

Feasibility and reliability of farmer-recorded plant diversity indicators in European grasslands

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ABSTRACT

European grasslands are biodiversity hotspots but face ongoing threats from intensification and abandonment. Monitoring is essential for evaluating policies that promote grassland biodiversity, but conventional expert-led surveys are costly and difficult to scale. Farmer-led biodiversity recording offers a potential solution, but its feasibility and reliability remain uncertain. This study aimed to assess whether farmer-recorded indicators can provide reliable and practical measures of grassland plant diversity that could support broader biodiversity monitoring and assessment of public goods delivery. We firstly reviewed 14 European monitoring case study schemes, supplemented by stakeholder interviews in eight of these schemes. Secondly, we compared simple farmer-recorded indicators at the field and farm system levels with expert botanical assessments across 26 low-intensity farms in the UK, Sweden, and Romania. Analysis of case study monitoring schemes revealed that limited time and technical expertise were major barriers to farmer participation, while adequate incentives, scheme simplicity, and supportive technology acted as key enablers alongside the well-documented need for training and support. Comparisons with botanical assessments showed that simple farmer-recorded measures, particularly forb species counts, were strong proxies for plant species richness and diversity, while some abundance-based measures such as vegetation cover estimates also showed significant relationships with botanist assessments. In contrast, farmer-recorded indicator species performed poorly, likely due to short indicator species lists and the lack of farmer training. Farm system metrics were also weak predictors of species richness and diversity, although they may be informative across broader gradients of management intensity. Overall, our findings demonstrate that farmer-led biodiversity recording is feasible when based on straightforward, observable indicators, combined with adequate motivation. These approaches could complement expert assessments in supporting biodiversity goals and results-based agri-environment schemes.

1. Introduction

European grasslands support a rich diversity of plant and animal species, making a major contribution to the continent's biodiversity and providing a range of ecosystem services (Bengtsson et al., 2019; Feurdean et al., 2018; Habel et al., 2013). Restoration of grasslands has been posited as the highest priority for biodiversity restoration, given that the majority of endangered plant species are associated with open ecosystems (Staude et al., 2023). Grasslands are also vital for rural economies

through livestock production and tourism, and form part of Europe's cultural landscapes (Balázs et al., 2021; Bengtsson et al., 2019).

Despite their ecological and socio-economic importance, grasslands are under threat from habitat loss, abandonment, and agricultural intensification, leading to declines in biodiversity (Schils et al., 2022). In response, policy frameworks across Europe have sought to incentivise sustainable land management, including of grasslands, through instruments such as the Common Agricultural Policy (CAP), the EU Biodiversity Strategy for 2030, and national-level agri-environment

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schemes (e.g. England's Environmental Land Management scheme). These policies aim to align agricultural production with environmental stewardship, yet their success depends heavily on the ability to monitor biodiversity outcomes effectively and cost-efficiently. This is particularly pertinent for results-based payment schemes, which reward farmers based on the delivery of measurable environmental outcomes rather than adherence to prescribed management actions. Such schemes require robust indicators and reliable monitoring data to verify outcomes and ensure accountability (von Haaren et al., 2012). However, implementing these schemes at scale remains challenging.

Conventional biodiversity monitoring methods, typically involving expert-led field surveys, are often resource-intensive, requiring specialist knowledge, time, and funding. This limits their scalability across time and space (Geijzendorffer et al., 2016; Targetti et al., 2014), creating a major bottleneck for the implementation of large-scale biodiversity monitoring and evaluation of agri-environment policies. As a result, there has been considerable interest in participatory approaches that engage farmers and land managers directly in biodiversity recording and monitoring, which is essentially a form of citizen science (Herzog and Franklin, 2016; Ruck et al., 2024). These citizen science initiatives have demonstrated the potential to generate large volumes of ecological data while simultaneously raising awareness of biodiversity and encouraging stewardship (Alblas and van Zeven, 2023; Billaud et al., 2021; Chandler et al., 2017). Farmers occupy a unique position in that they are largely responsible for managing the European grassland resource, have local knowledge of their land, and may be able to adapt management practices in response to ecological feedback. Moreover, grasslands are especially conducive to farmer-led biodiversity recording, due to their importance for farmland biodiversity (Staude et al., 2023) and the direct links between biodiversity outcomes and management actions, such as fertilisation and the timing and intensity of grazing and cutting (e.g. Norton et al., 2022).

In the context of this study, monitoring refers to the repeated collection of biodiversity data through time using consistent methods. Effective biodiversity monitoring depends not only on sampling design and temporal consistency, but also on the selection of indicators that reliably reflect ecological condition. Indicators used for monitoring must also be sufficiently sensitive to ecological change through time, although assessment of this temporal responsiveness was beyond the scope of the present study. Here, we focus on one component of monitoring systems: the feasibility, reliability, and ecological relevance of farmer-recorded biodiversity indicators assessed at a single point in time. Biodiversity indicators are central to feasible and meaningful farmer-led recording, and their selection is an important component of wider monitoring systems. Indicators are measurable surrogates that reflect ecological condition or change, and are widely used to track trends, assess policy impacts, and guide adaptive management (de Bello et al., 2010; Noss, 1990). In grassland systems, plant indicators are particularly valuable due to their sensitivity to management, familiarity to farmers (particularly agriculturally-important species) and the relatively limited time, expertise and resources required for recording them (Herzog and Franklin, 2016; Landsberg and Crowley, 2004; Targetti et al., 2016). These indicators provide a practical entry point for participatory biodiversity recording and could allow for meaningful comparisons between farmer- and expert-collected data. As such, in this study, we focus mainly on plant indicators. Landscape and farm system indicators, such as habitat diversity metrics and intensity of inputs or grazing, can also be relatively easily recorded by farmers and often correlate with detailed biodiversity measurements (Billaud et al., 2021; Tasser et al., 2019; Triquet et al., 2024).

Technological advances have further expanded the feasibility of farmer participation in biodiversity recording. Smartphone apps and digital platforms now offer tools for species identification, geolocation, and automated data submission, reducing barriers to entry and enhancing data standardisation (Dehnen-Schmutz et al., 2016; Hart et al., 2023). Nevertheless, uptake remains uneven, and concerns persist

regarding data quality, consistency, and the practical challenges of engaging farmers in long-term monitoring efforts (Ruck et al., 2024). In this context, data quality refers to the reliability of farmer-recorded observations relative to expert assessments, and their ability to accurately reflect underlying ecological condition.

While several grassland monitoring frameworks have been developed across Europe (e.g. JNCC, 2004; Matzdorf et al., 2008; Milberg et al., 2020), few have rigorously assessed the feasibility, drivers, barriers to engagement, and data quality of farmer-recorded biodiversity indicators in European grasslands. This gap is important given the scalability constraints of conventional expert-led monitoring approaches, and is particularly salient in the context of European policy, where effective, cost-efficient biodiversity monitoring is necessary to evaluate the delivery of public goods through agricultural policy instruments (Targetti et al., 2016).

As such, this study addresses the need to evaluate the feasibility and reliability of farmer-derived data, and the extent to which simple indicators can accurately reflect ecological condition of grasslands, particularly in light of the scalability constraints associated with conventional expert-led monitoring. This need is particularly important given the increasing policy emphasis on outcome-based approaches, which rely on credible, cost-effective monitoring systems. In this study, farmer-recorded indicators are intended to provide direct observations of grassland ecological condition at the field scale.

Here, we present a novel cross-country assessment of farmer-recorded plant diversity indicators in European grasslands, combining qualitative and quantitative methods to assess feasibility, data quality, and policy relevance. The study aims to evaluate whether farmer-derived data can provide reliable measures of grassland plant diversity that could support broader biodiversity monitoring frameworks. Drawing on comparative data collected by farmers and botanists in the United Kingdom (UK), Sweden, and Romania, alongside a review of case studies, we address three key questions: (1) What are the constraints and opportunities for farmer recording of biodiversity? (2) What is the quality of the data received from farmers in terms of its agreement with expert botanist assessments? and (3) Can simple farmer-recorded indicators reliably reflect biodiversity in grasslands?

2. Methods

We reviewed 14 plant monitoring schemes involving farmers (Table 1), supplemented by stakeholder interviews relating to eight of the case studies, to identify constraints and opportunities for farmer-led biodiversity recording, focusing on engagement and data quality. Following this, we developed and tested simple plant diversity recording protocols designed for farmer use, relating to both field-recorded data and farm system metrics, and compared these with expert botanical assessments.

2.1. Case Studies: review and interviews

A structured review was undertaken to identify strengths and weaknesses of a diverse range of existing or recent farmer-led plant recording schemes in European grasslands. The review was designed to capture a range of existing approaches to farmer-led plant recording rather than provide an exhaustive inventory of all relevant schemes operating in Europe. We focused on 14 case studies (Table 1), following a similar approach to Herzog and Franklin (2016). Schemes were identified through online searches of scientific and grey literature, and through contacts of the co-authors. To qualify as a case study, schemes had to (i) be operational (currently or in the past), (ii) involve farmers in biodiversity recording, (iii) include grassland habitats, and (iv) have publicly available information on scheme design, purpose, field protocols, and verification procedures. Selected case studies represented a range of European countries and interface formats (e.g. smartphone apps, paper forms). For each scheme, a standardised set of attributes was

Table 1

Key attributes of case study farmer biodiversity recording schemes. Further detail is presented in [Supplementary Material 1](#).

Scheme name	Region, Country	Taxa	Tool type	Purpose
Soilmentor	Primarily UK	Various	Phone app	Monitor biodiversity to assess regenerative practices
Diverse Swards Grassroots Club	Cumbria, UK	Grassland plants	Paper forms	Monitor biodiversity to assess management practices
Results-based Agri-environment Pilot Scheme (RBAPS)	Ireland and Spain	Various	Paper score cards	Score for quality of biodiversity targets for results-based payment schemes
E-Surveyor	UK	Vascular plants	Phone app	Assess quality of habitats and assess agri-environment schemes
Goal-oriented biodiversity promotion (ZiBiF)	Switzerland	Vascular plants (positive indicators), birds, butterfly colours	Paper score cards	Results-based payments via a points scheme, aiming to promote farmer motivation for biodiversity management
Results-oriented management (EBW)	Austria	Various, positive and negative indicators	Phone app	Results-based payments based on bespoke indicators co-defined with each farmer
Species-rich grassland – outcome-based grassland management	Bavaria, Germany	Vascular plants (positive indicator species)	Phone app (paper forms until 2024)	Results-based payments based on indicator presence
Remuneration of species-rich grassland	Baden-Wuerttemberg, Germany	Vascular plants (positive indicator species)	Phone app, previously paper forms	Results-based payments based on indicator presence
RBAPS Romania (Fundatia ADEPT)	Romania	Vascular plants (positive indicator species)	Paper forms	Results-based payments based on indicator presence
Blooming Meadows	Latvia	Vascular plants (positive and negative indicator species)	Phone app or paper forms	Combined payments approach based on practice or results
Nature-rich Estonia: Heritage Meadows	Estonia	Vascular plants (positive and negative indicators), birds	Paper score cards	Voluntary top-up payments based on indicators
Conservation of Flowering	Lithuania	Vascular plants	Paper forms	Results-based payments

Table 1 (continued)

Scheme name	Region, Country	Taxa	Tool type	Purpose
Natural Meadows		(positive and negative indicators) Plants		based on indicator presence
Mozaic Earth	UK-based, operate internationally		Phone app	Quantify biodiversity to enable participation in voluntary markets e.g. Biodiversity Net Gain
XNatura	Global	Various, mainly plants and pollinators	Remote sensing, field sensors, phone app	Assessment for biodiversity credits and voluntary markets

reviewed (see [Supplementary Material 1](#)).

Of the 14 case studies included in the review, semi-structured interviews were conducted for a subset of eight of these schemes, based on the availability and willingness of relevant stakeholders to participate. Interviewees were individuals involved in the design, coordination, or implementation of the schemes (e.g. researchers, advisors, NGO staff), rather than participating farmers. These interviews provided more detailed insights into scheme operation, farmer engagement, and perceptions of data quality. Semi-structured interviews were conducted in April to May 2025. Five respondents were from non-governmental organisations (including conservation organisations, research institutes and advisory centres), and three were from public institutions. An interview guide was developed based around the overarching question, how effectively have farmers engaged with biodiversity monitoring of grassland, and how is the quality of the data received? Questions covered topics around feasibility and fairness of farmer monitoring, indirect incentives, and the operation of the scheme including farmer engagement, data quality, implementation constraints and solutions (see [Supplementary Material 2](#) for interview guide). Interviews were held via recorded online videocalls and lasted between 35 and 50 min. All interviews were carried out in English, transcribed using the Microsoft Teams AI transcription tool alongside manual editing and correction of transcripts, and subsequently anonymised. The process was undertaken in accordance with University of Reading's research ethics procedures with prior ethical approval obtained.

Interview data was analysed using human-led thematic analysis aided by AI ([Jalali and Akhavan, 2024; Naeem et al., 2025; Turobov et al., 2024](#)). The objective of this approach was not to automate thematic analysis or replace researcher interpretation, but to provide a structured and consistent aid to theme identification across interviews. This dual approach provides a structured and consistent analytical framework, while human oversight and review mitigates the limitations of Large Language Models (LLMs) ([Jalali and Akhavan, 2024; Naeem et al., 2025; Turobov et al., 2024](#)). Microsoft Copilot was selected as the LLM, based on its availability and improved confidentiality of uploaded files (which in any event were fully anonymised and subsequently deleted). A LLM prompt was developed (see [Supplementary Material 3](#)) based on [Turobov et al. \(2024\)](#) and iteratively refined through a testing process to improve the balance and weighting of information across interviews. Once finalised, the prompt was applied and repeated three times using separate chat sessions to assess the consistency of themes generated by the model. Recurring themes across runs were retained for further consideration. Themes that did not recur consistently across runs were also reviewed against the interview transcripts and were only retained where they were considered relevant and adequately supported by the underlying data. The lead author subsequently reviewed all

transcripts, candidate themes and supporting quotations against the original interview data to assess whether themes were adequately supported by the evidence and to identify any omissions. Final themes were therefore derived through a combination of AI-assisted analysis and researcher interpretation, with the latter taking priority.

The case study review was supplemented by a pilot online survey of farmers in the UK. The survey was advertised on the online Pasture for Life forum, an organisation which promotes grazing animals on 100% pasture. A total of 25 responses were received in March to April 2024.

2.2. Testing farmer-recorded data

In this second part of the study, we aimed to compare plant diversity data collected by trained botanists against indicator data derived from farmers/photos, comprising (i) field-based indicators and (ii) farm system indicators. Farmers were financially compensated for participation in Sweden, but not in Romania or the UK due to project funding constraints.

2.2.1. Study countries

The study focussed on three countries: the UK (certified Pasture for Life 100% pasture-fed livestock farms), Sweden (Naturbeteskött i Sverige semi-natural grasslands), and Romania (Cooperativa Agricola Tibles-Someş-Meleş semi-natural grasslands). These countries were selected to capture variation in grassland types, management intensity, and socio-economic context within predominantly agroecological systems. The UK sites comprised primarily pasture-based livestock systems, including improved and semi-improved grasslands, while sites in Sweden and Romania represented semi-natural grasslands under long-term low-input management. Romanian sites in particular reflected traditionally managed, species-rich High Nature Value grasslands. Although more intensively managed grasslands were under-represented, these case studies reflect conditions that are highly relevant to agri-environment policy, particularly where the conservation and restoration of species-rich grasslands is prioritised. As such, they provide a useful test of the applicability of farmer-led biodiversity recording approaches within these systems, while not aiming to represent the full spectrum of European grassland management.

In total, 26 farms were assessed, comprising ten in each of the UK and Romania and six in Sweden (see Fig. 1 for map of locations and Fig. 2 for example photographs). Farms were selected through their membership

of the organisations described above. Farmers were invited to participate via email or telephone. This sample size reflects a balance between achieving coverage across three countries and maintaining feasibility for labour-intensive, field-based botanical surveys and farmer participation.

2.2.2. Field indicators

The field-collected data focused on vascular plants due to their suitability as indicators of grassland biodiversity and their frequent use in previous studies (see Introduction). The protocol was developed taking into consideration previous indicator recording methods on Pasture for Life farms (Norton et al., 2023). Data collection took place in June 2024 (Romania), June to August 2024 (UK), and September 2024 (Sweden). Surveys later in the flowering season could be expected to reduce farmers' ability to record indicator species and estimate forb counts, although there was no evidence of this in the data.

At each participating farm, one field was chosen for biodiversity sampling, in consultation with the farmer. Fields were selected to be broadly representative of the farm and, where possible, with sufficiently tall sward vegetation to facilitate plant identification. All fields were in active agricultural use, typically managed for hay or silage production or rotationally grazed by ruminants. Farmer and botanist recordings were completed using paper forms, although the protocol could readily be adapted for digital data entry in the future.

The botanist recording protocol, which was standardised across countries, involved selecting three 5 by 5 m quadrats within each field. Quadrats were measured and marked by the botanist in locations considered representative of the field. Within each quadrat, a complete list of vascular plant species was recorded, and the percentage cover of each species visually estimated. All assessments were conducted by trained and experienced botanists with relevant regional expertise. To minimise surveyor bias, the same botanist visited all farms within each country. This data was used to calculate species richness and diversity (Shannon index) in each quadrat.

The farmer recording protocol varied between countries to account for regional constraints and differences in farmer engagement. The approach in the UK ($n = 10$) and Sweden ($n = 6$) was similar and incorporated three main elements applied within the same three quadrats used for the botanist assessments. A trained botanist accompanied each farmer into the field, explained the procedure, and then allowed the farmer to complete the assessment independently. In each of the three quadrats, farmers recorded: (i) the estimated percentage cover of grasses, legumes, and other vascular plants (in some cases the botanist had to explain the meaning of legumes, i.e. clovers and vetches); (ii) the total number of forb species (including legumes); and (iii) the percentage cover of positive and negative indicator species. Positive indicators were plants associated with high conservation value habitats, whereas negative indicators comprised agricultural weeds and species typical of intensively managed grasslands. Lists of indicator species were compiled independently for the UK and Sweden. To ensure ease of field recording, each list was restricted to four to seven easily identifiable species or species groups characteristic of grassland habitats, selected using published sources (DEFRA, 2023; Milberg et al., 2020; Öster et al., 2008; UKHab Ltd, 2023). Farmer recording forms for the UK and Sweden are provided in Supplementary Material 4. The whole process typically took around one hour of the farmer's time. After the farmer had finished, the botanist conducted the more detailed vegetation survey described above.

In Romania ($n = 10$), a different approach was adopted due to lower farmer participation. Here, the botanist collected a small bouquet of flowering plants from each quadrat and photographed it, as a proxy for farmer-recorded forb count (see Supplementary Material 5 for photographs). The bouquet was intended to represent flowering species richness rather than abundance, and therefore comprised a single representative stem of each flowering forb species observed within the quadrat. The photographs were later analysed by a second botanist to determine the number of forb species present. While this method differs

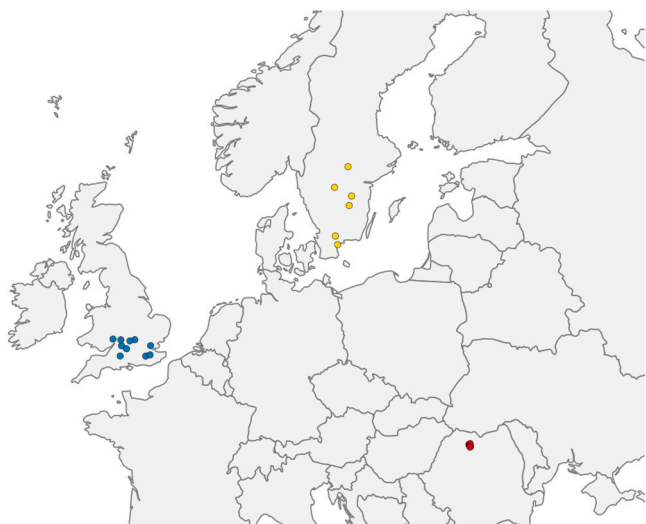


Fig. 1. Locations of study farms included in the field-based biodiversity assessment across Romania, (red, $n = 10$), Sweden (yellow, $n = 6$) and the United Kingdom (blue, $n = 10$). Points indicate individual farms. Farms in Romania were located within a relatively small geographic area.



Fig. 2. Examples of study farms in Romania, Sweden, and UK (from left to right).

from the farmer-based assessments used in the UK and Sweden, it was designed to capture the same underlying metric (forb species richness based on easily observable plants) in a way that was feasible under local conditions, and the results from this approach were broadly comparable to those observed for farmer-recorded data in the UK and Sweden (see Results).

2.2.3. Farm system indicators

In each of the three countries, farm system information was collected using the Public Goods Tool (PG Tool, [Gerrard et al., 2012](#)), which is a whole-farm sustainability assessment. The PG Tool evaluates the delivery of a range of public goods at the farm scale over one representative year within the previous five years. Assessments were conducted separately from the field surveys, between January and May 2023, as part of the wider project. The temporal difference between PG Tool data collection and field surveys is unlikely to substantially affect comparisons, as the PG Tool captures representative management over a typical year within the preceding five years, and grassland plant communities are generally influenced by longer-term management regimes, while none of the participating farms were known to have substantially changed management in recent years. Therefore, the two datasets are considered broadly comparable for the purposes of this analysis. The Tool was completed through a researcher-led visit to each farm, during which the researcher asked questions directly to the farmer (see bullet point list below). The PG Tool data was collected for all study farms in UK and Sweden, and four of the ten farms in Romania.

Farm system data relating to agri-environmental management was extracted from the PG Tool to test their association with botanist-recorded plant diversity. The following indicators were included in the analysis, calculated using PG Tool data (all at the farm scale):

- Stocking rate (livestock units per hectare of utilised agricultural area, including arable and grassland).
- Habitat diversity quantified using the Shannon index, calculated from the relative area of each habitat type (arable, fruit, energy crops, temporary grassland, fertilised grassland, low input grassland, unfertilised grassland, woodland, other).
- Proportion of semi-natural habitats (unfertilised grassland, low input grassland, woodland).
- Proportion of unfertilised permanent grassland.
- Overall agri-environmental management score (1–5), representing the composite score from the PG Tool's agri-environmental management spur, which accounts for stocking rate, habitat diversity and extent, biodiversity management on arable and grassland areas, and pesticide use (see [Supplementary Material 6](#)).

In Romania, one additional variable, years since last cultivation of the sampled field, was included. This information was collected separately from the PG Tool, during the botanist's visit.

2.2.4. Analysis

The analysis aimed to assess data quality in terms of the agreement of farmer-recorded indicators with expert (botanist) assessments, and their

ability to reflect underlying biodiversity metrics such as plant species richness and diversity. Indicators included both richness-based measures (forb species counts) and abundance-based measures (percentage cover of vegetation groups and indicator species). Data quality was therefore evaluated by testing the strength and direction of relationships between farmer-recorded indicators and botanist-derived measures of biodiversity using statistical models.

All statistical analyses were conducted in R version 4.3.3 ([R Core Team, 2024](#)). Linear mixed-effects models were used to test relationships between field-based and farm system (PG Tool) indicators versus botanist-recorded species richness and diversity (Shannon index), and to assess agreement between farmer- and botanist-recorded vegetation and indicator species cover. This approach was chosen rather than correlation analysis because of the nested data structure, with multiple quadrats sampled within each farm.

To account for multicollinearity among predictors, each indicator was analysed in a separate model for each country. The general model structure was: $\text{lmer}(\text{response} \sim \text{indicator} + (1|\text{farm}))$, where the response variable was either species richness or diversity (recorded by the botanist), and 'farm' was included as a random intercept to account for repeated measures (i.e. quadrats). Although this approach required a relatively large number of models, these addressed related hypotheses and formal multiple-testing correction was therefore not applied. Model outputs were tested using diagnostic plots. Potential outliers (Cook's distance > 1) were inspected for their influence on the model, including re-running models without the outliers and considering their ecological relevance. Two outliers were ultimately removed from the final models, comprising an unusually high cover of positive indicators in a UK quadrat (75%), and high cover of grasses/sedges in a Sweden plot (100%) which represented an atypical sedge-dominant inundation community.

3. Results

3.1. Case studies of farmer biodiversity recording schemes

We identified and reviewed 14 case studies across Europe ([Table 1](#)), each representing a plant monitoring scheme that involves farmers in data collection, supplemented by stakeholder interviews for eight of the schemes. The case study schemes varied widely in scope, target taxa, data submission methods, and alignment with results-based payment schemes (RBPS). Eleven of the 14 focused mainly on vascular plants, and were implemented primarily in western and northern European countries. Levels of farmer training, engagement, and data verification differed significantly across schemes, reflecting diverse governance models and resource availability. A comparative summary of key attributes is presented in [Table 1](#), with further detail available in [Supplementary Material 1](#). Four key themes emerged from the case study review and interviews, which are set out in the following sections.

3.1.1. Incentives and motivation

Two key incentives for monitoring emerged from the review and interviews: direct financial incentives and interest in biodiversity and

land management. Financial incentives in our case study schemes included results-based payments for protection of high nature value grasslands such as in Ireland, Spain, Switzerland and Germany, while a combined approach in Latvia allowed farmers to be paid based on either practice or results. Natural capital markets such as biodiversity credits also provide opportunities for financial incentives, and tech-based monitoring tools such as Mozaic Earth and XNatura aim to facilitate collection of rigorous, validated biodiversity data for these purposes.

Alongside direct financial benefits, interviewees recognised that some farmers are motivated by biodiversity and how it is impacted by their grassland management. For example, the Soilmentor scheme was designed for farmers to assess the biodiversity impacts of regenerative farming practices, without any direct financial incentive. Interview participants associated with the case studies highlighted the importance of incentives (NB many quotes are from non-native English speakers):

"The incentives are everything. Whether it's financial, it's education... we need to use all of this in combination." (Startup CEO)

Schemes designed primarily around financial incentives also tended to attract farmers who were interested in learning about biodiversity:

"There are farmers who are totally nature conservation..." (Government researcher)

"Some people are just curious and they want to learn more." (Government environmental officer)

The financial-based schemes also increased farmer enthusiasm for biodiversity, which was reported as an incidental outcome by interviewees:

"The main outcome was that the farmers really change their perception on the grasslands and learned a lot." (Environmental NGO officer)

"It was a surprise for us that it [biodiversity] is so important for them [farmers]." (Government environmental officer)

3.1.2. Time and technical barriers to participation

Limited time and technical skills emerged as key barriers to farmer participation in plant monitoring schemes, according to the case study review and interviews, which was supported by the online farmer survey results (Supplementary Material 7, Q15). Farmer time was a particular constraint given that the optimal timings for biodiversity monitoring, or required timings under results-based schemes, often conflict with busy times on the farm:

"They have to step off their tractor and walk through the meadow." (Government researcher)

"It [data collection] has to be in May and June. And it's also then when you have to do all the other works on the farm." (Independent advisory centre)

Technical knowledge barriers were mainly associated with species identification skills. This was particularly relevant for schemes which rely on indicator species, such as results-based payment trials:

"Most difficult for them [farmers] is to understand the species..." (Government environmental officer)

"Knowledge on species is important. Because you can't take a picture from all species and hope that it's one of the 33 [indicator species]." (Government researcher)

3.1.3. Technology as an enabler

Technology, such as digital tools and apps, emerged as a potential solution to the technical knowledge barrier. For example, automated species identification was a feature of three case studies. Technology was also seen as useful for increasing farmer engagement and interest in recording schemes:

"Quite a lot of them are really excited being like 'oh, we didn't know we had that plant here.'" (Academic)

"If we didn't have that app, we wouldn't be able to do it at all." (Academic)

Technology was also seen as a mechanism to improve data quality, which is particularly important for schemes linked to financial incentives, such as results-based payments and schemes linked to biodiversity credits:

"All of the data points are geotagged, time stamped, and we can validate with quite a high level of precision." (Startup CEO)

"Now you have this geo reference, pictures with the app and you can't trick the government." (Government researcher)

However, app development can be a more costly process than paper forms, particularly for small schemes, and there were also concerns relating to their accessibility across the farming community:

"We had no money to develop an app." (Independent advisory centre)

"Some people are less familiar with using a mobile app and still prefer traditional paper." (Academic)

Nevertheless, digital tools designed for accessibility, such as Mozaic Earth and XNatura, aim to enhance farmer engagement and participation in an inclusive manner. As one developer explained:

"We've developed a mobile application that was intuitive enough even for farmers with limited digital literacy." (Startup CEO)

3.1.4. Simplicity

Building on this, simplicity emerged as a key theme to engage farmers and scale up biodiversity recording, and to overcome barriers associated with time and technical expertise. Interviewees either criticised the complexity of the schemes in which they were involved, or praised their simplicity:

"...less is more... to do it in a most simple way for ordinary people, and this is the biggest challenge." (Government environmental officer)

"...it's very farmer centred... that was the main focus, that it's easy to document in the field." (Environmental consultant)

"All of the data collection process is built to be really, really intuitive and requires minimum training and that's a fundamental design principle for us...scalability is essential." (Startup CEO)

"I think our field form is super, super crazy complicated." (Government environmental officer)

3.1.5. Online survey

A survey of 25 Pasture for Life farmers in the UK broadly supported these findings (Supplementary Material 7). Although responses may not be representative of the wider farming community, results indicated a high level of interest in biodiversity recording, with all farmers expressing an interest in knowing about the botanical composition of their grasslands (Q8) and participating in biodiversity monitoring (Q12). However, most farmers (14/25) did not participate in any established biodiversity recording scheme, while 5 of 25 used their own methods to record biodiversity (Q7). Major constraints to monitoring biodiversity were time, suitable methods and technical expertise (Q13). The most popular incentive for monitoring biodiversity was an easy monitoring protocol (12/25 responses, Q14). These findings emphasise the requirement for simple biodiversity monitoring protocols tailored to the needs of farmers who are interested in recording biodiversity.

3.2. Farmer-recorded indicators

Plant diversity data collected by trained botanists were compared with indicator data derived from farmers/photos, comprising (i) field-based indicators and (ii) farm system indicators, across three countries. Botanist-recorded species richness and diversity were highest in Romania; levels in Sweden and the UK were comparable but considerably lower than those for Romania (Fig. 3).

Forb count was significantly related to botanist-recorded species richness and/or diversity in all countries (see Fig. 3, Table 2), despite methodological differences between countries, with a photographic approach applied in Romania and farmer-recorded forb counts in the UK and Sweden. Farmer-recorded percentage cover of grasses and non-legume forbs were also significantly associated with botanist-derived richness and diversity in the UK. In Sweden, only percentage grass cover showed a significant correlation, with botanist-recorded species diversity (Shannon Index).

Farmer-recorded percentage cover of positive and negative indicator species showed no significant relationships with botanist-recorded metrics in any country (Table 2). However, when using botanist-recorded estimates of negative indicator species cover, significant negative relationships were observed with both species richness and diversity in the UK (species richness: slope coefficient = -0.230 , p -value < 0.01 , species diversity (Shannon Index): slope coefficient = -0.0115 , p -value < 0.01 ; results not presented in Table 2).

In addition, to assess observer agreement, farmer- and botanist-recorded estimates of vegetation and indicator species cover were compared directly for the same quadrats (Supplementary Material 8). Significant positive relationships were observed for positive and negative indicator cover in the UK and for negative indicator cover in

Sweden, while the relationship for positive indicator cover in Sweden was close to significance. Agreement for percentage cover estimates of grasses, legumes and other forbs was more variable, although significant positive relationships were found for grass and non-legume forb cover in the UK, and for legume cover in Sweden. These findings suggest that farmers were generally able to estimate indicator species cover with reasonable consistency, although agreement varied between indicator types and countries.

Farm system indicators were generally weak predictors of botanist-derived metrics. The only significant relationships were observed for: (i) years since cultivation in Romania, which was positively associated with species richness; (ii) stocking rate in the UK, which was negatively associated with species diversity (Shannon Index); (iii) PG Tool score for agri-environmental management in the UK, which showed a positive association with species diversity (Shannon Index) in the UK; and (iv) PG Tool score for agri-environmental management in Romania, which was unexpectedly significantly negatively associated with species richness, but with a small sample size ($n = 4$) (Fig. 4). Other farm system indicators, including those related to habitat diversity, the proportion of semi-natural habitats, and the extent of unfertilised grassland, showed no significant relationships with botanist-derived metrics (Supplementary Material 6).

4. Discussion

This study combined a review of existing farmer-led plant monitoring schemes, stakeholder interviews, and testing of farmer-reported indicators across three European countries to evaluate the feasibility of farmer-led biodiversity recording in grasslands. The findings highlight the importance of farmer motivation, including financial incentives

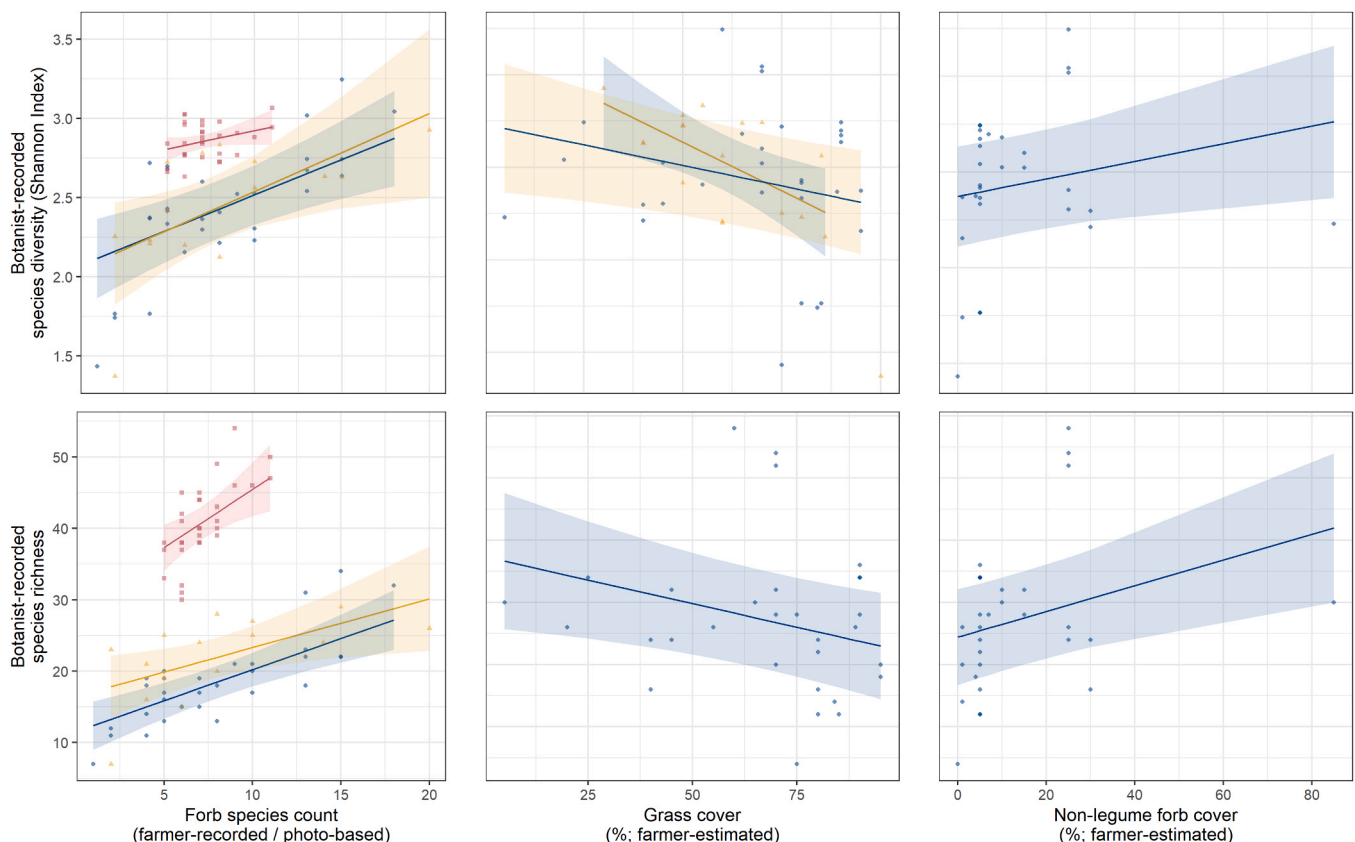


Fig. 3. Relationships between field-based indicators (x-axes) and botanist-derived plant biodiversity metrics (y-axes) across countries (red = Romania, yellow = Sweden, blue = UK). Forb species counts were recorded by farmers in the UK and Sweden, and estimated from photographs in Romania. Lines show country-specific linear mixed-model predictions, and shaded ribbons represent 95% confidence intervals. All relationships shown are significant (after accounting for outliers, see Table 2 for full details of significant and non-significant relationships (not shown)).

Table 2
Slope coefficients, 95% confidence intervals and marginal R^2 values for relationships between field-based indicators (rows) and botanist estimates of plant diversity (columns, species diversity (Shannon Index) and richness across three countries. Results are derived from mixed-effects models with farm as a random effect. Significance codes: *** $p < 0.001$, ** $p < 0.01$, * $p < 0.05$, † $p < 0.1$, N/A = not tested (no data). One outlier was removed for positive indicators in the UK (75% cover) and grass / non-legume forb cover in Sweden (100% grasses, 0% forbs).

Indicator	UK		Sweden		Romania	
	Species Shannon Index	Species richness	Species Shannon Index	Species richness	Species Shannon Index	Species richness
Forb count	0.045 (0.021, 0.070) *** $R^2 = 0.315$	0.869 (0.518, 1.238) *** $R^2 = 0.514$	0.049 (0.014, 0.084) * $R^2 = 0.373$	0.684 (0.188, 1.180) * $R^2 = 0.340$	0.023 (-0.003, 0.048) † $R^2 = 0.097$	1.626 (0.439, 3.160) ** $R^2 = 0.265$
Positive indicator species %	0.027 (-0.009, 0.066) $R^2 = 0.026$	0.232 (-0.305, 0.830) $R^2 = 0.008$	0.058 (-0.088, 0.222) $R^2 = 0.025$	0.702 (-1.668, 3.210) $R^2 = 0.018$	N/A	N/A
Negative indicator species %	-0.002 (-0.017, 0.011) $R^2 = 0.002$	-0.071 (-0.312, 0.136) $R^2 = 0.009$	0.002 (-0.017, 0.015) $R^2 = 0.005$	0.017 (-0.237, 0.227) $R^2 = 0.002$	N/A	N/A
Grass cover %	-0.004 (-0.008, -0.001) * $R^2 = 0.059$	-0.076 (-0.134, -0.016) * $R^2 = 0.075$	-0.011 (-0.017, -0.004) ** $R^2 = 0.375$	-0.102 (-0.214, -0.012) $R^2 = 0.162$	N/A	N/A
Non-legume forb cover	0.005 (0.0004, 0.009) * $R^2 = 0.034$	0.103 (0.040, 0.166) ** $R^2 = 0.076$	0.005 (-0.002, 0.011) $R^2 = 0.101$	0.073 (-0.023, 0.170) $R^2 = 0.120$	N/A	N/A

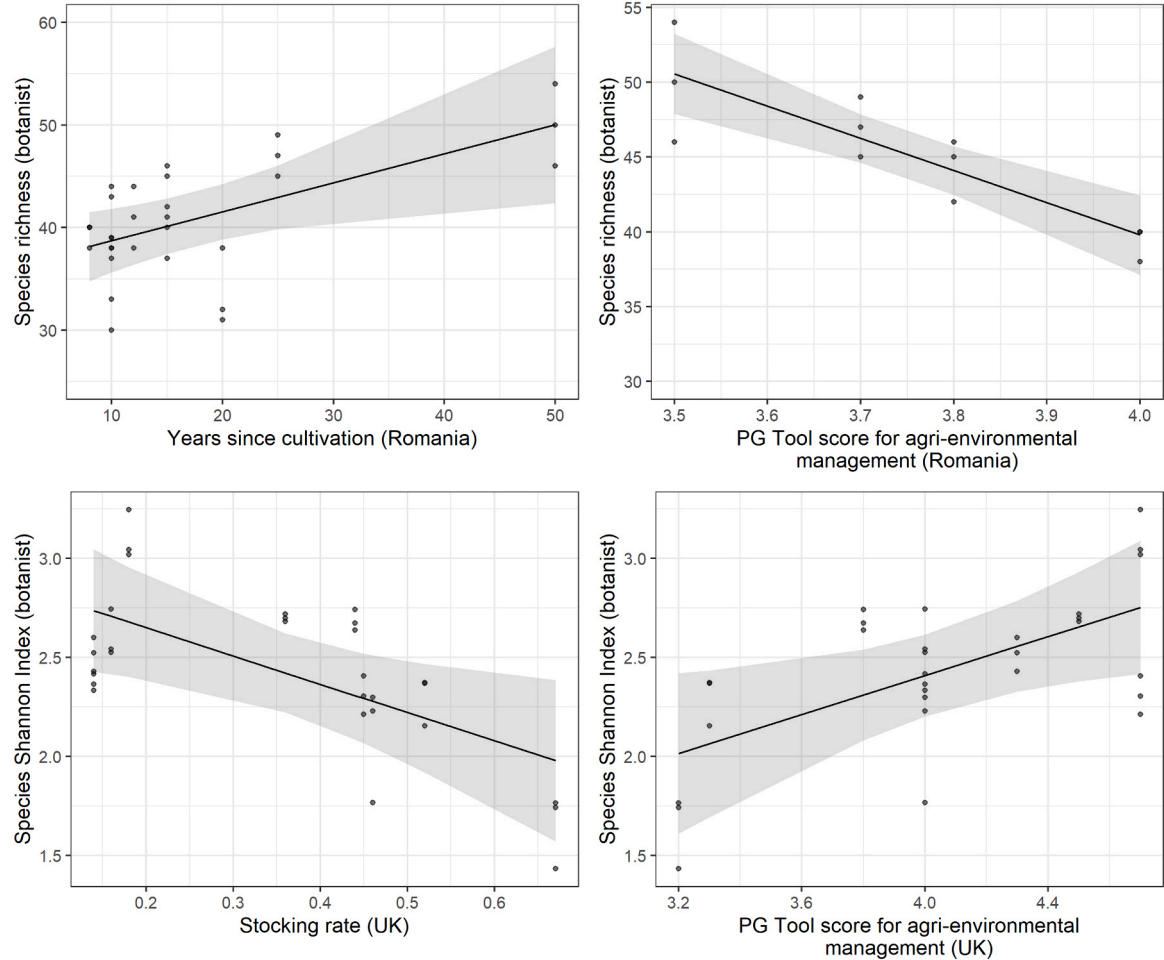


Fig. 4. Significant relationships between farm system indicators (x-axes) and botanist-derived biodiversity metrics (y-axes). Lines show country-specific linear mixed-model predictions, and shaded ribbons represent 95% confidence intervals.

and personal interest in biodiversity. Time constraints and limited technical knowledge were identified as major barriers to participation, though emerging technologies offer potential solutions. Simplicity was consistently emphasised as key to overcoming these challenges and

encouraging farmer engagement. Field testing revealed that simple counts of forb species estimated by farmers or from photos were a strong proxy for botanist-assessed plant richness and diversity, whereas indicator species and farm system metrics were generally poor predictors.

Overall, the results demonstrate that farmer-led biodiversity recording is feasible when based on straightforward, observable field characteristics that are closely linked to ecological condition.

4.1. Constraints and opportunities for farmer-led biodiversity recording

Findings from the case study review and interviews indicate that successful farmer participation in biodiversity monitoring depends on balancing practicality with scientific rigour. Achieving this balance is essential to ensure scalability and trust within, for example, results-based payment frameworks. Sufficient motivation, whether financial or value-based (Klebl et al., 2024), combined with simplicity of scheme design, are key to overcoming the well documented barriers of time and technical expertise (Alblas and van Zeven, 2023; Garratt et al., 2019; Ruck et al., 2024). Technology can also help overcome these barriers, while previous studies also highlight the importance of farmer advice, training and support for improving data quality and appreciation of biodiversity (Hagemann et al., 2024; Pe'er et al., 2022). Similar themes emerged from the online survey of Pasture for Life farmers in the UK, which identified time constraints, limited technical expertise, and lack of suitable methods as major barriers. Farmers in this survey expressed strong interest in biodiversity monitoring but emphasised the need for simple, practical protocols; an 'easy monitoring method' was the most popular incentive (12/25 responses). Despite the small sample size, these findings reinforce the importance of simplicity and clear guidance in promoting engagement. Overall, the case studies and survey confirm that farmer-monitoring is most effective when designed to be intuitive, time-efficient, and supported by accessible tools and/or training, ensuring both usability and data reliability.

4.2. Effectiveness of farmer-recorded biodiversity indicators

The indicators evaluated in this study included both richness-based measures (forb count) and abundance-based measures derived from estimates of vegetation (grasses vs forbs) and indicator species cover. Among the farmer-derived field indicators, forb count was the most effective proxy for biodiversity, showing significant associations with botanist-recorded species richness and/or diversity in all countries (Fig. 3, Table 2). The consistency of results across countries, despite methodological differences in Romania, suggests that simple measures of forb richness are relatively robust to differences in data collection approaches. This is notable given the varying levels of effort that farmers applied when estimating forb species counts, ranging from rapid visual assessments to more detailed species-based approaches, suggesting that simple measures of forb richness may be relatively robust to differences in observer effort and recording approach. Forb-rich swards typically indicate low-input systems that maintain high plant diversity (Norton et al., 2022; Stevens et al., 2006). The success of the photographic method used in Romania, where forb richness was estimated from images of bouquets, further demonstrates that visual or image-based approaches can provide reliable, scalable alternatives for farmer-led biodiversity recording. For example, a simple index of flower colour can be a strong proxy for plant species richness in grassland (Tasser et al., 2019).

In contrast, the percentage cover of positive and negative indicator species performed poorly, showing no significant relationships with botanist-derived metrics in any country. This is despite the frequent use of indicator species in results-based payment schemes (Table 1), and the generally strong relationships with botanist-recorded indicator species cover. The poor performance of indicators as proxies of plant richness and diversity in our study is therefore likely to be explained primarily by the limited number of indicator species included in our farmer protocols, although challenges in species identification and a lack of farmer training may also have contributed. Our indicator lists had 4–7 species per country, compared with 30 in RBAPS Romania and 161 in a Lithuanian scheme (Supplementary Material 1). This limited indicator list

meant that 58% of quadrats in our study had zero positive indicator cover according to both farmer and botanist assessments. While farmers often recorded the presence of negative indicator species, their estimates were highly variable and tended to underestimate values compared to botanist assessments (Supplementary Material 8). These observations highlight the need for an appropriate range of indicator species combined with targeted training. This is supported by the case study review, which highlighted challenges with farmer recognition of indicator species, while 12 of the 14 case studies implemented farmer training for indicator species recording, such as courses and/or educational material.

Farm system indicators derived from the PG Tool showed weak and inconsistent relationships with botanist-assessed grassland biodiversity. This could reflect a mismatch in scale, with PG Tool variables such as habitat diversity and semi-natural habitat proportions representing whole-farm characteristics, whereas botanist-recorded plant diversity was assessed within a single field. As farm sizes varied substantially, particularly in the UK (Supplementary Material 6), the sampled field may not always have been fully representative of wider farm conditions, potentially weakening relationships between farm-scale indicators and field-scale biodiversity. In addition, the farms included in our study were generally agro-ecological, e.g. with relatively low stocking rates and levels of fertilisation, which likely limited our ability to observe trends which may be apparent across a broader range of farm management intensities. In the UK, where management intensity across farms was somewhat broader, stocking rates and agro-environmental management scores were significantly associated with species diversity (Shannon Index). This is consistent with abundant existing evidence that biodiversity is influenced by habitat composition and farm management such as use of pesticides and fertilisers (Triquet et al., 2024), which can be monitored by farmers (Billaud et al., 2021; Tasser et al., 2019). Farm system indicators are therefore more likely to be relevant across broader scales of management regimes, rather than monitoring finer trends within semi-natural grasslands.

4.3. Policy implications

Our findings offer actionable insights for the design and implementation of biodiversity monitoring frameworks, whether motivated by financial incentives such as results-based payment schemes (RBPS) or ecocentric values. Farmer biodiversity recording can serve as a cost-effective complement to expert surveys, particularly in high nature value grasslands where frequent professional assessments are financially or logistically unfeasible. While incentives such as results-based payment schemes can support farmer participation and motivation, farmer-led biodiversity recording is best understood as a complementary approach rather than a replacement for professional surveys. Expert-led assessments remain essential for validation, calibration, and detailed ecological evaluation, while farmer-recorded data offer a scalable means of extending monitoring coverage and frequency when combined with adequate incentives. Simple field indicators, such as forb counts, are intuitive, quick to record, and have strong alignment with expert-derived biodiversity metrics. While indicators derived from farm systems or remote sensing (e.g. nutrient inputs, stocking rates, or satellite-based vegetation metrics) can provide valuable information on land use and management, they do not directly capture biodiversity outcomes. Farmer-led biodiversity recording therefore offers a complementary approach, particularly for assessing biodiversity condition in grasslands.

To integrate farmer-led biodiversity recording into RBPS, we recommend the development of regionally tailored protocols that prioritise simplicity and ecological relevance. These should ideally be co-designed with farmers to ensure usability and buy-in, supported by clear and simple guidance and in-person advice (Chivers et al., 2025; Sutherland et al., 2013). Validation mechanisms, potentially leveraging technologies such as smartphone applications, which feature in eight of our case studies (see Table 1 and Supplementary Material 1), can help

maintain data integrity while potentially reducing cost and time for participants and administrators (Dehnen-Schmutz et al., 2016; Reboud et al., 2021; Zavalloni et al., 2025). Protocols should be complemented by tailored advisory services and training, as these remain vital for uptake and data quality, particularly for indicator species recording (Hagemann et al., 2024; Pe'er et al., 2022).

Beyond data collection, farmer involvement in biodiversity recording could catalyse broader behavioural change. By engaging directly with biodiversity indicators, farmers may develop a deeper understanding of ecological processes and a stronger sense of stewardship, aligning with long-term goals of sustainable land management and public goods delivery (Alblas and van Zeven, 2023; Zacharias and Ressi, 2018).

4.4. Limitations

It is important to note that our assessment of biodiversity is limited to indicators of plant communities. Other important monitoring considerations include sampling scheme design, such as the location of sample points, consistency of surveyed locations through time, and the sensitivity of indicators to detect ecological change. The present study focused specifically on the feasibility, reliability and ecological relevance of farmer-recorded biodiversity indicators at a single point in time, rather than evaluating the performance of a complete long-term monitoring framework. Consequently, while the indicators evaluated here reflected ecological condition, their sensitivity to management-driven ecological change through time remains to be tested.

The interview results provide the perspective of those who work with farmers, who offer their interpretation of farmer attitudes rather than a direct representation of farmer views and experiences. Our study focused primarily on agroecological farms, including semi-natural grasslands in Sweden and Romania and Pasture for Life farms in the UK. As such, more intensively managed grasslands were under-represented. This limits the generalisability of our findings to the full spectrum of European grassland systems, particularly those with higher inputs or more conventional management practices. However, this focus on semi-natural or agroecological grasslands and their associated farmers is highly relevant to policy, because these habitats are central to wider goals of conserving and expanding semi-natural grassland areas and reversing biodiversity declines. As such, RBPS are often targeted at high nature conservation value habitats where farmers are financially incentivised to maintain or enhance biodiversity (Supplementary Material 1). In this context, the types of farms included in our study reflect the real-world settings where farmer-led biodiversity recording is currently most likely to be applied. Nevertheless, monitoring of grasslands that are currently species poor may be essential to assess the extent to which both species diversity and productivity are enhanced in the future (Zetterlind et al., 2025).

Farmer participation and incentives differed across countries in this study. In Sweden, farmers were financially compensated for participation in the study, while in the UK and Romania participation was voluntary and often driven by interest in biodiversity or agroecological management, with low levels of engagement in Romania necessitating a modified data collection approach. As such, participants may represent a more engaged subset of the farming population, particularly in the UK where farmers were engaged voluntarily, which could influence both participation and data quality and may limit generalisability to less engaged farming systems. While this highlights the importance of locally adapted protocols in enabling participation under different conditions, it also constrained our ability to apply a fully standardised comparison across all sites. This variation reflects real-world conditions, where farmer-led biodiversity recording may be supported through a combination of financial incentives and intrinsic motivation.

Future research should test the applicability of simple farmer-led biodiversity recording protocols in a wider range of farming systems, including more intensive and mixed-use farms. Long-term studies could

also assess the consistency of farmer-derived data over time and explore how participation in biodiversity recording and monitoring influences management decisions and outcomes. Further development of digital tools for real-time data submission and validation could enhance both scalability and data quality.

4.5. Conclusion

This study demonstrates that farmer-derived field indicators with minimal training requirements can provide practical and ecologically meaningful measures of plant diversity in grasslands. When based on simple and observable vegetation features such as an estimate of forb species count, these indicators can serve as reliable proxies for expert assessments. However, the use of indicator species is likely to require farmer training to be effective. Farm system indicators, while useful for contextualising management practices, were less effective as biodiversity surrogates at the field level, at least in our agroecological field sites, which could reflect a mismatch in spatial scale. Empowering farmers to collect biodiversity data through adequate incentivisation and simple protocols, potentially aided by technology, offers a promising route to improve both the effectiveness and inclusiveness of biodiversity monitoring in European agricultural landscapes. With appropriate support, farmer-recorded biodiversity data could become a key component of efforts to align agricultural policy with biodiversity goals and the provision of public goods.

CRedit authorship contribution statement

Tom Staton: Writing – review & editing, Writing – original draft, Visualization, Methodology, Investigation, Formal analysis. **Markus Wagner:** Writing – review & editing, Methodology, Investigation. **Kate Farley:** Writing – review & editing, Investigation. **Adrian Gliga:** Writing – review & editing, Methodology, Investigation. **Mignon Sander:** Writing – review & editing, Methodology. **Laurence G. Smith:** Writing – review & editing, Methodology, Funding acquisition, Conceptualization. **Lisa Norton:** Writing – review & editing, Methodology, Conceptualization.

Declaration of Generative AI and AI-assisted technologies in the writing process

During the preparation of this work the authors used the Microsoft Teams AI transcription tool and Microsoft CoPilot in order to assist interview transcript analyses and to aid preparation of the manuscript. After using this service, the authors reviewed and edited the content as needed and take full responsibility for the content of the published article.

Declaration of Competing Interest

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

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Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at [doi:10.1016/j.agee.2026.110772](https://doi.org/10.1016/j.agee.2026.110772).

Data availability

Research Link Provided.

Farmer and botanist grassland biodiversity indicators from 26 European farms (Figshare)

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