that flowering fields have a limited and less diverse species composition, containing only a few dominant flowering species and traits that support only a few ecosystem services, including pollination (Meyer & Leuschner, 2015; Schmied et al., 2023). Their ecological value should thus be lower than the ecological value of fallow fields, which are subject to natural succession. In turn, we expect fallow fields to host a more diverse mix of species with more functional groups providing different ecosystem services and habitats (Albrecht et al., 2016). We assume that the interviews with farmers reveal diverse motivations for implementing set-aside measures and that financial motivation plays a major role overall, but that farmers also recognize the social and ecological benefits of set-aside measures.

METHODS

Study region and field selection

Our study region "Altkreis Delitzsch" is located in northwest Saxony, Germany, and has a total area of 861 km^2 (Figure 1). Several nature reserves are concentrated in the east of the study region and 70% of the area is used for agriculture (56% cropland, 14% grassland). The rest entails forest (17%), sealed surfaces (6%), water bodies (2.5%), heathland and wetlands (3%).

We considered four types of set-aside measures: annual fallows, perennial fallows, annual flowering areas, and perennial flowering areas. These measures accounted for ca. 60% of all agri-environmental measures implemented on farmland in our study region (SMEKUL, 2015). Annual flowering areas accounted for the largest share at ca. 30%, followed by annual fallows (20%), perennial flowering areas (10%), and perennial fallows (2%) (SMEKUL, 2022). The main difference between the set-aside measure types is that fallows are self-vegetated, whereas flowering areas are sown. Moreover, annual fallows and flowering areas are plowed once per year, while perennial fallows and flowering areas are non-plowed. We selected four fields per measure type, which resulted in 16 fields in total. Field selection was primarily limited by farmers' agreement to conduct vegetation surveys on their fields. All selected fields were

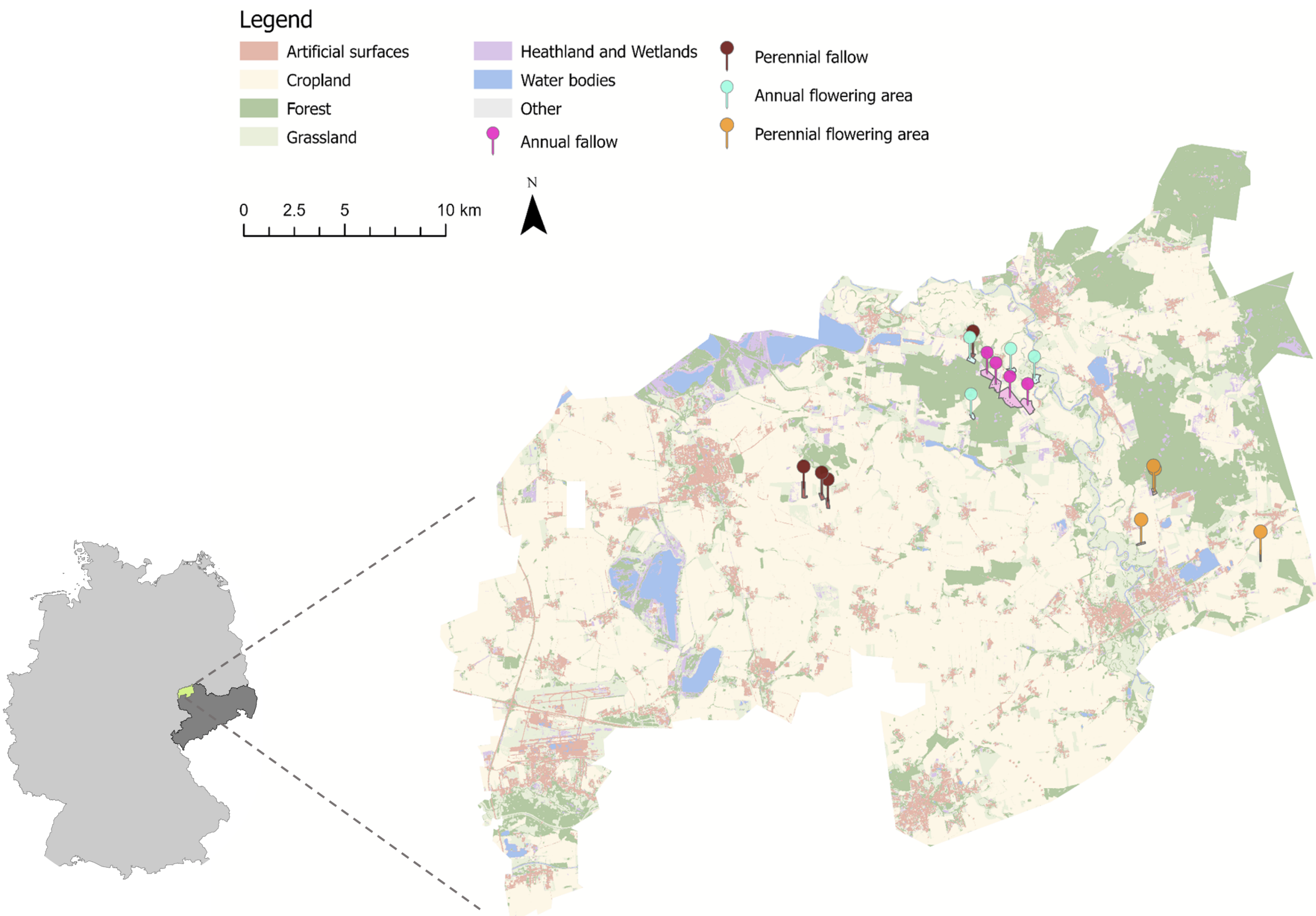

FIGURE 1 Land use map of the study region with the locations of the selected fields. Sentinel 2 land cover data were used from Malinowski et al. (2020).

cultivated in accordance with the relevant state regulations since 2015 (Appendix S1: Table S1), which prohibit pesticides and fertilizers. The management of all fields can therefore generally be regarded as extensive cultivation. Fallows must be established by February 15, with a cultivation break from February 16 to September 15. Mowing with clearing, mulching, and grazing is permitted on the perennial fields every 2 years but was only carried out on one of the selected fields. Reseeding is permitted on perennial flowering fields but was not carried out on any of the fields included in this study. All flowering areas were sown using the same two seed mixtures—one for annual flowering areas (containing 10 species) and one for perennial flowering areas (containing 32 species). All species of the seed mixtures were regional species with long flowering periods (Appendix S1: Table S2). The funding amount for the measures was US\$869 (747€) ha^{-1} $year^{-1}$ for annual fallows, US\$706 (607€) ha^{-1} $year^{-1}$ for perennial fallows, US\$967 (831€) ha^{-1} $year^{-1}$ for annual flowering areas, and US\$971 (835€) ha^{-1} $year^{-1}$ for perennial flowering areas (Appendix S1: Table S1).

Fieldwork

Arable plant species were surveyed in two 5 m × 5 m plots per field. The entire fields were walked once to select representative plots (e.g., covering the whole spectrum of species, avoiding dips, and elevations) at least 5 m from field boundaries to minimize edge effects. Percent cover of each arable plant species, as well as percent cover of bare soil, grass, and rock was estimated once in May and once in June 2022, to cover the different flowering periods. Average percentage covers from the two surveys were calculated. Plant species identification was conducted by two supervisors and six students, who received training in field methods before starting the field campaign.

Ecological data analysis

For each plot, we calculated species richness, species diversity, total abundance, and the ecological value of arable plant communities. Species richness per plot was calculated as the sum of species present per plot. The Shannon index was used as indicator for species diversity, which considers the identity and abundance of each species (R package "vegan"). Total abundance was calculated as the sum of relative abundances of all species per plot. The ecological value per plot was quantified following Fanfarillo and Kasperski (2021), who define the ecological value of arable plant communities using six plant features, to which we added a seventh feature (Table 1; Appendix S1: Section S1). In this approach, a score of either +1 or −1 is attributed to each species and feature to indicate whether the species does or does not fulfill this feature.

"Support to feeding insects" by native caterpillars was added as a seventh plant feature because Lepidoptera (i.e., adult caterpillars) are agricultural indicator species and an important food source for insectivorous birds (Hallmann et al., 2017; Seibold et al., 2019). We also used the conservation status of Saxony and Europe instead of only using the European conservation status. If the species was endangered in Saxony or Europe, it was assigned a higher value. Finally, we adapted the original index by using species abundances as weights when calculating the ecological index. Thus, the ecological value depends not only on the number of different species but also on their relative abundance.

To calculate the ecological value of a plant community per plot (ArEco), we first assigned the values +1 or −1 to each plant species found in the field for each plant feature. We then calculated the absolute sum of the plant features for each plant species, which can range from −7 to +7 (e.g., *Centaurea cyanus*: +4, *Conyza canadensis*: −3). The absolute sum of the seven features was then multiplied by the relative abundance of the respective plant species on the respective plot, resulting in a specific weight per plant species and plot.

$$\begin{aligned}&\text{Weight per species and plot}\\&\quad=|\text{Sum of the seven plant features}|\\&\qquad\times\text{relative abundance of the respective species.}\end{aligned}$$

The weights per species and plot were normalized so that the sum of all weights on a plot equals one, which makes it possible to compare ArEco values between plots (Fanfarillo & Kasperski, 2021).

$$\begin{aligned}&\text{Normalized weight per species and plot}\\&\quad=\text{Weight per species and plot}\\&\qquad/\text{Sum of the weights of all species per plot.}\end{aligned}$$

Finally, the ArEco indicator was calculated for each plot. It basically presents the sum of the normalized weights per species and plot. However, in order to build the correct sum of the normalized weights, each weight must be multiplied with a plus one (+1), a zero (0), or a minus one (−1), indicating whether the sum of the seven plant features was less than, equal to, or greater than zero

TABLE 1 Features of plant species used for calculating the ecological value.

Name of the feature	Scoring system	Sources used to define the feature for each species
Life form	Species that are therophytes or bulbous geophytes are of higher ecological value (score +1) than non-bulbous geophytes, hemicryptophytes, chamaephytes, or phanerophytes (score −1).	BiolFlor Database
Ellenberg nutrient value	Species preferring nutrient-poor soils, having an Ellenberg nutrient value below 7, are of higher ecological value (score: +1) than species preferring nutrient-rich soils, having an Ellenberg nutrient value of 7 or more (score: +1).	Ellenberg values: https://statedv.boku.ac.at/zeigerwerte
Native status	Species that are native, archaeophyte, or cryptogenic are of higher ecological value (score +1) than neophytes (score −1).	BiolFlor Database
Conservation status	Species considered rare or threatened in Saxony or Europe have a higher ecological value (score: +1) than non-threatened species (score −1).	Red list of Saxony (Schulz, 2013), IUCN list
Support to pollinator insects	Entomogamous species have a higher ecological value (score: +1) than anemogamous species (score −1).	BiolFlor Database
Support to feeding birds	Species producing seeds that are food for European farmland birds have a higher ecological value (score: +1) than species that do not produce such seeds (score −1).	Holland et al. (2006)
Support to feeding insects	Species that serve as food for native caterpillars have a higher ecological value (score: +1) than species that do not (score −1).	Clarke (2022) and LEPIDAT-Database (Pretscher & Kleifges, 2000)

for the respective species. This reintegration of the signums (plus or minus signs) is necessary due to the previous use of absolute sums (Das & Dennis, 1997; Fanfarillo & Kasperski, 2021).

$$\text{ArEco per plot} = \sum (\text{Normalized weight per species and plot} \times \text{sign per species}).$$

Soil analyses and land cover diversity

To analyze the relationship between soils and the plant communities, a representative soil profile was taken in each field in October 2022. Two soil samples were collected from the Ap horizon and characterized by the following soil parameters: soil pH, $CaCO_3$ availability, bulk density, total nitrogen, plant available phosphorus, organic carbon, density of fine and coarse roots, and grain size distribution (Appendix S1: Section S2). Land cover diversity was calculated in a circular buffer with a radius of 1, 2, and 5 km surrounding the centroid of each field using Sentinel 2 land cover data (Malinowski et al., 2020), considering 10 land cover classes and using the Simpson's diversity index as an indicator (R package "landscape metrics," Hesselbarth et al., 2019).

Statistical analyses

First, we tested whether there were significant differences between the average species richness, species diversity, ecological value, soil parameters, and land cover diversity in the four set-aside measures. Normality of the distributions was tested with the Shapiro–Wilk test (R package "stats"). Homogeneity of variances in the distributions was tested with Levene's test (R package "car"). If the data were not normally distributed or the variances were not homogeneous, we used a Kruskal–Wallis test instead of an ANOVA (R package "stats"). Effect sizes for the ANOVAs or Kruskal–Wallis tests were calculated using Eta-squared (η^2, R packages "effectsize" and "rstatix"). Pairwise *t*-tests with Bonferroni corrections were computed for multiple pairwise comparisons between the means of the measure types, and significant differences were identified at a level of $p < 0.05$ (R package "stats").

To test the effects of soil parameters, land cover diversity, and measure type on the ecological value of each plot ($n = 32$), we conducted a multiple linear regression analysis (R package "stats"). To reduce multicollinearity among the 11 soil parameters, we performed linear Pearson correlation analysis, retaining five soil parameters with low intercorrelation ($|r| < 0.7$, $p < 0.05$) and low variance inflation factors (VIF predictor = ArEco, VIF < 2.0, R package "car"), namely soil pH, $CaCO_3$

availability, bulk density, plant available phosphorus, and clay content (Appendix S1: Table S3). A VIF analysis with ArEco as the predictor was also applied to select the land cover diversity metric with the lowest VIF factor (i.e., land cover diversity at a 5-km buffer, VIF = 4.24) from three candidates. In a second step, we assessed whether plant community composition influenced the ecological value using redundancy analysis (RDA, R package "vegan"). Species abundance data were Hellinger-transformed and the statistical significance of the model was tested via ANOVA.

Interview data

Semi-structured interviews and field visits were conducted from April to August 2022 to gain insight into farmers' perceptions of set-asides. Farmers' perceptions account for their core values and the context in which they assess the value of a particular object (Brown, 1984). Fifteen farmers, selected by the regional landscape management association, were interviewed. The sample is purposeful and relied on the association's judgment for choosing farmers who could provide a range of insights that reflected the experiences of different types of farmers in the study region (Creswell & Creswell, 2003). This included four organic farms, nine conventional farms, and two farms that have both branches. The organic farms were smaller farms, below the regional average of ca. 500 ha. Almost all farms rented land, with an average of 58% of their land being rented. On average, about a third of all farmland was managed in ways that support conservation (including being located in protected areas). Set-aside measures were applied by eight of the farmers. Only two of them managed fields where vegetation and soil data were collected for this study (Appendix S1: Table S4), but as farmers are constantly navigating different management options for their land, they were all well informed about the four set-aside types. The results of all 15 interviews were further used to explore farmers' perceptions of biodiversity conservation broadly (Kernecker et al., in press). The interviews included questions about agri-environmental schemes and farmers' experiences with them, specifically in regard to their conservation value. The interview guide was comprised of four sections: first, farmers' relationships with agriculture, land, landscape, and region; second, their experience and perceptions of biodiversity conservation on agricultural land; third, decision-making with regard to farm management and agri-environmental schemes; and fourth, concrete farm and farmer characteristics, including their use of annual or perennial flowering and fallow areas (Appendix S1: Section S3). The interviews were recorded and transcribed (Shackleton et al., 2021). If a recording was not desired, we used verbatim transcription. Interview transcripts were then thematically coded deductively according to ecological, economic, and social perceptions of set-aside areas (Mayring, 2021). The findings complement the ecological findings and were used to discuss recommendations for set-aside fields in an inductive way.

RESULTS

Biodiversity indicators

Our study demonstrated that there is a significant difference in plant communities between the four types of set-aside measures in our study region. The type of conservation measure had a significant effect on species richness (ANOVA, $p = 0.001$, $\eta^2 = 0.43$), species diversity (ANOVA, $p = 0.007$, $\eta^2 = 0.35$), total abundance (ANOVA, $p = 0.001$, $\eta^2 = 0.42$), and the ecological value (Kruskal–Wallis test, $p = 0.004$, $\eta^2 = 0.37$) of the plant communities per plot.

The two perennial conservation measures had higher average species richness, species diversity, and total abundance than the corresponding annual conservation measures (Figure 2, Table 2). Significant differences were found between annual fallows and perennial flowering areas, as well as between annual and perennial flowering areas for species richness and species diversity (post hoc test, $p < 0.05$). Total abundance of arable plants was significantly higher in perennial fallows and perennial flowering fields compared to the annual fallows and annual flowering fields. Moreover, the two fallow conservation measures had higher average ecological values than the two flowering field conservation measures (Figure 2, Table 2). Significant differences for this indicator were found between annual fallows and annual flowering areas, as well as between perennial fallows and annual flowering areas (post hoc test, $p < 0.05$).

The proportion of species that received a positive score (+1) for each feature differed among the four types of set-aside measures (Figure 3). Annual flowering areas, for example, had only a small proportion of species (7.4%) that achieved positive scores for "conservation status," while in annual fallows a larger number of species (33.8%) were endangered and therefore achieved positive scores for this feature (Appendix S1: Table S5). A commonality of all measure types was that they had a high proportion of species with positive scores for "native status" (i.e., natives or archaeophytes) and "pollination mode" (i.e., pollinated by insects). Moreover, a high proportion of species of all measure types were annual species ("life form"), preferred nutrient-poor soils

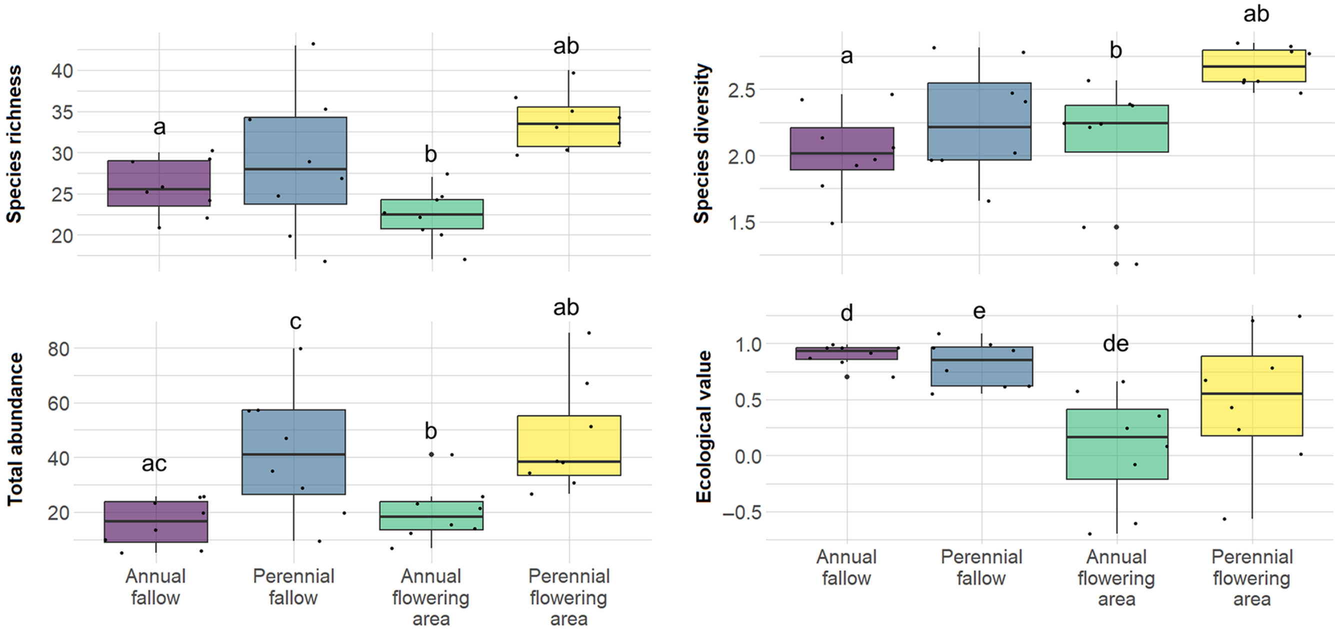

FIGURE 2 Species richness, species diversity, total abundance, and ecological value per measure type. Black dots present individual plots. Midlines present the median. The box limits show the upper and lower interquartile range (25th and 75th percentiles). The whiskers show the range of the data excluding outliers. Letters present statistically significant differences (a, between annual fallows and perennial flowering areas; b, between annual and perennial flowering areas; c, between annual and perennial fallows; d, between annual fallows and annual flowering areas; e, between perennial fallows and annual flowering areas).

TABLE 2 Species richness, species diversity, total abundances, and ecological value per measure type (mean ± SD).

Measure type	Species richness	Species diversity	Total abundance	Ecological value
Annual fallow	25.75 ± 3.37	2.03 ± 0.32	16.07 ± 8.01	0.87 ± 0.14
Perennial fallow	28.75 ± 8.46	2.26 ± 0.42	41.79 ± 21.51	0.81 ± 0.21
Annual flowering area	22.38 ± 3.11	2.08 ± 0.49	19.89 ± 9.84	0.10 ± 0.53
Perennial flowering area	33.75 ± 3.54	2.67 ± 0.15	46.56 ± 19.02	0.39 ± 0.64

("nutrient status"), and served as "food for caterpillars." In contrast, the proportion of endangered species was very low ("conservation status") as well as the proportion of species serving as food for birds ("trophic support of birds"; Appendix S1: Table S5).

Annual flowering fields, which had the lowest ecological values compared to the other measure types (Figure 2, Table 2), also had the lowest proportion of species with positive values for five of the seven plant features. Compared to the other measure types, they were particularly low in natives or archaeophytes (65%, "native status"), in species that prefer nutrient-poor soils (43%, "nutrient status"), and in endangered species (7.4%, "conservation status"), while annual fallows that had the highest ecological values had particularly high proportions of annual species (70%, "life form"), natives or archaeophytes (93%, "native status"), species that prefer nutrient-poor soils (70%, "nutrient status"), and in endangered species (34%, "conservation status"). Finally, perennial fallows had the highest proportion of species serving as food for birds and caterpillars (51%: "trophic support of birds", 72%: "food for caterpillars"; Appendix S1: Table S5).

Soil parameters and landscape diversity

Significant differences between the measure types regarding the soil parameters existed only for clay and phosphate (Table 3). In particular, annual fallows had a significantly lower clay content than annual flowering areas (1.42% and 3.42%, respectively), but a significantly higher phosphate content than perennial flowering areas (53.68% and 11.38%, respectively). Moreover, we found that fields of both annual measure types were surrounded by higher land use diversity in a 1- and 2-km buffer than

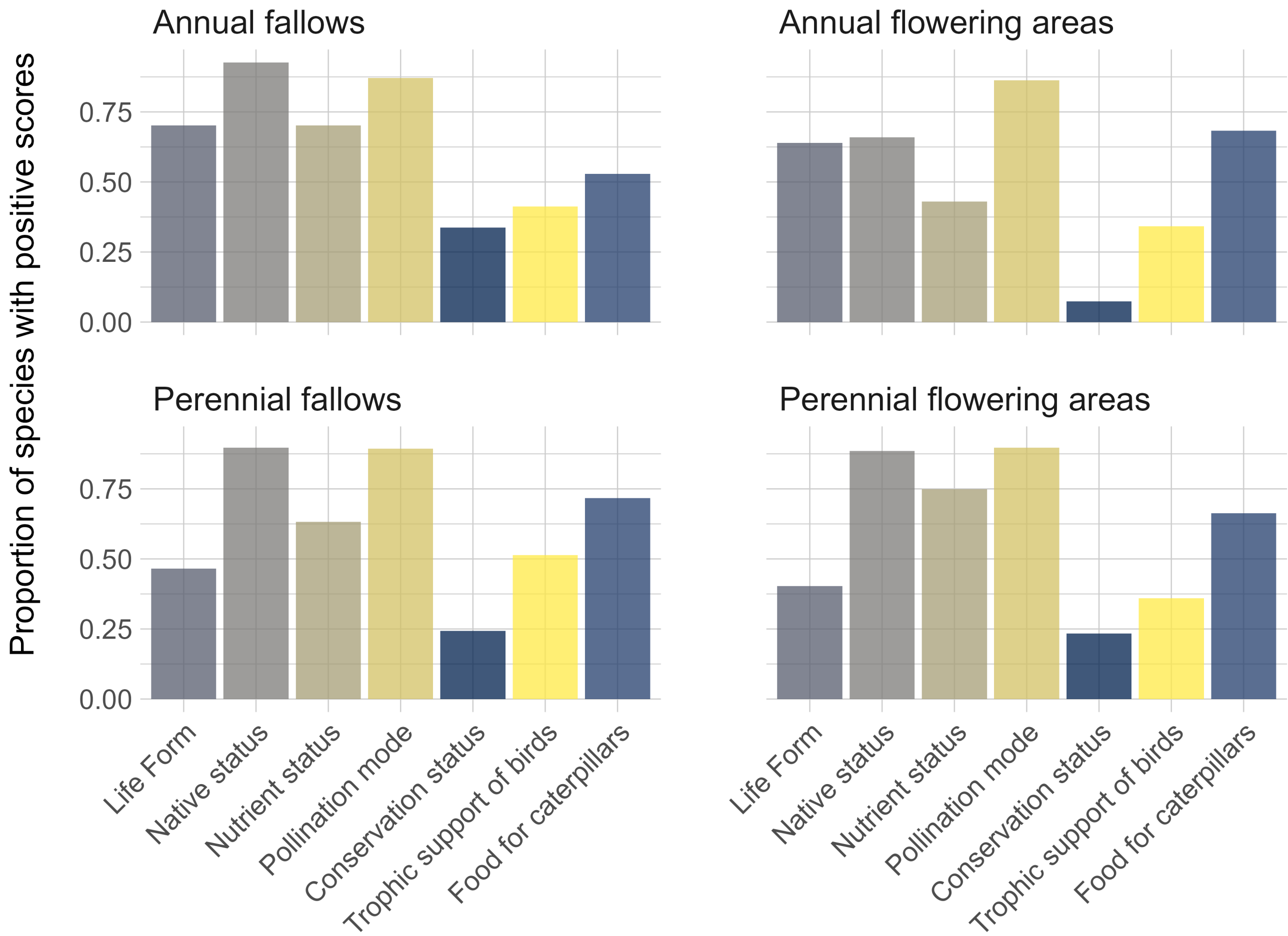

FIGURE 3 Proportion of species that received a positive score (+1) for each feature and measure type. Exact numbers are provided in Appendix S1: Table S5.

fields of both perennial measure types (Table 3). However, there was no significant effect between the measure types regarding landscape diversity for the three buffers.

Predictors of the ecological value based on regression and redundancy analyses

The multiple linear regression model explained a substantial portion of the variation in ecological value across plots (adjusted $R^2 = 0.50$, $p = 0.002$). Among the selected soil parameters, clay content and $CaCO_3$ availability were significant predictors but had only a small effect on the ecological value: Higher clay content was positively associated with the ecological value ($r = 0.291$, $p = 0.041$), while higher $CaCO_3$ was negatively associated ($r = -0.459$, $p = 0.015$; Appendix S1: Table S6). The measure type had a much greater influence on the ecological value: Compared to the reference category (annual fallows), both annual and perennial flowering fields were significantly associated with lower ecological value ($r = -1.309$, $p = 0.005$ and $r = -1.748$, $p < 0.001$, respectively), while perennial fallows showed a marginal effect ($r = -0.63$, $p = 0.098$; Appendix S1: Table S6). Bulk density showed a marginally positive effect ($r = 1.793$, $p = 0.082$), while soil pH, phosphate, and land cover diversity had no statistically significant effects.

RDA was used to assess whether plant species composition could explain variation in the ecological value (ArEco) across plots. The model accounted for 71% of the total variance in ArEco, with the first constrained axis (RDA1) capturing all of this explained variation (Appendix S1: Table S7). However, the ANOVA indicated that the model was only marginally significant ($F = 2.60$, $p = 0.052$).

Farmers' perceptions of set-aside fields

In general, farmers had mixed experiences and presented a range of observations of set-aside fields. We did not note any patterns among different farm sizes and farmer characteristics in regard to their

TABLE 3 Differences in soil parameters of the Ap-horizons and land cover diversity between the four set-aside measure types.

Parameters	Annual fallow	Perennial fallow	Annual flowering area	Perennial flowering area	*p*-value	Eta-squared
Sand (%)	79.53 ± 1.99	68.33 ± 13.1	75.08 ± 4.13	76.38 ± 8.6	0.4054 (K)	−0.00735
Silt (%)	19.05 ± 2.25	28.91 ± 12.45	21.49 ± 4.21	21.16 ± 7.98	0.5439 (K)	−0.0717
Clay (%)	1.42 ± 0.54	2.76 ± 1.03	3.42 ± 0.47	2.46 ± 0.70	**0.0142 (A) ***	**0.5727**
Bulk density (g/cm^3)	1.40 ± 0.13	1.39 ± 0.07	1.40 ± 0.04	1.48 ± 0.08	0.4910 (A)	0.1757
pH value	5.17 ± 0.64	6.00 ± 1.52	4.70 ± 0.63	4.80 ± 0.52	0.2310 (A)	0.2916
Organic carbon (%)	1.30 ± 0.22	1.54 ± 0.65	1.45 ± 0.28	0.86 ± 0.10	0.1060 (A)	0.3879
Total nitrogen (%)	0.09 ± 0.02	0.13 ± 0.07	0.10 ± 0.02	0.08 ± 0.03	0.3031 (K)	0.0533
Phosphate (mg/100 g)	53.68 ± 21.44	32.92 ± 14.88	19.73 ± 9.52	11.38 ± 4.70	**0.0060 (A) ***	**0.6314**
$CaCO_3$ (%)	0.99 ± 0.20	1.43 ± 1.26	0.99 ± 0.18	0.72 ± 0.21	0.5230 (K)	−0.1120
Density of fine roots	3.50 ± 0.41	4.50 ± 0.35	2.88 ± 1.14	3.88 ± 1.14	0.2090 (A)	0.3269
Density of coarse roots	2.00 ± 0.00	1.75 ± 0.56	1.38 ± 1.19	2.88 ± 0.74	0.2040 (K)	0.1330
Land cover diversity (1 km)	0.71 ± 0.09	0.51 ± 0.19	0.70 ± 0.06	0.57 ± 0.19	0.2000 (A)	0.0202
Land cover diversity (2 km)	0.75 ± 0.02	0.51 ± 0.15	0.70 ± 0.06	0.66 ± 0.11	0.0091 (K)	0.2890
Land cover diversity (5 km)	0.71 ± 0.01	0.45 ± 0.19	0.71 ± 0.03	0.74 ± 0.04	0.1339 (K)	0.2150

Note: Values are given as mean values per measure type ± SD. The *p* values below 0.05 are marked with an asterisk (*), indicating significant differences between the four types of measures for the respective parameter.
Abbreviations: A, ANOVA; K, Kruskal–Wallis test.

perceptions. Economically, the payments associated with set-aside fields were particularly beneficial to farms that had low-quality soils, but farmers had to use resources (i.e., time) for navigating the complexities of the different payment schemes, and their incongruence with ecological timescales. Farmers have had different experiences with the ecological value of set-aside fields. Some did not note any benefits for insects, while others highlighted the co-benefits of set-aside fields—for soils (annual flowering areas) and other wildlife (perennial flowering and fallow areas). Set-asides were frequently mentioned as being aesthetically enticing and representing farmers' role as landscape stewards but were simultaneously perceived as socially deceiving society by misrepresenting agricultural goals.

Economic perceptions of set-aside fields

Several farmers perceived an economic benefit of implementing set-asides, as payments are designed to cover income foregone, meaning that the payments compensate farmers for the lost incomes of not using their fields for production. However, several farmers did not perceive the payments as sufficiently covering the efforts (e.g., related to informing themselves, changing their routine) associated with implementing set-asides. One farmer managing both conventional and organic branches on their 2200-ha farm (F5) explained precisely that in regard to annual flowering areas and fallows: "… of course the subsidy allowed us to do that, but we were compensated for the loss. And that, of course, has an appeal." This farmer largely perceives the implementation of the set-aside as transactional, being compensated for foregone yields. However, this was viewed differently among farmers. While the measures are voluntary, in many places in the region, the soil quality is so poor that agricultural cultivation is hardly worthwhile. The farms thus feel obliged to use set-aside measures in order to receive any income from the land. Accordingly, one farmer who also has both conventional and organic branches on their 280-ha farm (F9) spoke about annual flowering areas and fallows on their land: "You can't survive on the poor soils here, nothing grows there. So, they are voluntary measures, but I am financially obliged."

One conventional farmer who manages 110 ha was very positive regarding their use of several of the set-aside options to maximize conservation on half of their land while working with a small arable crop rotation on the other half. However, several farmers were critical of the incentive structure associated with set-aside fields due to their design, logic, and implementation. For example, the timeframe of the incentives is not congruent with timelines inherent in farming and natural systems. One conventional farmer managing 870 ha (F3) stated: "…in politics, things change in a couple of years and then [...] you start from scratch again to work for what you believe in." Another organic farmer with 55 ha (F1) added: "I find it a bit difficult [...] to fit in the 5 years-tranche of the environment program." These quotes highlight that farmers use the set-aside fields to adapt their business concept to their core values, but that the farmers' workload associated with navigating the changes between CAP periods reduces the economic benefits of set-asides. Moreover, the Saxon agri-environmental payments associated with set-aside fields are largely incompatible with organic farming, due to the policy design for organic farms.

Ecological perceptions of set-aside fields

Farmers' perceptions of the ecological effectiveness of set-aside fields were ambivalent. Most farmers indicated that they had high expectations for set-asides in terms of floral and insect diversity, but that their observations of ecological impact were low. This was especially the case in low-quality soils, where, for example, seed mixtures for annual flowering areas did not germinate well and therefore did not provide much ecological value. However, there were a few exceptions. One farmer (F15) said that they would try flowering areas, since it fits their land, available subsidy schemes, and their image as "nature protector" in their role as an organic farmer, even if they did not attribute high ecological value to the measure: "I see enough bugs and everything, maybe it's because of our area. [...] If even the organic farms are bad in this sense though, we have to do more [...] if that brings so many more insects that are useful to us... I don't know, I don't...I have to say honestly." Another organic farmer (F13), who is also a beekeeper, paid close attention to the resources available to pollinators in their annual flowering area, suggesting: "If [I] have blooms, I have potential for the fauna and flora that use gaps between lower and higher [flower/plant] stands." The same farmer perceived annual flowering areas as ecologically important also in their contribution to restoring and regenerating soils due to the diverse root lengths of the plants in the floral mixtures, which are associated with diverse soil biotic activity: "We try to make the soils more resilient over a longer period of time." This is perceived as supporting the farm in adapting to climate change.

Beyond benefits for plant and insect diversity, a few farmers also perceived some success of their long-term fallows and flowering areas as habitat for wildlife, mentioning their observation of more wildlife, confirmed through feedback they had received from hunters. One farmer (F8) said: "My flowering area, which I have had for 7 years, has created a world that is so beautiful. The hunter also says to me that I should go there in the evening and [...] observe all the animals."

In other cases, farmers expressed their concern of spreading problematic plants either through seed mixtures for annual flowering areas or through fallows as they develop over time. One conventional farmer (F11) who did not apply any agri-environmental schemes, but prided themselves on their high crop diversity mentioned: "there is a weed (in the seed mixture), [...], which has many problems for (onion) cultivation, and the herbicides that we can use are always becoming fewer." This quote points to a perceived contradiction in the ecological goals codified in conservation measures. While the ecological value of flowering set-aside fields is supposed to improve habitats for insects, the farmer perceives a lack of agency in then subsequently dealing with weedy plants in their production system, undermining the farmer's own goals.

Perceptions of the social value of set-aside fields

Several farmers perceived set-aside fields as socially valuable, primarily when they were in bloom, and the landscape became aesthetically enticing for all. They acknowledged the beauty of set-asides for themselves and were proud of the recognition they received by other land users such as hunters or beekeepers (e.g., see quote by F8 above) in response to these areas. On the other hand, farmers felt that it was precisely the blooming of the flowers that deceived society by misrepresenting farming, since aesthetic enhancement falsely connects the public to agricultural landscapes. One farmer (F15) commented: "...in any case they are happy that it blooms [...] They don't know why it's here. It's only here so that it looks good. That actually annoys me." Some farmers found this shallow and expressed their desire for society to appreciate food and agriculture through other venues that could more effectively repair society's connection to agricultural landscapes.

DISCUSSION

Differences between the four set-aside measures

Annual fallows achieved the highest ecological values, although they had lower species richness, species diversity, and total abundance compared to the other measures. Lower richness, diversity, and total abundance in these fields can be explained by the fact that they were annually plowed and that no seed mixtures were applied.

At the same time, this management type supported rare arable species—which are annual, native, and endangered species, which need nutrient-poor soils and serve as an important food source for insects and granivorous birds—and therefore received high ecological values (Albrecht et al., 2016; Fanfarillo & Kasperski, 2021). Farmers in our study region made extensive use of this measure, and our interview results suggest that they did so not only for financial reasons but also because of social and ecological benefits.

Annual flowering areas, on the other hand, had the lowest ecological values, showed low species richness, rather low species diversity, and low total abundance. Our results further showed that annual flowering areas support only a very low proportion of species that are native, prefer nutrient-poor soils, and are endangered. Nevertheless, farmers in our study region used this measure most frequently compared to the other set-aside measures, probably due to its high financial remuneration. While some farmers questioned their ecological value, one also considered some potential benefits for soil biological activity (due to the different rooting depths of these mixtures). In general, sowing annual flowering areas has been debated since the start of the CAP funding (Meyer & Leuschner, 2015). Their ecological value is widely questioned in the literature, mainly since their seed mixtures contain species that compete with rare winter annuals (Meyer & Leuschner, 2015). This measure type is no longer funded as agri-environmental measures, although they are still listed as a measure under the eco-schemes (SMEKUL, 2022).

The two perennial set-aside measures were less widely implemented in our study region compared to annual set-aside measures. This might be due to their comparatively low financial remuneration (Appendix S1: Table S1)—especially for perennial fallows, which had similarly high ecological values as annual fallow areas, but received the lowest financial support and were only implemented on 2% of the farmland. The mean ecological value of perennial flowering areas was lower than the mean ecological value of perennial fallows. This is in line with findings from other studies that highlight the ecological importance of self-vegetated, perennial fallows (Kohler et al., 2011; Manthey, 2003; Tscharntke et al., 2011; Van Elsen & Günther, 1992). In our study, the contribution to the conservation of insects and birds in perennial fallows was particularly high compared to the other set-aside measures. Moreover, in both perennial set-aside measures, the long natural succession with low disturbance promoted a high total abundance of arable plants, which, in accordance with farmer interviews and literature, is particularly suitable for the protection of wildlife (e.g., hares, bats, birds of prey) (Firbank et al., 1993; Krings et al., 2022; Schai-Braun et al., 2020). Nevertheless, it is recommended to plow set-asides every 3 years to prevent them from becoming grassy or woody (Albrecht et al., 2016; Tscharntke et al., 2011).

Based on our results, supporting annual and perennial self-vegetated fallows is most valuable for nature conservation in terms of rare arable plants. The ecological value of perennial flowering fields could potentially be increased by regular reseeding and improving the seed mixture toward species with more functional groups (Schmidt et al., 2020; Schmied et al., 2023).

Soil and landscape effects

Regular plowing can affect the species community, as well as the soil chemical and physical properties (Blaix et al., 2018; Yvoz et al., 2021). Yet, the soil analyses in our study showed that differences between sites in soil characteristics were very small. Annual plowing neither affected bulk density nor nutrient availability, except for phosphate. Higher phosphate levels were measured in both annual measures, indicating that more phosphates remain in the topsoil during annual plowing and that phosphates may be translocated to the subsoil when not plowed. This could be due to increased biological activity or higher leachate. Interestingly, the differences between the soil properties of the measures were small, which might also be driven by the spatial clustering of fields. Fields of the same measure type were in close proximity to each other, while fields of different measure types were further apart (Figure 1). This is reflected by a high landscape diversity in the center of the study region surrounding both annual measure types and a lower landscape diversity surrounding the two perennial measure types. From the results of the regression analysis, we can deduce that the management types had the greatest influence on the ecological value, while soil properties and land cover diversity played only a minor role.

Farmers' perceptions of set-asides

Set-asides are widely advocated and promoted as conservation measures in Europe (Kovács-Hostyánszki et al., 2021; Morales et al., 2022). The evidence for conservation is there (Dicks et al., 2020), and farmers have consistently implemented these measures (Ma & Herzon, 2014; Morales et al., 2022). However, our interview results indicate that farmers have diverse perceptions related to set-aside fields and that farmers weigh them when they make decisions regarding their implementation. In the same study region, Wittstock et al. (2022)

found that farmers implemented agri-environmental schemes if they were sufficiently paid for and could easily be implemented on the farm and in everyday life. Moreover, farmers usually decide against implementing measures on soils with high productivity. While economic aspects are crucial, farmers also value how flowering areas influence landscape aesthetics and the image of farmers in society (Junge et al., 2011) and may value ecological effects if they were observable. The remuneration that farmers received for implementing set-asides differs between the set-aside types in our study. The remuneration for the four types of set-aside measures in our case study was highest for perennial flowering fields. Set-aside management moreover requires work and time by farmers, so cost savings due to financial support from the state are not necessarily given. Moreover, it is unclear whether the economic effects of improved ecosystem services, such as pollination or pest control, are notable for the farmers.

To support biodiversity conservation, it is important to understand the diversity of perceptions that underlie the decisions to implement conservation measures. Farmers' practical experiences and needs need to be integrated better into the design of conservation schemes (Hölting et al., 2022). In our case, farmers had both positive and negative experiences or expectations with the four set-aside measures, and their perceptions of the measures differed depending on their farm characteristics (e.g., conventional or organic, size, soil quality of fields) and their own values (e.g., those associated with their identity). Exploring farmers' perceptions of set-asides allows us to derive the opportunities and obstacles associated with these conservation measures:

1. The farmers' direct advantages when implementing set-asides mainly relate to the financial compensation, which is especially important on low productivity soils and the possibility to support conservation efforts—especially wildlife habitats, farmland birds, but also insects and soil biodiversity.
2. Direct obstacles preventing the successful implementation of set-asides are the high bureaucratic workload for the farm and the low ecological efficiency of set-asides when the flowering species do not grow well.
3. Long-term opportunities for the farms include the opportunity to experiment with improving soil fertility, habitat for other wildlife, and landscape aesthetics, while supporting the connection between nature and people in the region.
4. Finally, farmers fear that the low ecological knowledge of society combined with society's high expectations of farmers could pressure them into investing more time in conservation management and less time in productive agricultural work (i.e., long-term threats).

Conflicts between farmers' values and those codified by farmland conservation measures can hamper their own success (Chapman et al., 2019), largely because of differences between the goals of conservation and economic pressures. Clearly, conservation practices need to be more embedded in all aspects of farming (Burton & Paragahawewa, 2011), while also offering farmers clear, context-specific explanations of the biodiversity goals of each conservation measure in their farming context. Together, this would help promote the benefits and long-term opportunities of set-asides. So far, the measures have been seen more as a bureaucratic burden whose implementation is demanded by society, rather than as compatible with their farming practice and identity (Burton et al., 2008; Junquera et al., 2022; Kernecker et al., 2021). Only if farmers carry out the measures of their own conviction and see conservation tasks as part of their role can the measures be successful in the long term (Burton et al., 2008).

CONCLUSIONS

This study is the first to quantify ecological values for four types of set-asides, which are important agri-environmental measures. We have shown that, in our case study area, fallows had higher ecological values than flowering areas—especially annual flowering areas. However, the ecological values often played only a secondary role in farmers' decisions to set aside land, while the primary drivers are economic and practical reasons. Understanding how and why farmers choose certain measures and management is crucial for the conservation of biodiversity and ecosystem functions. More emphasis should be placed on discussing and designing measures with farmers on site, on monitoring the ecological effectiveness of conservation measures, and discussing the results with farmers and the public. Finally, it is important to consider what the goal of a measure is when deciding which type of set-aside to use and where to implement it. If the aim is to support annual arable species and increase landscape aesthetics, even annual flowering areas should be considered.

AUTHOR CONTRIBUTIONS

Lisanne Hölting, Maria Kernecker, and Anna F. Cord conceived the ideas and designed the methodology. Lisanne Hölting, Julian Wendler, Lisa Zwanzig, Carsten Marburg, Lisanne Hölting, and Maria Kernecker

collected the data. Lisanne Hölting, Maria Kernecker, Carsten Marburg, Luise Hofmann, and Lisa Zwanzig analyzed the data. Sabine Hänel contributed to the modification of the ecological value and Julian Wendler contributed to specific parts of the data analyses. Lisanne Hölting and Maria Kernecker led the writing of the manuscript. All authors contributed critically to the drafts and gave final approval for publication.

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CONFLICT OF INTEREST STATEMENT

The authors declare no conflicts of interest.

DATA AVAILABILITY STATEMENT

Data and R code (Hölting, 2025) are available from Zenodo: (https://doi.org/10.5281/zenodo.15963796).

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SUPPORTING INFORMATION

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

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