Agriculture, Ecosystems and Environment 330 (2022) 107891

Contents lists available at ScienceDirect

Agriculture, Ecosystems and Environment

journal homepage: www.elsevier.com/locate/agee

Permanent grasslands in Europe: Land use change and intensification decrease their multifunctionality

René L.M. Schils[a,*], Conny Bufe[a], Caroline M. Rhymer[b], Richard M. Francksen[b], Valentin H. Klaus[c], Mohamed Abdalla[d], Filippo Milazzo[e], Eszter Lellei-Kovács[f], Hein ten Berge[a], Chiara Bertora[g], Anna Chodkiewicz[h], Claudia Dămătîrcă[g], Iris Feigenwinter[c], Pilar Fernández-Rebollo[i], Shiva Ghiasi[c,1], Stanislav Hejduk[j], Matthew Hiron[k], Maria Janicka[h], Raoul Pellaton[f], Kate E. Smith[l], Rachel Thorman[l], Tom Vanwalleghem[e], John Williams[l], Laura Zavattaro[g,2], Jarl Kampen[m], Ria Derkx[n], Pete Smith[d], Mark J. Whittingham[b], Nina Buchmann[c], J. Paul Newell Price[l]

[a] Agrosystems Research, Wageningen Plant Research, Droevendaalsesteeg 1, 6708 PB Wageningen, The Netherlands
[b] School of Natural and Environmental Sciences, Newcastle University, United Kingdom
[c] Department of Environmental Systems Science, Institute of Agricultural Sciences, ETH Zürich, Switzerland
[d] Institute of Biological and Environmental Sciences, University of Aberdeen, United Kingdom
[e] Department of Agronomy, ETSIAM, University of Córdoba, Spain
[f] Institute of Ecology and Botany, Centre for Ecological Research, Hungary
[g] Department of Agricultural, Forest and Food Sciences, University of Torino, Italy
[h] Department of Agronomy, Institute of Agriculture, Warsaw University of Life Sciences - SGGW, Poland
[i] Department of Forestry, ETSIAM, University of Córdoba, Spain
[j] Department of Animal Nutrition and Forage Production, Mendel University in Brno, Czech Republic
[k] Department of Ecology, Swedish University of Agricultural Sciences, Sweden
[l] ADAS, United Kingdom
[m] Biometris, Department of Plant Sciences, Wageningen University, The Netherlands
[n] Library, Wageningen University and Research, The Netherlands

ARTICLE INFO

Keywords:
Agro-ecology
Ecosystem services
Grassland
Land use change
Systematic literature review

ABSTRACT

Permanent grasslands cover 34% of the European Union's agricultural area and are vital for a wide variety of ecosystem services essential for our society. Over recent decades, the permanent grassland area has declined and land use change continues to threaten its extent. Simultaneously, the management intensity of permanent grasslands increased. We performed a systematic literature review on the multifunctionality of permanent grasslands in Europe, examining the effects of land use and management on 19 grassland ecosystem service indicators. Based on the evidence in 696 out of 70,456 screened papers, published since 1980, we found that both land use change and intensification of management decreased multifunctionality. In particular, preventing conversion of permanent grasslands to croplands secured the delivery of multiple ecosystem services. A lower management intensity was associated with benefits for biodiversity, climate regulation and water purification, but impacted the provision of high-quality animal feed. Increasing the number of species in the sward enhanced multifunctionality of permanent grassland without significant trade-offs such as losses in production. Our review covered many aspects of land use, management and ecosystem services, but we also identified areas with no or only few studies. The most prominent gaps were related to comparisons between permanent and temporary grasslands, and effects of management practices on the provision of cultural values, and on erosion and flood control. We suggest that, despite apparent changes in human dietary preferences, the protection of permanent grasslands in Europe must be prioritised. At the same time, considering the need to reduce ruminant livestock's

* Corresponding author.
E-mail address: rene.schils@wur.nl (R.L.M. Schils).
[1] Current address: Water Protection and Substance Flows Group, Agroscope Reckenholz, Switzerland.
[2] Current address: Department of Veterinary Sciences, University of Torino, Italy.

https://doi.org/10.1016/j.agee.2022.107891
Received 7 November 2021; Received in revised form 18 January 2022; Accepted 31 January 2022
Available online 12 February 2022
0167-8809/

contribution to climate change, the time seems ripe to increase support for low-intensity grassland management to optimise the provision of essential ecosystem services from Europe's permanent grasslands.

1. Introduction

Permanent grasslands cover 34% of the European Union's agricultural area (Eurostat, 2020) and are vital for human wellbeing as they contribute to a wide variety of essential ecosystem services (O'Mara, 2012; Habel et al., 2013; Bengtsson et al., 2019). Thus, any change in their area or the capacity of grassland to provide ecosystem services will have significant societal impacts. For centuries, permanent grasslands have been the basis for livestock production and the main pillar of nutrient cycling on farms all over Europe (Green, 1990; Lemaire et al., 2011; Hejcman et al., 2013). After the Second World War, the goal of self-sufficiency in food production stimulated the improvement and intensification of management of permanent grasslands, or their conversion to temporary grasslands or croplands. In less versatile areas, like mountainous regions or wet lowlands, large areas of permanent grasslands were abandoned or afforested (Habel et al., 2013; Boch et al., 2020). While statistical data on the loss of permanent grasslands are fragmented, the available figures illustrate the significant loss during the last decades. For example, in the EU-6 countries (Belgium, Netherlands, Luxemburg, France, Former West Germany, Italy), permanent grassland losses have been estimated at about 30% between 1967 and 2007 (Huyghe et al., 2014). Regionally, losses have been even higher, as in Upper Normandy, France, where about 50% of the permanent grassland area was lost between 1970 and 2000 (Van Den Pol-Van Dasselaar et al., 2019). In Eastern Europe, the political transformations at the end of the 1980s triggered large scale abandonment of permanent grasslands, as in Slovakia where 42% of permanent grasslands were left unused (Kizeková et al., 2018).

Today, grass is still among the cheapest high-quality feed sources for efficient ruminant meat and dairy production (Van Den Pol et al., 2018). In addition to the provision of feed, permanent grasslands sustain a broad range of additional ecosystem services, including climate regulation through carbon sequestration (Soussana et al., 2010), cultural values (Hussain et al., 2019), protection against erosion and flooding (Macleod et al., 2013), and pollination of food crops (Klein et al., 2007; Scheper et al., 2013).

Permanent grasslands across Europe are very diverse in appearance (Fig. 1). This is partly driven by inherent factors such as climate and soil, but also by varying intensities of grassland management, resulting in continuous gradients of fertilisation and defoliation (mowing or

Fig. 1. Permanent grasslands still dominate the agricultural areas in many European regions, especially in places where growth conditions are unfavourable as in mountainous regions (A, Switzerland). Historically, grasslands were relatively nutrient-poor and extensively managed (B, Poland, and C, Germany), but a significant extent of grasslands experienced either intensification of management (D, United Kingdom) or were lost due to conversion to cropland (E, Czech Republic) or abandonment (F, Switzerland). Pictures by V.H. Klaus (A, C, F), M. Janicka (B), ADAS (D), S. Hejduk (E).

grazing) intensities (Blüthgen et al., 2012). Some studies have addressed aspects of multifunctionality of grasslands for a specific region (Allan et al., 2015) or specific experimental sites (Werling et al., 2014; Meyer et al., 2018). Others focused on temperate grasslands (Pilgrim et al., 2010), cultivated grasslands (Sollenberger et al., 2019), (semi)-natural grasslands (Bengtsson et al., 2019) or grazing lands (D'Ottavio et al., 2018). For European permanent grasslands we thus have a restricted understanding of land use and management effects on multi-functionality, which limits our ability to understand and predict the effects of land use change and management intensification on the provisioning of vital grassland ecosystem services. Here, we analyse the body of, mainly monodisciplinary, studies across Europe in a comprehensive multidisciplinary systematic literature review with a focus on experimental contrasts in land use and management aspects. Our aim was to understand the effects of land use change and management intensification on the provision of several major grassland ecosystem services. We considered the "big five" grassland ecosystem services, i.e. *provision of animal feed*, *biodiversity*, *climate regulation*, *water purification,* and *cultural values* (Isselstein and Kayser, 2014), and added a sixth important service, *erosion and flood control*.

Our study addressed two central research questions: first, what are the reported effects of land use change, i.e. the conversion to other land uses such as temporary grassland, cropland or forest, on the delivery of grassland ecosystem services? Second, what are the reported effects of intensification and specific management options on the delivery of ecosystem services by permanent grassland? The outcomes of this review draw a comprehensive overview of ecosystem service delivery from permanent grasslands across Europe, including an integrated assessment of multifunctionality. Furthermore, we identified relevant gaps in ecosystem service research that limit the understanding of land use and management effects on multifunctionality required for policy and farm management decisions.

2. Methods

2.1. Permanent grassland

We used the European Union's definition of permanent grassland, as land used to grow grasses or other herbaceous forage that has not been included in the crop rotation of the holding for a duration of five years or longer (EU, 2004).

2.2. Indicators of ecosystem services

We selected a set of indicators (Table S1) that comprised a cross-cutting representation of biodiversity and ecosystem services of permanent grasslands. We are aware of the multiple roles of biodiversity in the delivery of ecosystem services, as a regulator of ecosystem processes, as a service in itself and as a good (Mace et al., 2012). For clarity, we consider biodiversity as one of the ecosystem services.

2.3. Search strategy – inclusion criteria

In the fourth quarter of 2019, we searched the Scopus and CAB abstracts databases for grassland studies on 19 indicators of ecosystem services in Europe, published in the English language from 1980 onwards (Table S2). Scopus and CAB abstracts were used for this systematic review because both databases can effectively perform complex Boolean searches with regards to precision, recall and reproducibility, which is a prerequisite for systematic searching (Gusenbauer and Haddaway, 2020). CAB Abstracts is the leading database on applied life sciences, including crop sciences and grasslands, animal science, environmental science, and recreation/tourism. The multidisciplinary database Scopus is the largest abstract and citation database of peer-reviewed literature in the field of science, technology, medicine, and social sciences.

Search strings were evaluated and refined in several steps by assessing the relevance of the papers returned, and by checking against key papers in the field. A wide range of search terms were used to cover the diversity of methods used to assess the provision of ecosystem services of permanent grasslands. We developed a search string for the concept "grass", and combined this, using an AND-operator, with the search string for each one of the 19 ecosystem service indicators.

We combined the 19 sets of search results into de-duplicated Endnote libraries, one for each ecosystem service. We collected a total of 70,456 papers, varying from 7181 papers for *water purification* to 16,201 papers for *biodiversity* (Table S3). These papers, including abstracts, were uploaded to the dedicated systematic review analysis software 'EPPI reviewer 4 tool' (http://eppi.ioe.ac.uk/cms/), as six corresponding reviews.

2.4. Exclusion criteria

Titles and abstracts were screened in two stages, using the following set of exclusion criteria:

- Not in the English language.
- Outside these Natura 2000 biogeographic zones of interest: Alpine, Atlantic, Boreal, Continental, Mediterranean or Pannonian. Biogeographical boundaries are a combination of official delineations used in the Habitats Directive (92/43/EEC) and for the EMERALD Network under the Convention on the Conservation of European Wildlife and Natural Habitats (Bern Convention). They are independent of political boundaries of Emerald Network countries or EU Member States (https://www.eea.europa.eu/data-and-maps/data/biogeographical-regions-europe-3).
- Outside these countries in Europe: Member states of the EU-28 or Albania, Belarus, Bosnia Herzegovina, Kosovo, Macedonia, Moldova, Montenegro, Norway, Serbia, Switzerland or Ukraine.
- Unit of study was not grassland.
- The outcome was not one of the 19 indicators of interest.
- Papers on urban amenity grasses.
- Reviews.
- Modelling studies.
- Experiments under controlled conditions: laboratories, greenhouses or pots.

2.5. Study selection on contrasts

The papers retained after the title and abstract screening contained the body of literature on European experimental studies, published after 1980 and in the English language, and on one or more of the 19 indicators for grassland. From this set of 11,619 papers, we selected papers that contained at least one of eight experimental contrasts in land use (permanent grassland versus cropland, forest or temporary grassland) or contrasts in management (sward renewal, legume presence, number of species in the sward, defoliation frequency and nitrogen input).

2.6. Data extraction

After screening for eligible contrasts, we retained 3664 studies for full text screening. Retrieved papers were read and either extracted or excluded with reasons (Fig. S1 and Table S3). For time management reasons, we developed a stepwise sampling procedure among eligible papers within the ecosystem services *biodiversity* and *provision of animal feed*, which each had more than 1000 eligible papers. We took consecutive random samples of 300 papers out of the eligible papers for data extraction until a maximum of 300 extracted papers. Eventually, 510 papers out of the 1313 papers of the *provision of animal feed* domain were not included in the sample.

Data from valid sampled full text papers were extracted using a data extraction form, developed in MS Excel, consisting of two sections

(Table S4). The first form (Study) was used to extract data per paper: bibliographical identification, study type, geography, experimental contrasts, and methods for assessment of the relevant indicators. If a paper was excluded at this stage, the reason was recorded in this form as well. The second form (Contrast) was used to extract data on the experimental contrasts. Each paper consisted of at least one contrast and in total the 696 papers contained 1032 eligible experimental contrasts, which we define as a 'case'. Here, we registered the outcome: no conclusion, favourable, neutral, or unfavourable (Table S5). The outcome was based on the numerical data and statistical significance in tables, figures, or text, or based on authors' claims in the text. This approach allowed us to combine the extremely heterogeneous data and

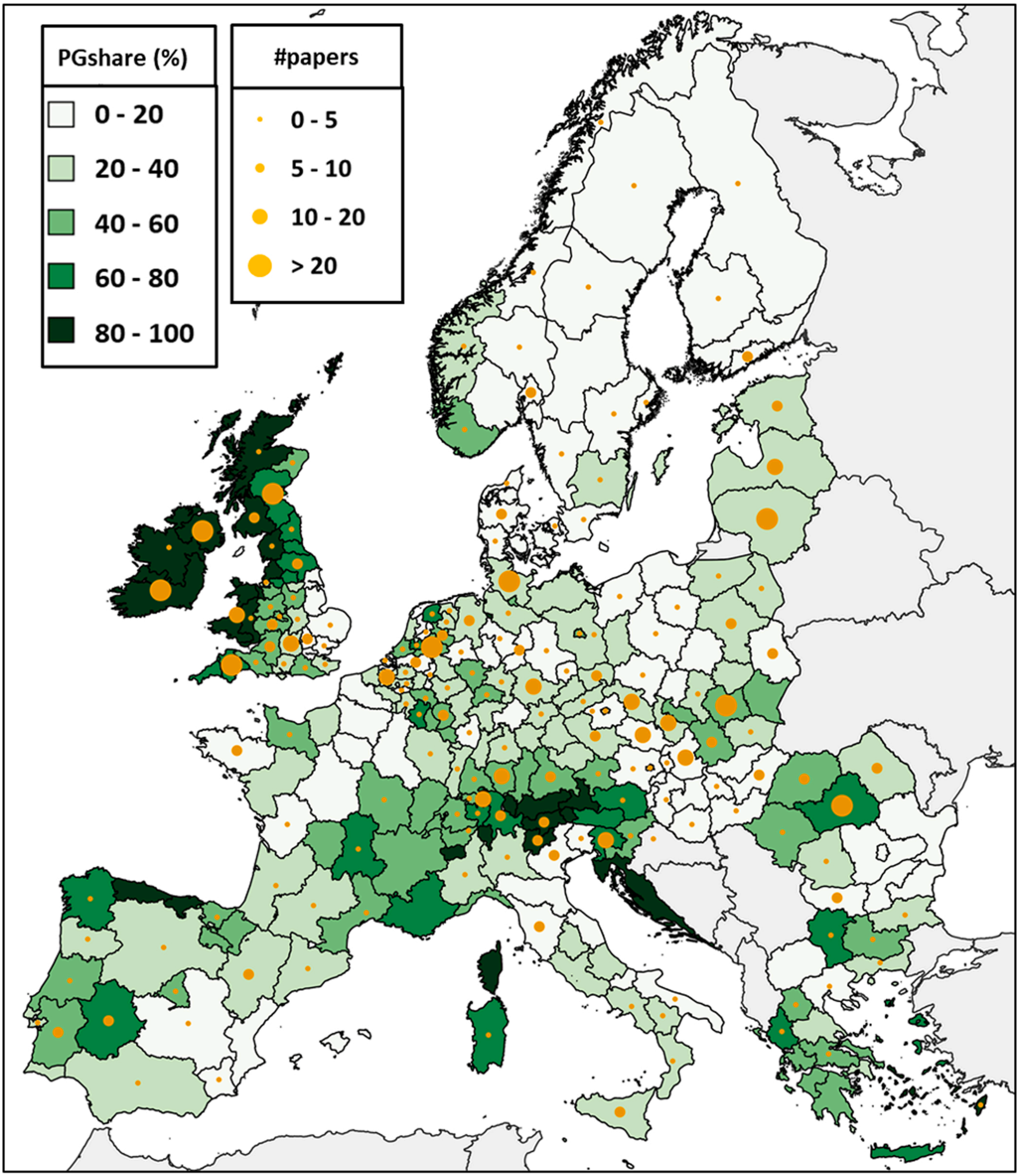


Fig. 2. Geographical distribution, across NUTS2 regions in Europe, of included papers (#papers), published since 1980, and the share of permanent grassland (PGshare) in the total utilised agricultural area (UAA); data from 2016, except Norway and Macedonia from 2013 (Eurostat, 2020); grey areas indicate no data.

metrics across ecosystem service indicators, allowing a greater number of studies to be compared for a more comprehensive answer to our research questions. Rather than simply counting which studies had outcomes in a certain direction, sometimes referred to as 'vote-counting' (Stewart, 2010), we applied strict criteria for the inclusion of studies and for the assessment of the direction of interventions on the outcome of ecosystem service indicators.

2.7. Data analysis

The outcomes from the data extraction form were tabulated per contrast. For statistical analysis, the outcomes were transformed to numerical values (favourable = 1, neutral = 0, unfavourable = −1). Cases with no conclusion were discarded from the analysis. A one-sample t-test was carried out, with H_0 assuming no effect (outcome = 0). The analysis was carried out with the facilities of SPSS version 25 (SPSS, 2020).

2.8. Reviewer bias

Screening and data extraction were carried out by expert teams, consisting of a lead-reviewer and at least one co-reviewer per ecosystem service. The assessment of the lead-reviewer, an expert in the field, was the benchmark against which the co-reviewers' assessments were compared. To align the scoring in screening and extraction, intermediate results including arising disputes were discussed and resolved. At least 5% of the papers were double-screened, independently by the lead-reviewer and one or more co-reviewers. We assessed the number and proportion of 'false exclusions', i.e. when the co-reviewer excluded a paper that was included by the lead-reviewer. If the proportion of false exclusions was higher than 10%, we reconciled the issues.

3. Results and discussion

3.1. Spatial and temporal outline of the evidence

We considered 70,456 papers, identified for 19 indicators of grassland ecosystem services (Table S3) across Europe, published since 1980 (Fig. S1 and Table S1). After screening, we included 696 papers in the final analysis (1%). While we found papers covering almost all regions of Europe, the majority were found in a broad northwest to southeast range, roughly stretching from the British Isles to Eastern Europe (Fig. 2). Although most of the papers included in this review were identified in regions where over 40% of the utilised agricultural area (UAA) was covered by permanent grasslands, regions with less than 20% permanent grasslands were also represented. Around two thirds of the extracted papers originated from the Atlantic or Continental biogeographic regions (Fig. S2). Studies on the environmental ecosystem services *water purification* and *climate regulation* were overrepresented in the Atlantic region, most likely related to the high grassland productivity (Smit et al., 2008) and higher intensity of livestock farming in these areas (Leip et al., 2015).

Over the past 40 years, the scientific literature on permanent grasslands in Europe has been dominated by studies on the *provision of animal feed* (Fig. S3). We found that the number of papers focusing on other grassland ecosystem services increased gradually, in line with developments in societal debates (Hall et al., 2004) and European Union's regulations like the Nitrates Directive (EU, 1991), Birds and Habitats Directive (EU, 1992), Soil Strategy (EU, 2006), climate change policies (Jordan and Rayner, 2010) and greening measures in the Common Agricultural Policy (Hauck et al., 2014). Despite the change in policy priorities, permanent grasslands' role as provider of animal feed remained among the top priorities of the research agenda.

While our review allowed us to cover many important aspects of land use, management and ecosystem services, some study topics were underrepresented such as the comparison between permanent and temporary grasslands, effects of species diversity on climate regulation, the relation between grassland management and cultural values, and the topics erosion and flood control (Fig. S5 and S7). Moreover, we did not find any eligible papers on pesticides leaching into ground and surface water from permanent grasslands.

3.2. Preserving permanent grasslands secures vital ecosystem services

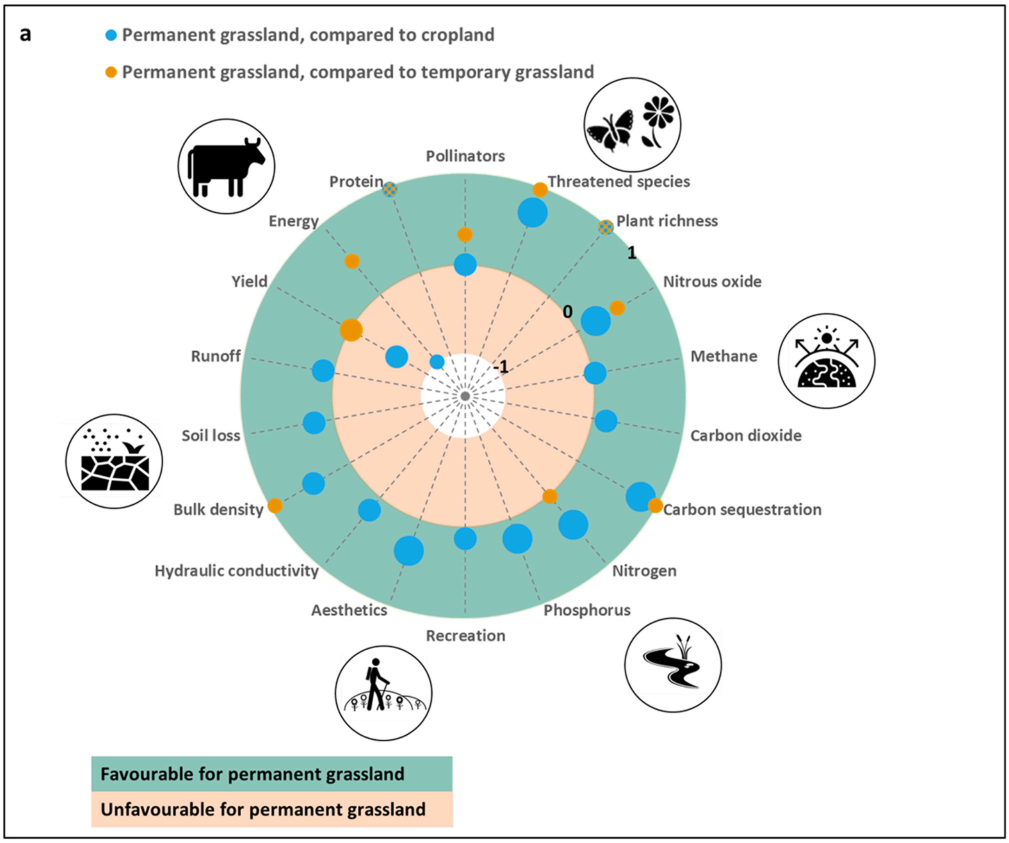
We found that most studies reported favourable outcomes for permanent grasslands compared to croplands across all ecosystem service indicators, except for forage yield and energy content (Fig. 3a, Fig. S4 and Fig. S5). A significantly high proportion of studies reported favourable outcomes for permanent grasslands on threatened species (e.g. Bretagnolle et al., 2011), carbon sequestration (e.g. Gregory et al., 2016) and nitrogen losses to water (e.g. Webster et al., 1999). Furthermore, the favourable outcomes of all indicators for *climate regulation, water purification, erosion and flood control,* and *cultural values* were supported by at least five cases.

Only a few studies compared permanent to temporary grasslands, with the outcomes generally supported by less than five cases. We found no consistent evidence, with only seven cases available, of higher grass yields from temporary grasslands compared to permanent grasslands, contrary to the common expectation when converting permanent grasslands into temporary grasslands (Søegaard et al., 2007). Temporary grasslands are, by definition, always part of a rotation with other crops. This implies that the outcomes of the comparison with croplands are also relevant for the assessment of the conversion from permanent to temporary grassland.

Even though permanent grasslands are extremely diverse across Europe, a common denominator is that the livelihood of farms with permanent grasslands depends to some extent on ruminant animal production. Therefore, the current feed-food debate (Tilman and Clark, 2014; Di Paola et al., 2017) and the interlinked urgency to reduce methane emissions from ruminant livestock (Gerber et al., 2013) is highly relevant for the future of permanent grasslands. So, while in some areas there may be arguments for conversion of suitable permanent grassland to cropland for direct human food production, such conversion would clearly come with an impact on vital ecosystem services such as carbon sequestration*, biodiversity* and *water purification.*

The European Union's Common Agricultural Policy recognises the value of the ecosystem services provided by permanent grasslands (EU, 2013). Under the current policy, a so-called "green direct payment" is provided. The measure aimed to limit declines in the ratio of permanent grassland to total utilised agricultural area to less than 5%, and to protect the most environmentally sensitive permanent grasslands from conversion. In future, these payments will fall under the new conditionality element of the post-2020 Common Agricultural Policy (EU, 2019). Enhanced management of permanent grasslands will be promoted under the new eco-schemes in which national authorities have more flexibility and can be more ambitious to direct and extend these measures.

When permanent grasslands were compared to forests, the reported outcomes suggest trade-offs between the studied ecosystem services (Fig. 3b). We found consistent evidence of studies reporting a better performance of forests regarding all indicators for *erosion and flood control* (Fig. S4 and Fig. S5). In contrast, most studies reported higher levels of *biodiversity* and *cultural values* for permanent grasslands compared to forests, in particular for the indicators threatened species and aesthetic value. The reported outcomes on *climate regulation* and *water purification* did not show a consistent effect. A small majority of cases (9 versus 6; Fig. S5) showed higher soil carbon sequestration in forests (e.g. Prescher et al., 2010). However, our assessment did not include the overall ecosystem carbon sequestration of forests which is typically higher than in permanent grasslands due to the long term build-up of above ground biomass (Schulze et al., 2009). For harvested forests, the timing of harvest and the fate of the harvested wood determines its overall carbon sequestration effect (Ciais et al., 2008).



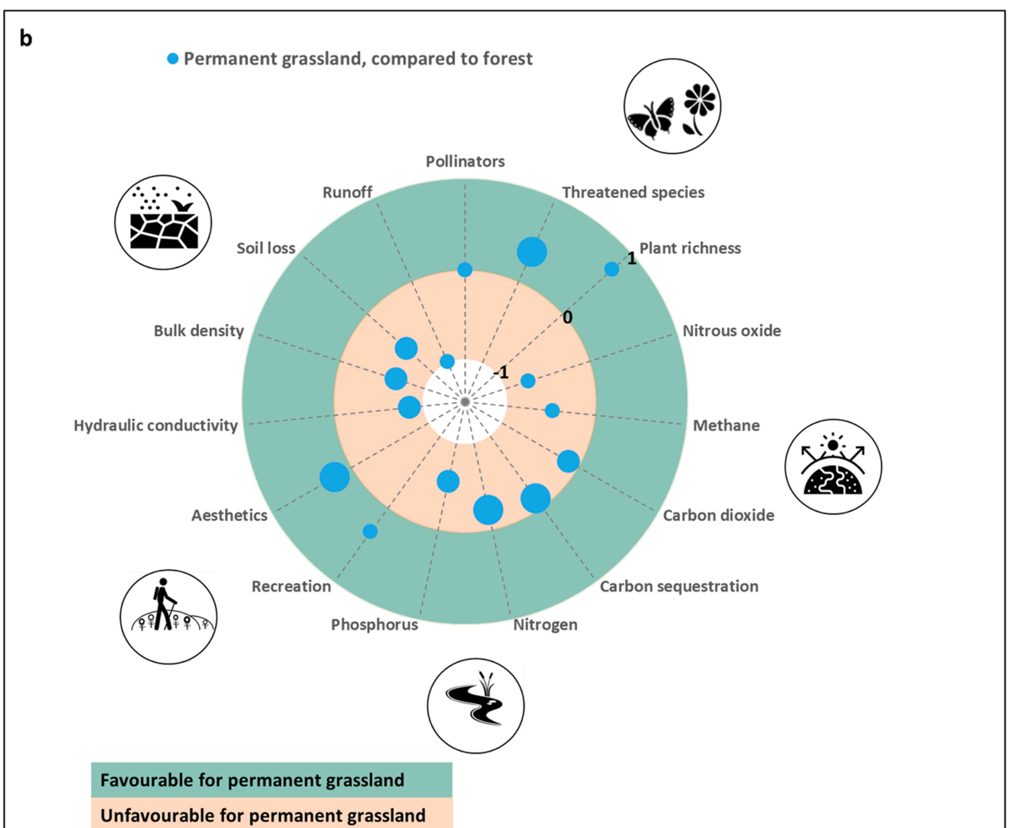


Fig. 3. Comparison between land use types for indicators of ecosystem services, (a) permanent grassland compared to cropland and temporary grassland, (b) permanent grassland compared to forest. The boundary between the outer and inner shaded zones represents a mean score of 0. The shaded outer zone represents a favourable score for permanent grassland (moving outwards, the mean score increases from 0 to 1), the shaded inner zone represents an unfavourable score (moving inwards, the mean score decreases from 0 to −1). Dot size indicates number of underlying cases (small: <5 cases, medium: 5–9 cases. large: >9 cases). Full statistical data are presented in Fig. S4. For example, the aesthetics score in the green shaded outer zone (Figure b) indicates a preference of people for permanent grassland over forest but the score was 0.21 which means that some cases showed opposite outcomes, but the overall score favoured permanent grasslands. The large size of the dot indicates the aesthetics score was underpinned by at least 10 cases. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

Our findings on the comparison between permanent grasslands and forests are also relevant for the broader land use debate. Withdrawal of permanent grasslands from agriculture and subsequent afforestation, as suggested for example by the Bonn Challenge could reduce the environmental impacts of livestock, if dietary demand by consumers declined in parallel. However, such conversion to forest would not be able to sustain the high multifunctionality provided by permanent grasslands under reduced or extensive management (Temperton et al., 2019). To integrate the advantages of forestry in agricultural land use, there is also a role for silvopastoral systems in conserving biodiversity and enhancing broad ecosystem service provision, including animal feed (Torralba et al., 2016).

We identified a lack of studies that compared permanent to temporary grasslands, especially across the whole spectrum of non-feed ecosystem services (Fig. S5). These research gaps can be addressed by either long-term plot experiments under controlled conditions or monitoring campaigns at the scale of fields or landscapes, depending on the targeted ecosystem service indicator.

3.3. Reduced management intensity benefits multifunctionality

We found consistent trade-offs in the reported outcomes between indicators for feed and non-feed ecosystem services for three types of management options that represent increasing management intensity, i.e. nitrogen input, increasing defoliation frequency and grass renewal (Fig. 4a). For nitrogen input, we found significantly unfavourable effects on all indicators for *biodiversity, water purification*, and *climate regulation*, except carbon sequestration (Fig. S6 and Fig. S7). In contrast, there were significantly favourable effects of nitrogen on forage yield and protein content. Yield and quality were oppositely affected by defoliation frequency. With increasing frequency, we found a significant improvement of forage quality, but a significantly lower forage yield (e.g. Hopkins et al., 1990; Nerusil et al., 2008). There were few studies on the effect of defoliation frequency on the non-feed ecosystem services. We found a limited number of studies for *climate regulation (7)* and *water purification (6)* but no cases for *erosion and flood control* or *cultural values.* However, the overall negative effects of increasing defoliation frequency on all indicators of *biodiversity* and on nitrogen losses to water were supported by at least five cases. Finally, grass renewal showed significant favourable effects on forage yield, but no consistent effect on forage quality, across 30 cases for energy content and 28 cases for protein content (e.g. Badia et al., 1994; Butkuviene and Butkute, 2007). In contrast, we found that grassland renewal significantly increased nitrous oxide emissions (e.g. Merbold et al., 2014) and nitrogen losses to water (e.g. Velthof et al., 2010). It is remarkable that only 40% of the studies stated the sward age at renewal. Of these, the dominant sward age at renewal was between 5 and 25 years, while only 10% were younger than 5 years (e.g. Vliegher and Carlier, 2007) and 20% older than 25 years (e.g. Bommele et al., 2006).

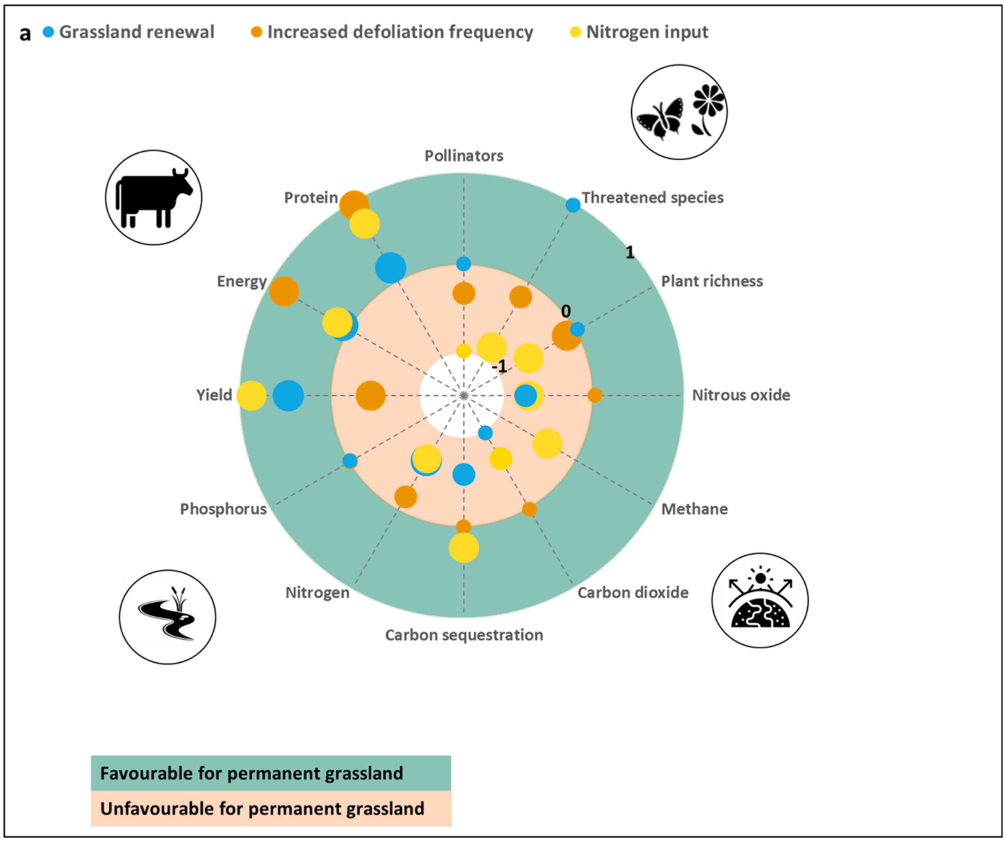
In addition to the above interventions which relate to intensity of management, diversification of the sward was studied as a separate category of management options, which we do not consider as a dimension of intensity. The reported outcomes of increased number of species in the sward showed mainly favourable effects on the indicators for *biodiversity, cultural values* and *water purification* and mixed effects on *provision of animal feed* (Fig. 4b). An increased number of species significantly increased the number of pollinators and threatened species. There were less than five cases for *cultural values* and *water purification*, but they consistently reported a favourable effect of number of species in the sward. An increased number of species significantly increased yield, but decreased the energy content, and showed no consistent effect on protein content.

We found that papers comparing swards with and without legumes, with similar nitrogen fertiliser inputs, reported significant favourable effects of legumes on yield and protein content, whereas energy content was not affected. Papers on the non-feed ecosystem services of legume presence were relatively underrepresented. A consistent favourable effect of legumes, based on eight cases, was reported for the abundance of pollinators (e.g. Woodcock et al., 2014). The papers on nitrogen losses to water showed a small unfavourable effect of the presence of legumes (e.g. De Vries et al., 2006).

Our findings on the key role of grassland management in regulating the provision of ecosystem services are in line with earlier non-systematic reviews, limited to temperate grasslands in lowland Europe (Pilgrim et al., 2010) or cultivated grasslands (Sollenberger et al., 2019). Over the past 60 years, the average management intensity of European grasslands has clearly increased (Hopkins and Wilkins, 2006). In many regions permanent grasslands also experienced increasing livestock densities, received higher nutrient inputs, and were subjected to higher cutting frequencies, modulated by drainage, irrigation, resowing and oversowing with improved cultivars, as well as weed control with herbicides (Peeters, 2009). We found that an increased management intensity of permanent grasslands substantially decreased multifunctionality and especially had unfavourable impacts on *biodiversity*, *climate regulation* and *water purification*. Therefore, we argue that a low or reduced management intensity of permanent grasslands can help to better strike the balance between the environmental impact of ruminants and the utilisation of herbage on these areas. First, in regions like Eastern Europe where intensification is still ongoing in some areas (Török et al., 2020), the main aim should be to identify options to support management that enables securing the current level of all ecosystem services and avoid drastic intensification. Second, in regions with predominantly intensive grasslands, simply reducing management intensity will not lead to an immediate recovery of all ecosystem services as the extensification pathway is not the exact inverse of the intensification pathway (Bakker and Berendse, 1999). While, for instance, greenhouse gas emissions would decrease relatively fast, the response of biodiversity will be rather slow, and might require active measures of ecological restoration (Isselstein et al., 2005; Klaus et al., 2016). Besides technical innovations, effective restoration requires integrated socio-economic solutions including recognition of grasslands in global policy and enhancing knowledge transfer and data sharing on restoration experiences (Bardgett et al., 2021).

Prioritising non-feed ecosystem services comes at a cost of the *provision of animal feed.* While this trade-off is clear for reducing nitrogen input, other management interventions show mixed or even synergistic outcomes and thus should be implemented more frequently. For instance, we found that a higher number of species in the sward is favourable for *biodiversity* and *provision of animal feed*, albeit with predominantly lower herbage energy content. Introduction of multiple species in species-poor swards, including legumes, will however require some form of sward renewal, which itself can have unfavourable effects on *climate regulation* and *water purification.* Grassland renewal should thus only be carried out infrequently, with as little soil disturbance as is manageable to achieve the seeding objective and when conditions are favourable to maximise the probability of successful establishment. The proposed shift from feed to non-feed ecosystem services will come with a reduced stocking rate and thus lower milk or meat production per hectare with potential negative effects on farm income, as long as payments for public goods are widely lacking (Pe'er et al., 2020). However, increasing the number of species in the sward for example, can also have positive effects on magnitude and stability of economic revenues, in particular for risk-averse farmers (Binder et al., 2018; Schaub et al., 2020).

With regard to management interventions, we identified several options with a limited number, or even a complete lack, of studies (Fig. S7). Especially, clarification of management effects on indicators of *cultural values,* and on *erosion and flood control* will require additional research efforts in the future. Furthermore, we found underrepresentation of studies looking into effects of plant richness in the sward, defoliation frequency and legume presence on indicators of *climate regulation.*



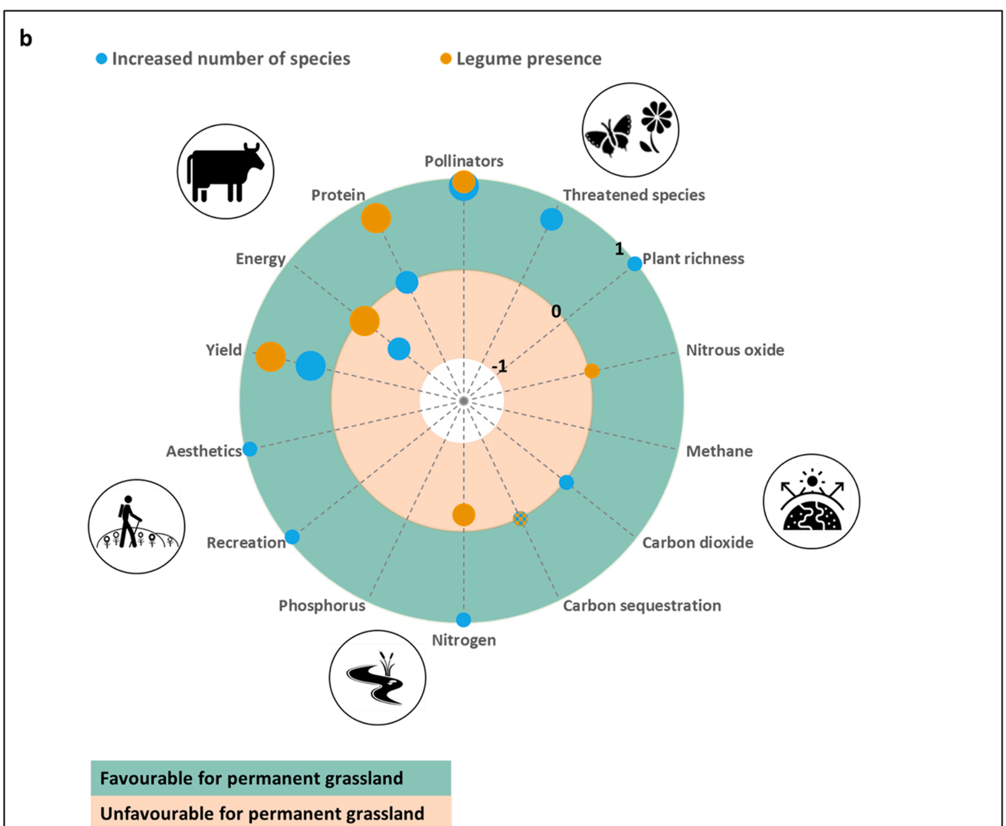


Fig. 4. Effects of management options on indicators for ecosystem services; (a) management interventions related to intensification, (b) management interventions on species in the sward. The boundary of the outer and inner shaded zones represents a mean score of 0. The shaded outer zone represents a favourable score (moving outwards, the mean score increases from 0 to 1), the shaded inner zone represents an unfavourable score (moving inwards, the mean score decreased from 0 to −1). Dot size indicates number of underlying cases (small: <5 cases, medium: 5–9 cases. large: >9 cases). Full statistical data are presented in Fig. S6. For example, the threatened species score in the green shaded outer zone indicates a favourable effect of the number of species. The score was 0.95 which means that most cases showed consistent favourable outcomes. The medium size of the marker indicates the score was underpinned by 5–9 cases. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

3.4. Outlook for permanent grassland

In this extensive systematic review of the literature on permanent grasslands across Europe, we found that preventing the conversion of permanent grassland to cropland or temporary grassland secures the provision of multiple ecosystem services. In addition, we found that intensification of existing permanent grasslands threatens multi-functionality. These findings are important for the future of permanent grasslands in view of the impact of our food system, and especially ruminant livestock, on environmental change.

When addressing the question of land use change, it is important to consider that permanent grasslands are not by default without alternatives for other land uses (Van Zanten et al., 2018). As such, non-agricultural options, for instance re-wilding and afforestation, may be viable alternatives as well, though come with their own social and ecological implications (Navarro and Pereira, 2015). In areas where other agricultural land uses are possible as alternatives for permanent grassland, many factors need to be considered when planning the most sensible and beneficial land use. Societal developments, including the changing demand for red and white meats, but also an increasing shift towards vegetarian and vegan diets will exert pressures that may shift the ratio between grassland and cropland (Garnett et al., 2017), and thereby affect biodiversity (Crenna et al., 2019), and the overall land footprint of food production (Rizvi et al., 2018). The need to mitigate global warming prompts action to protect carbon stocks that have meanwhile accumulated in permanent grasslands. In the light of climate change, permanent grasslands' significant role in reducing erosion and flooding risk is also likely to increase, as the frequency of extreme events is expected to rise (Tabari, 2020). Livestock numbers play a key role in the total greenhouse gas budget of grasslands, including methane (Chang et al., 2021). Although grassland-based ruminant livestock production systems contribute a minority to the total ruminant livestock emissions (Garnett et al., 2017), they still produce a potent greenhouse gas, which should be evaluated within the widely acknowledged need to stabilise or reduce total ruminant livestock numbers (Gerber et al., 2013). Finding the optimal role for permanent grassland in sustainable land use configurations requires systemic analyses at regional scales that include consideration of land capability, consumer preferences, farmer livelihoods and environment, but also biodiversity and cultural values (Poux and Aubert, 2018; Le Clec'h et al., 2019).

Our review showed that, in general, a lower management intensity allows for a higher multifunctionality. At the same time, we identified that prioritising non-feed ecosystem services comes at a cost for the provision of animal feed. Here, we need to emphasise that there is no simple general blueprint for the implementation of a reduced management intensity. Extensification is more than just reducing inputs and may require some kind of ecological restoration including the supply of seed mixtures for diverse grasslands (Schaub et al., 2021). Moreover, multifunctionality is likely to be optimised differently depending on the local context (Text S1). An optimal configuration on a farm in the Italian Alps might not work for farms on the west coast of Ireland. That level of detail has not been drawn out in this assessment. However, many farmers are locked in production-orientated systems, influenced by persistently low prices for milk and meat (Erisman et al., 2016). Therefore, a wide-scale transition to more reliance on extensively managed permanent grasslands requires a multifaceted approach, including knowledge transfer, policy development and alternative payment schemes for ecosystem service delivery. Runhaar (2021) reasoned that these types of regime changes are only possible if four conditions are met, (i) concrete goals or actions, (ii) political and societal pressure, (iii) a broad coalition for change, and (iv) institutions to support and sustain the regime change. The presence of these conditions will vary widely in different contexts across Europe. Furthermore, different stakeholders hold different views towards permanent grassland which may affect their priorities and goals (Tindale et al., 2020).

Over recent decades, the permanent grassland area suffered significant losses. The outcomes of our review suggests that, in spite of apparent changes in dietary preferences, the protection of permanent grasslands in Europe has to be prioritised to prevent further losses of the area and thus the provision of multiple ecosystem services. At the same time, in view of the need to reduce ruminant livestock's impact on climate change, the time seems ripe to increase support for low-intensity management on existing permanent grasslands. The combined approach of protection and extensification will help secure multiple benefits from Europe's permanent grasslands.

Authors contribution

RS, CBu, CR, RF, VK, MA, FM, EL, HB, TV, RD, JK, PS, MW, NB, PN designed research. RS, CBu, CR, RF, VK, MA, FM, EL, HB, CBe, AC, CD, IF, PF, SG, SH, MH, MJ, RP, KS, RT, TV, JW, LZ performed research. RS, CBu, CR, RF, VK, MA, FM, EL, JK analyzed the data. RS, CBu, CR, RF, VK, MA, FM, EL, HB, TV, PS, MW, NB, PN wrote the paper.

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.

Data Availability

The data that support the findings of this study are available at https://doi.org/10.4121/17888573.

Acknowledgments

We acknowledge the financial support of this work by European Union Horizon 2020 research and innovation programme, under grant agreement 774124, project SUPER-*G* (Developing Sustainable Permanent Grassland Systems and Policies).

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.agee.2022.107891.

References

Allan, E., Manning, P., Alt, F., Binkenstein, J., Blaser, S., Blüthgen, N., Böhm, S., Grassein, F., Hölzel, N., Klaus, V.H., Kleinebecker, T., Morris, E.K., Oelmann, Y., Prati, D., Renner, S.C., Rillig, M.C., Schaefer, M., Schloter, M., Schmitt, B., Schöning, I., Schrumpf, M., Solly, E., Sorkau, E., Steckel, J., Steffen-Dewenter, I., Stempfhuber, B., Tschapka, M., Weiner, C.N., Weisser, W.W., Werner, M., Westphal, C., Wilcke, W., Fischer, M., 2015. Land use intensification alters ecosystem multifunctionality via loss of biodiversity and changes to functional composition. Ecol. Lett. 18, 834–843.

Badia, D., Marti, C., Terreros, J., 1994. Nutritional value of semi-arid pastures: influence of soil type and grass sowing. Agric. Mediterr. 124, 289–300.

Bakker, J.P., Berendse, F., 1999. Constraints in the restoration of ecological diversity in grassland and heathland communities. Trends Ecol. Evol. 14, 63–68.

Bardgett, R.D., Bullock, J.M., Lavorel, S., Manning, P., Schaffner, U., Ostle, N., Chomel, M., Durigan, G., Fry, E, L., Johnson, D., Lavallee, J.M., Le Provost, G., Luo, S., Png, K., Sankaran, M., Hou, X., Zhou, H., Ma, L., Ren, W., Li, X., Ding, Y., Li, Y., Shi, H., 2021. Combatting global grassland degradation. Nat. Rev. Earth Environ. 2, 720–735.

Bengtsson, J., Bullock, J.M., Egoh, B., Everson, C., Everson, T., O'Connor, T., O'Farrell, P. J., Smith, H.G., Lindborg, R., 2019. Grasslands—more important for ecosystem services than you might think. Ecosphere 10, e02582.

Binder, S., Isbell, F., Polasky, S., Catford, J.A., Tilman, D., 2018. Grassland biodiversity can pay. Proceedings of the National Academy of Sciences 115, 3876.

Blüthgen, N., Dormann, C.F., Prati, D., Klaus, V.H., Kleinebecker, T., Hölzel, N., Alt, F., Boch, S., Gockel, S., Hemp, A., Müller, J., Nieschulze, J., Renner, S.C., Schöning, I., Schumacher, U., Socher, S.A., Wells, K., Birkhofer, K., Buscot, F., Oelmann, Y., Rothenwöhrer, C., Scherber, C., Tscharntke, T., Weiner, C.N., Fischer, M., Kalko, E.K. V., Linsenmair, K.E., Schulze, E.-D., Weisser, W.W., 2012. A quantitative index of land-use intensity in grasslands: Integrating mowing, grazing and fertilization. Basic Appl. Ecol. 13, 207–220.

Boch, S., Biurrun, I., Rodwell, J., 2020. Grasslands of Western Europe. In: Goldstein, M.I., DellaSala, D.A. (Eds.), Encyclopedia of the World's Biomes. Elsevier, Oxford, UK.
Bommele, L., Reheul, D., Maes, I., Eekeren, N.V., 2006. White clover content in mixed swards installed in fields with different preceding crop. In: Lloveras, J., Gonzalez-Rodriguez, A., Vazquez-Yanez, O., Pineiro, J., Santamaria, O., Olea, L., Poblaciones, M.J. (Eds.), Sustainable grassland productivity Sociedad Espanola para el Estudio de los Pastos, 11. SEEP, Madrid, pp. 336–338.
Bretagnolle, V., Villers, A., Denonfoux, L., Cornulier, T., Inchausti, P., Badenhausser, I., 2011. Rapid recovery of a depleted population of Little Bustards Tetrax tetrax following provision of alfalfa through an agri-environment scheme. Ibis 153, 4–13.
Butkuviene, E., Butkute, R., 2007. The changes of sward botanical and chemical composition depending on pasture improvement measures. Grassland Science in Europe 12, 118–121.
Chang, J., Ciais, P., Gasser, T., Smith, P., Herrero, M., Havlík, P., Obersteiner, M., Guenet, B., Goll, D.S., Li, W., Naipal, V., Peng, S., Qiu, C., Tian, H., Viovy, N., Yue, C., Zhu, D., 2021. Climate warming from managed grasslands cancels the cooling effect of carbon sinks in sparsely grazed and natural grasslands. Nat. Commun. 12, 118.
Ciais, P., Schelhaas, M.J., Zaehle, S., Piao, S.L., Cescatti, A., Liski, J., Luyssaert, S., Le-Maire, G., Schulze, E.D., Bouriaud, O., Freibauer, A., Valentini, R., Nabuurs, G.J., 2008. Carbon accumulation in European forests. Nat. Geosci. 1, 425–429.
Crenna, E., Sinkko, T., Sala, S., 2019. Biodiversity impacts due to food consumption in Europe. J. Clean. Prod. 227, 378–391.
De Vries, F.T., Hoffland, E., Van Eekeren, N., Brussaard, L., Bloem, J., 2006. Fungal/bacterial ratios in grasslands with contrasting nitrogen management. Soil Biol. Biochem. 38, 2092–2103.
Di Paola, A., Rulli, M.C., Santini, M., 2017. Human food vs. animal feed debate. A thorough analysis of environmental footprints. Land Use Policy 67, 652–659.
D'Ottavio, P., Francioni, M., Trozzo, L., Sedić, E., Budimir, K., Avanzolini, P., Trombetta, M.F., Porqueddu, C., Santilocchi, R., Toderi, M., 2018. Trends and approaches in the analysis of ecosystem services provided by grazing systems: a review. Grass Forage Sci. 73, 15–25.
Erisman, J.W., Eekeren, Nv, Wit, Jd, Koopmans, C., Cuijpers, W., Oerlemans, N., Koks, B. J., 2016. Agriculture and biodiversity: a better balance benefits both. AIMS Agric. Food 1, 157–174.
EU, 1991. Council Directive 91/676/EEC of 12 December 1991 concerning the protection of waters against pollution caused by nitrates from agricultural sources.
EU, 1992. Council Directive 92/43/EEC of 21 May 1992 on the conservation of natural habitats and of wild fauna and flora.
EU, 2004. Commission Regulation (EC) No 796/2004 of 21 April 2004 laying down detailed rules for the implementation of cross-compliance, modulation and the integrated administration and control system provided for in of Council Regulation (EC) No 1782/2003 establishing common rules for direct support schemes under the common agricultural policy and establishing certain support schemes for farmers.
EU, 2006. Proposal for a Directive of the European Parliament and of the Council establishing a framework for the protection of soil and amending Directive 2004/35/EC.
EU, 2013. Regulation (EU) No 1307/2013 of the European Parliament and of the Council of 17 December 2013 establishing rules for direct payments to farmers under support schemes within the framework of the common agricultural policy and repealing Council Regulation (EC) No 637/2008 and Council Regulation (EC) No 73/2009.
EU, 2019. The post-2020 common agricultural policy: Environmental benefits and simplification.
Eurostat, 2020. Share of main land types in utilised agricultural area (UAA) by NUTS 2 regions.
Garnett, T., Godde, C., Muller, A., Röös, E., Smith, P., De Boer, I., zu Ermgassen, E., Herrero, M., Van Middelaar, C., Schader, C., 2017. Grazed and confused?: ruminating on cattle, grazing systems, methane, nitrous oxide, the soil carbon sequestration question-and what it all means for greenhouse gas emissions. FCRN.
Gerber, P.J., Steinfeld, H., Henderson, B., Mottet, A., Opio, C., Dijkman, J., Falcucci, A., Tempio, G., 2013. Tackling Climate Change through Livestock: A Global Assessment of Emissions and Mitigation Opportunities. Food and Agriculture Organization of the United Nations (FAO),.
Green, B.H., 1990. Agricultural intensification and the loss of habitat, species and amenity in British grasslands: a review of historical change and assessment of future prospects†. Grass Forage Sci. 45, 365–372.
Gregory, A.S., Dungait, J.A.J., Watts, C.W., Bol, R., Dixon, E.R., White, R.P., Whitmore, A.P., 2016. Long-term management changes topsoil and subsoil organic carbon and nitrogen dynamics in a temperate agricultural system. Eur. J. Soil Sci. 67, 421–430.
Gusenbauer, M., Haddaway, N., 2020. Which academic search systems are suitable for systematic reviews or meta-analyses? Evaluating retrieval qualities of google scholar, PubMed and 26 other Resources [OPEN ACCESS]. Research Synthesis. Methods 11, 181–217.
Habel, J.C., Dengler, J., Janišová, M., Török, P., Wellstein, C., Wiezik, M., 2013. European grassland ecosystems: threatened hotspots of biodiversity. Biodivers. Conserv. 22, 2131–2138.
Hall, C., McVittie, A., Moran, D., 2004. What does the public want from agriculture and the countryside? A review of evidence and methods. J. Rural Stud. 20, 211–225.
Hauck, J., Schleyer, C., Winkler, K.J., Maes, J., 2014. Shades of greening: reviewing the Impact of the new EU Agricultural Policy on Ecosystem Services. Change Adapt. Socio-Ecol. Syst. 1, 51.
Hejcman, M., Hejcmanová, P., Pavlů, V., Beneš, J., 2013. Origin and history of grasslands in Central Europe – a review. Grass Forage Sci. 68, 345–363.
Hopkins, A., Wilkins, R.J., 2006. Temperate grassland: key developments in the last century and future perspectives. J. Agric. Sci. 144, 503–523.
Hopkins, A., Gilbey, J., Dibb, C., Bowling, P.J., Murray, P.J., 1990. Response of permanent and reseeded grassland to fertilizer nitrogen. 1. Herbage production and herbage quality. Grass Forage Sci. 45, 43–55.
Hussain, R.I., Walcher, R., Eder, R., Allex, B., Wallner, P., Hutter, H.-P., Bauer, N., Arnberger, A., Zaller, J.G., Frank, T., 2019. Management of mountainous meadows associated with biodiversity attributes, perceived health benefits and cultural ecosystem services. Sci. Rep. 9, 14977.
Huyghe, C., De Vliegher, A., Van Gils, B., Peeters, A., 2014. Grasslands and herbivore production in Europe and effects of common policies. éditions Quae.
Isselstein, J., Kayser, M., 2014. Functions of grassland and their potential in delivering ecosystem services. Grassland Science in Europe 19, 199–214.
Isselstein, J., Jeangros, B., Pavlu, V., 2005. Agronomic aspects of biodiversity targeted management of temperate grasslands in Europe–a review. Agron. Res. 3, 139–151.
Jordan, A., Rayner, T., 2010. The evolution of climate policy in the European Union: an historical overview. In: Jordan, A., Huitema, D., Berkhout, F., Van Asselt, H., Rayner, T. (Eds.), Climate Change Policy in the European Union: Confronting the Dilemmas of Mitigation and Adaptation? Cambridge University Press, Cambridge, pp. 52–80.
Kizeková, M., Hopkins, A., Kanianska, R., Makovníková, J., Pollák, Š., Pálka, B., 2018. Changes in the area of permanent grassland and its implications for the provision of bioenergy: Slovakia as a case study. Grass Forage Sci. 73, 218–232.
Klaus, V.H., Schäfer, D., Kleinebecker, T., Fischer, M., Prati, D., Hölzel, N., 2016. Enriching plant diversity in grasslands by large-scale experimental sward disturbance and seed addition along gradients of land-use intensity. J. Plant Ecol. 10, 581–591.
Klein, A.-M., Vaissière, B.E., Cane, J.H., Steffan-Dewenter, I., Cunningham, S.A., Kremen, C., Tscharntke, T., 2007. Importance of pollinators in changing landscapes for world crops. Proceedings of the Royal Society B: Biological Sciences 274, 303–313.
Le Clec'h, S., Finger, R., Buchmann, N., Gosal, A.S., Hörtnagl, L., Huguenin-Elie, O., Jeanneret, P., Lüscher, A., Schneider, M.K., Huber, R., 2019. Assessment of spatial variability of multiple ecosystem services in grasslands of different intensities. J. Environ. Manag. 251, 109372.
Leip, A., Billen, G., Garnier, J., Grizzetti, B., Lassaletta, L., Reis, S., Simpson, D., Sutton, M.A., de Vries, W., Weiss, F., Westhoek, H., 2015. Impacts of European livestock production: nitrogen, sulphur, phosphorus and greenhouse gas emissions, land-use, water eutrophication and biodiversity. Environ. Res. Lett. 10, 115004.
Lemaire, G., Hodgson, J., Chabbi, A., 2011. Grassland productivity and ecosystem services. ePDF 978-1-8459-3900-7. Cabi.
Mace, G.M., Norris, K., Fitter, A.H., 2012. Biodiversity and ecosystem services: a multilayered relationship. Trends Ecol. Evol. 27, 19–26.
Macleod, C.J.A., Humphreys, M.W., Whalley, W.R., Turner, L., Binley, A., Watts, C.W., Skøt, L., Joynes, A., Hawkins, S., King, I.P., O'Donovan, S., Haygarth, P.M., 2013. A novel grass hybrid to reduce flood generation in temperate regions. Sci. Rep. 3, 1683.
Merbold, L., Eugster, W., Stieger, J., Zahniser, M., Nelson, D., Buchmann, N., 2014. Greenhouse gas budget (CO_2, CH4 and N2O) of **intensively managed grassland follo**wing restoration. Glob. Change Biol. 20, 1913–1928.
Meyer, S.T., Ptacnik, R., Hillebrand, H., Bessler, H., Buchmann, N., Ebeling, A., Eisenhauer, N., Engels, C., Fischer, M., Halle, S., Klein, A.-M., Oelmann, Y., Roscher, C., Rottstock, T., Scherber, C., Scheu, S., Schmid, B., Schulze, E.-D., Temperton, V.M., Tscharntke, T., Voigt, W., Weigelt, A., Wilcke, W., Weisser, W.W., 2018. Biodiversity–multifunctionality relationships depend on identity and number of measured functions. Nat. Ecol. Evol. 2, 44–49.
Navarro, L.M., Pereira, H.M., 2015. Rewilding Abandoned Landscapes in Europe. Rewilding European Landscapes. Springer,, Cham, pp. 3–23.
Nerusil, P., Kohoutek, A., Komarek, P., Odstrcilova, V., 2008. Effects of utilisation intensity and fertilization level on forage production and quality of permanent grassland on a fluvisoil. Acta Univ. Agric. et Silvic. Mendel. Brun. 56, 153–162.
O'Mara, F.P., 2012. The role of grasslands in food security and climate change. Ann. Bot. 110, 1263–1270.
Pe'er, G., Bonn, A., Bruelheide, H., Dieker, P., Eisenhauer, N., Feindt, P.H., Hagedorn, G., Hansjürgens, B., Herzon, I., Lomba, Â., Marquard, E., Moreira, F., Nitsch, H., Oppermann, R., Perino, A., Röder, N., Schleyer, C., Schindler, S., Wolf, C., Zinngrebe, Y., Lakner, S., 2020. Action needed for the EU Common Agricultural Policy to address sustainability challenges. People Nat. 2, 305–316.
Peeters, A., 2009. Importance, evolution, environmental impact and future challenges of grasslands and grassland-based systems in Europe. Grassl. Sci. 55 (3), 113–125.
Pilgrim, E.S., Macleod, C.J.A., Blackwell, M.S.A., Bol, R., Hogan, D.V., Chadwick, D.R., Cardenas, L., Misselbrook, T.H., Haygarth, P.M., Brazier, R.E., Hobbs, P., Hodgson, C., Jarvis, S., Dungait, J., Murray, P.J., Firbank, L.G., 2010. Chapter four - interactions among agricultural production and other ecosystem services delivered from european temperate grassland systems. In: Sparks, D.L. (Ed.), Advances in Agronomy. Academic Press, pp. 117–154.
Poux, X., Aubert, P.-M., 2018. An agroecological Europe in 2050: multifunctional agriculture for healthy eating. Findings from the Ten Years For Agroecology (TYFA) modelling exercise, Iddri-AScA, Study N°09/18, Paris, France, 74 p'.
Prescher, A.K., Grunwald, T., Bernhofer, C., 2010. Land use regulates carbon budgets in eastern Germany: from NEE to NBP. Agric. For. Meteorol. 150, 1016–1025.
Rizvi, S., Pagnutti, C., Fraser, E., Bauch, C.T., Anand, M., 2018. Global land use implications of dietary trends. PLoS One 13, e0200781.
Runhaar, H., 2021. Four critical conditions for agroecological transitions in Europe. Int. J. Agric. Sustain. 19, 227–233.
Schaub, S., Buchmann, N., Lüscher, A., Finger, R., 2020. Economic benefits from plant species diversity in intensively managed grasslands. Ecol. Econ. 168, 106488.

Schaub, S., Finger, R., Buchmann, N., Steiner, V., Klaus, V., 2021. The costs of diversity: higher prices for more diverse grassland seed mixtures. Environ. Res. Lett. 16, 094011.
Scheper, J., Holzschuh, A., Kuussaari, M., Potts, S.G., Rundlöf, M., Smith, H.G., Kleijn, D., 2013. Environmental factors driving the effectiveness of European agri-environmental measures in mitigating pollinator loss – a meta-analysis. Ecol. Lett. 16, 912–920.
Schulze, E.D., Luyssaert, S., Ciais, P., Freibauer, A., Janssens, I.A., Soussana, J.F., Smith, P., Grace, J., Levin, I., Thiruchittampalam, B., Heimann, M., Dolman, A.J., Valentini, R., Bousquet, P., Peylin, P., Peters, W., Rödenbeck, C., Etiope, G., Vuichard, N., Wattenbach, M., Nabuurs, G.J., Poussi, Z., Nieschulze, J., Gash, J.H., the CarboEurope, T, 2009. Importance of methane and nitrous oxide for Europe's terrestrial greenhouse-gas balance. Nat. Geosci. 2, 842–850.
Smit, H.J., Metzger, M.J., Ewert, F., 2008. Spatial distribution of grassland productivity and land use in Europe. Agric. Syst. 98, 208–219.
Søegaard, K., Gierus, M., Hopkins, A., Halling, M., 2007. Temporary grassland-challenges in the future. Permanent and temporary grassland: plant, environment and economy. In: Proceedings of the 14th Symposium of the European Grassland Federation, Ghent, Belgium, 3–5 September 2007. Belgian Society for Grassland and Forage Crops, pp. 27–38.
Sollenberger, L., Moura Kohmann, M., Dubeux Jr., J., Silveira, M., 2019. Grassland management affects delivery of regulating and supporting ecosystem services. Crop Sci. 59, 441–459.
Soussana, J.-F., Tallec, T., Blanfort, V., 2010. Mitigating the greenhouse gas balance of ruminant production systems through carbon sequestration in grasslands. Anim.: Int. J. Anim. Biosci. 4, 334–350.
SPSS, 2020. IBM Corp. Released 2020. IBM SPSS Statistics for Windows, Version 27.0. Armonk, NY: IBM Corp.
Stewart, G., 2010. Biology Letters 6, 78–81.
Tabari, H., 2020. Climate change impact on flood and extreme precipitation increases with water availability. Sci. Rep. 10, 13768.
Temperton, V.M., Buchmann, N., Buisson, E., Durigan, G., Kazmierczak, Ł., Perring, M. P., de Sá Dechoum, M., Veldman, J.W., Overbeck, G.E., 2019. Step back from the forest and step up to the Bonn Challenge: how a broad ecological perspective can promote successful landscape restoration. Restor. Ecol. 27, 705–719.
Tilman, D., Clark, M., 2014. Global diets link environmental sustainability and human health. Nature 515, 518–522.
Tindale, S.J., Elliott, J., Elings, M., Gallardo-Cobos, R., Hunter, E., Lieberherr, E., Miškolci, S., Price, P.N., Quatrini, S., Sánchez-Zamora, P., Schlueter, H., Frewer, L.J., 2020. A systematic review of European farmer and non-farmer attitudes towards landscapes, ecosystem services, and agricultural management practices: Implications for permanent grassland management. bioRxiv, 2020.2006.2012.148585.
Török, P., Dembicz, I., Dajić-Stevanović, Z., Kuzemko, A., 2020. Grasslands of Eastern Europe. In: Goldstein, M.I., DellaSala, D.A. (Eds.), Encyclopedia of the World's Biomes. Elsevier, Oxford, pp. 703–713.
Torralba, M., Fagerholm, N., Burgess, P.J., Moreno, G., Plieninger, T., 2016. Do European agroforestry systems enhance biodiversity and ecosystem services? A meta-analysis. Agric., Ecosyst. Environ. 230, 150–161.
Van Den Pol-Van Dasselaar, A., Bastiaansen-Aantjes, L., Bogue, F., O'Donovan, M., Huyghe, C., 2019. Grassland use in Europe: A syllabus for young farmers. e-ISBN (pdf): 978-2-7592–3146-1 Quae.
Van Den Pol, A., Becker, T., Botana Fernandez, A., Hennessy, T., Peratoner, G., 2018. Social and economic impacts of grass based ruminant production. In: Horan, B., Hennessy, D., O'Donovan, M., Kennedy, E., McCarthy, B., Finn, J.A., O'Brien, B. (Eds.), 27th European Grassland Federation General Meeting Cork (EGF 2018). European Grassland Federation EGF, Zürich, pp. 697–708.
Van Zanten, H.H.E., Herrero, M., Van Hal, O., Röös, E., Muller, A., Garnett, T., Gerber, P. J., Schader, C., De Boer, I.J.M., 2018. Defining a land boundary for sustainable livestock consumption. Glob. Change Biol. 24, 4185–4194.
Velthof, G.L., Hoving, I.E., Dolfing, J., Smit, A., Kuikman, P.J., Oenema, O., 2010. Method and timing of grassland renovation affects herbage yield, nitrate leaching, and nitrous oxide emission in intensively managed grasslands. Nutr. Cycl. Agroecosyst. 86, 401–412.
Vliegher, A.d., Carlier, L., 2007. The effect of the age of grassland on yield, botanical composition and nitrate content in the soil under grazing conditions. Grassland Science in Europe 12, 51–54.
Webster, C.P., Poulton, P.R., Goulding, K.W.T., 1999. Nitrogen leaching from winter cereals grown as part of a 5-year ley-arable rotation. Eur. J. Agron. 10, 99–109.
Werling, B.P., Dickson, T.L., Isaacs, R., Gaines, H., Gratton, C., Gross, K.L., Liere, H., Malmstrom, C.M., Meehan, T.D., Ruan, L., Robertson, B.A., Robertson, G.P., Schmidt, T.M., Schrotenboer, A.C., Teal, T.K., Wilson, J.K., Landis, D.A., 2014. Perennial grasslands enhance biodiversity and multiple ecosystem services in bioenergy landscapes. Proceedings of the National Academy of Sciences, 111, 1652.
Woodcock, B.A., Savage, J., Bullock, J.M., Nowakowski, M., Orr, R., Tallowin, J.R.B., Pywell, R.F., 2014. Enhancing floral resources for pollinators in productive agricultural grasslands. Biol. Conserv. 171, 44–51.