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Pro-environmental diversification of pasture-based dairy and beef production in Ireland, the United Kingdom and New Zealand: a scoping review of impacts and challenges

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Review Article

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Abstract

Milk and beef derived from pasture-based systems have been characterized by higher nutritional values and a lower environmental footprint than their equivalents obtained via indoor systems. However, intensification of pasture-based production can have adverse impacts on biodiversity and the environment. To date, studies on pro-environmental diversification options leading to improvement of environmental performance of pasture-based dairy and beef production have rarely been synthesized. The present study sought to review current on-farm pro-environmental measures with the potential for enhancing biodiversity status and/or reducing the environmental impacts of pasture-based agriculture. Literature on farmer attitudes toward these measures was also reviewed to identify potential obstacles and opportunities for transitioning to pro-environmental agriculture. A systematic search of published research from high-income island countries characterized by oceanic temperate climate with a high dependence on pasture-based agriculture—the Republic of Ireland, the United Kingdom and New Zealand, was conducted. Thirty studies that assessed the impact of pro-environmental measures, eight 'attitudinal' studies of dairy and beef farmers and one study covering both aspects were identified. Inductive thematical analysis was subsequently undertaken. Environmentally sensitive management practices such as hedgerows and field margins management, mixed grazing (where two or more herbivorous animals graze the same land), rare livestock breeds, multispecies swards, organic farming and agroforestry were identified as primary themes studied under the auspices of pro-environmental diversification, while forestry, bioenergy crops and organic farming were the main themes identified within attitudinal research studies. Findings suggest that environmentally sensitive practices have varied effects on biodiversity. Mixed grazing was found to improve livestock production, while studies of organic farming reported multiple positive impacts on biodiversity and animal welfare. Effect of multispecies swards on methane emissions and urinary nitrogen extraction were found to be inconsistent. Attitudinal research suggests that the main barrier to implementing afforestation is its lack of attractiveness compared to 'traditional' farming and that organic farmer decisions regarding agricultural management practices might be less profit-oriented and influenced by ecological beliefs to a greater extent than decisions of conventional farmers. The results of this study confirm that pro-environmental diversification inherently encompasses multiple scientific disciplines; however, previous study designs and outcomes were found to be fragmented and narrowly focused. Considering the urgency and importance of climate and biodiversity crises, pro-environmental diversification of pasture-based dairy and beef production has rarely been holistically approached and remains understudied. The development of practical, sustainable solutions for farming based on circular economy and respect to nature and additional strategies to increase farmer and consumer environmental awareness should be prioritized by policymakers, advisory and scientific bodies.

Introduction

Grass-fed dairy and beef products are valued by consumers for their unique nutrient profile, enhanced animal welfare and lower environmental footprint compared to conventional produce derived from animals reared indoors on higher volumes of concentrate feeds (O'Callaghan *et al.*, 2018; Moscovici Joubran *et al.*, 2021). For the current study, pasture-based production of dairy and beef is defined as a system within which cattle graze freely outdoors on green pasture for ≥6 months per year, using grazed grass as the primary feed source (Läpple *et al.*, 2012). While pasture-based milk and beef production systems typically exhibit a considerably lower carbon footprint than indoor systems (Wassenaar *et al.*, 2009; O'Brien *et al.*, 2012, 2014), the impacts of intensive management of perennial ryegrass pastures and high stocking rates may have adverse effects on the environment and biodiversity (Delaby *et al.*, 2020). This type of intensive grass-based production is particularly popular in island countries characterized by temperate maritime/oceanic climates where grass grows for most of the year; and is predominant in the Republic of Ireland (ROI) and New Zealand (NZ) and widely practiced throughout the United Kingdom (UK) (DEFRA, 2019). For example, according to Teagasc National Farm Survey, in Ireland, in 2017, the diet of a typical Irish dairy cow constituted 95.4% of grass, from which 73.4% was grazed grass and 22.1% was grass silage (O'Brien *et al.*, 2019). Due to the length of grass growing season, pasture-based agriculture in these countries differs from continental pasture-based systems, e.g., Alpine cattle grazing in which cows graze high mountain meadows during summer, transhumance and other traditional approaches practiced on the continent (Carafa *et al.*, 2020). Moreover, in contrast to continental pasture-based agriculture, pasture-based dairy and beef sectors in island countries presented in this review are major contributors to growth in economic activity across the rural economy, milk processing/distribution, export marketing (>90% of milk and beef produced in ROI and NZ are destinated for exports) and research (Fitzgerald, 2019; Lee-Jones, 2019). Thus, to identify pro-environmental activities specific to the pasture-based system of interest, the selection of the reviewed studies was limited to research conducted in ROI, the UK and NZ—main island countries producing pasture-based milk and beef.

The ramifications of the intensive grass-based agriculture for the local environment may include trees/shrubs removal and increased biocide or fertilizer usage, potentially resulting in decreased levels of local flora and fauna (Delaby *et al.*, 2020). Several studies report that further simplification, homogenization and intensification of grass-based production will result in greater biodiversity losses and environmental pollution, including eutrophication and acidification of terrestrial and aquatic ecosystems (Bouwman *et al.*, 2002; Chislock *et al.*, 2013). Accordingly, farm management methods must be rethought and redesigned to ensure food security and nutrition while providing social and economic equity by protecting the ecosystem services on which agriculture depends (United Nations, 2015).

While there is a myriad of definitions used to characterize pro-environmental diversification, drawing on perspectives provided by Morris *et al.* (2017), Ridier and Labaethe (2019) and Sutherland *et al.* (2016), in this paper, we defined pro-environmental diversification as 'on-farm change or changes in agricultural practices that benefit the natural environment, promote agrobiodiversity, potentially leading to lowering of greenhouse gas emissions (GHG)'.

Notwithstanding its undoubted importance, to the best of the authors' knowledge, to date, no large-scale review has examined the pro-environmental diversification options available to pasture-based dairy and beef farmers in ROI, the UK and NZ and their motivations to undertake these activities. Accordingly, the present study sought to (1) identify and synthesize available peer-reviewed scientific literature on the pro-environmental diversification of dairy and beef farms in ROI, UK and NZ, and (2) identify and synthesize the literature pertaining to the underlying attitudes and motivations of dairy and beef farmers toward pro-environmental diversification.

The authors believe that the outputs from this study will contribute to a better understanding of pro-environmental actions applicable to pasture-based dairy and beef production in these countries. It further aims to enhance current knowledge of farmer decision-making processes underlying the implementation of pro-environmental diversification and thus assist in designing effective, attractive, evidence-based schemes and policies.

Methods

As most studies identified in this review focused on differing aspects of pro-environmental diversification and/or employed varying study designs, meta-analysis based on a systematic review was not considered possible, with a scoping review approach consequently chosen. Scoping reviews follow a similar methodology to systematic reviews and are often used to systematically map cross-cutting findings from a predefined subject and identify key concepts and gaps within the field to inform future research and/or policy (White and Schmidt, 2005; O'Brien *et al.*, 2016). However, unlike systematic reviews, the main focus of scoping reviews is on the research findings themselves; methodologies used to obtain them may differ between reviewed studies (Weeks and Strudsholm, 2008).

A methodological framework previously employed for several high-impact reviews (Arksey and O'Malley, 2005; O'Brien *et al.*, 2016; Tricco *et al.*, 2016; Andrade *et al.*, 2018) was followed. The five phases of the framework are:

- Phase 1: Defining the research question(s)
- Phase 2: Identification of potentially relevant studies
- Phase 3: Screening and selection of relevant literature
- Phase 4: Data extraction and thematic analysis
- Phase 5: Synthesis of results and identification of research gaps

Defining research questions and keywords

The primary research questions were:

1) What pro-environmental diversification approaches for grass-based dairy and beef production in ROI, the UK and NZ were presented in the scientific literature?
2) What are beef and dairy farmer attitudes toward pro-environmental diversification?
3) What research gaps and scientific challenges are associated with the diversification of grass-based dairy and beef production?

After defining research questions, relevant keywords (Table 1) were identified for searching and identifying potentially applicable studies on pro-environmental diversification of pasture-based dairy and beef production.

Search strategy

A systematic search of published papers was conducted in Scopus and Web of Science. Search terms and keywords defining the type of production, diversification action, impact and attitudes were used (Table 1). The search was limited to peer-reviewed journal papers published in English between 1 January 2000 and 25 September 2020. Literature scans employed Boolean positional operators ('AND', 'OR', 'AND NOT') to appropriately refine literature identification, with supplementary searches of article bibliographies employed to ensure saturation. Research papers

Table 1. Terms used in database search and correspondent classifications

Term classification	Searched terms
Production	Dairy, beef, cattle, cows, grass-based, pasture, pastoral, bovine
Action	Agricultural diversification, diversification, agro-diversity, rewilding, crop diversification, organic, agroforestry, chemical-free farming, mixed crop-livestock, farming for nature, high nature value farming, regenerative agriculture, value-added, indigenous breed, native breed, silvopasture
Impact	Environmental, greenhouse gas, biodiversity, sustainability, climate change, land-use change, animal welfare
Perception	Attitude, behavior, policy, awareness, change, farmer

reporting on the impacts of pro-environmental diversification on product quality, animal welfare, biodiversity, livestock performance, the environment and farmer attitudes toward diversification were included for review. Due to the relatively high volume of papers on attitudes toward policy instruments such as agri-environmental schemes (AES) and the absence of a direct link to pro-environmental action as such, this issue was excluded from this review.

Inclusion/exclusion criteria and quality assessment

The overarching literature identification and selection process are presented in Figure 1. As shown, 7557 potentially relevant articles were identified via Scopus and Web of Science, with an additional 19 records identified based on reference (snowball) analysis. Both sets of 4106 (Scopus) and 3451 (Web of Science) articles were consolidated using EndNote X9.2 (The EndNote Team, 2013, Clarivate, Philadelphia, PA, USA). After duplicates removal, 5161 records were identified. The first screening phase was undertaken using EndNote software via an article title, year and abstract assessment and based upon developed eligibility criteria (Table 2). Reviews, book chapters and conference proceedings were excluded at this stage, resulting in 86 articles continuing forward for further assessment. All 86 articles were independently assessed by two researchers based on full-text analysis, again using developed eligibility criteria (Table 2). Only peer-reviewed papers published in journals with a current impact factor were included to ensure study quality.

Articles excluded during the review phase were those that:

i) reviewed results of previously published studies,
ii) identified attitudes toward policy instruments (e.g., AES) rather than diversification itself,
iii) provided a vague or unclear description of study participants, i.e., no specific reference to dairy and beef farmers,
iv) investigated management practices such as manipulation of diet to control or reduce specific pollutants.

Qualitative data analysis

Data extraction, coding and thematic analyses were performed using NVivo 12 (QSR International Pty Ltd, 2018). NVivo is a qualitative data analysis software frequently used within scientific literature for qualitative and mixed-methods data analysis (Amrutha and Geetha, 2020).

After full-text analysis of 86 papers, 39 papers (referred to as cases in NVivo) were identified as eligible for the current review based on the inclusion criteria conditions. In NVivo, the case stores all relevant qualitative data. All cases were given the attributes such as author, year, country, category (diversification/attitude) and were classified accordingly. Thematic analysis was conducted following criteria defined by Braun and Clarke (2014) and prioritized establishing meanings and themes across data sets and cases, making it optimal for qualitative analysis (Mooney *et al.*, 2020). As part of thematic analysis, manual interpretive coding was employed, with the developed coding framework presented in Figure 2. Initially, in order to become familiar with the data, each paper was read and assigned into two main categories: ‘pro-environmental diversification’ or ‘attitudes towards diversification’, followed by extraction and analysis which consisted of creating free codes designed to identify the major categories of the analysis. Subsequently, similar codes were clustered, and themes were generated. In the following phase, thematic mapping and refinement, definition and labeling of themes were conducted. A thematic map of the coding hierarchy is presented in Figure 3. In order to establish coding intersections between two codes or codes and attributes, matrix coding was employed. Hierarchy charts such as tree maps were used to see patterns in coding or the attribute values of cases. Column charts and heat maps were also employed to examine and analyze the data. Finally, the results of the reviewed studies were synthesized using a qualitative descriptive approach.

Results

Included studies

Overall, 39 articles were identified, of which 30 focused on pro-environmental options applied on dairy and/or beef farms; eight papers focused on the attitudes of dairy and beef farmers toward pro-environmental diversification and one article covered both aspects.

All articles ($n = 39$) were published between 2000 and 2020, with a maximum ($n = 4$) number of articles on diversification options published during 2009 and on farmer attitudes during 2012 ($n = 2$) and 2013 ($n = 2$) (Fig. 4a). Overall, 49% of identified studies ($n = 19$) originated from the UK; ten studies originated from ROI and NZ, respectively (25.5% for each country) (Fig. 4b).

Pro-environmental diversification for dairy and beef enterprises and their impact on the environment, biodiversity, animal performance and animal welfare

Studies describing pro-environmental measures available for use on dairy and beef farms were delineated into seven main themes:

1 Environmentally sensitive management practices (ESMPs)—i.e., stubbles, patches of seed-rich crops, low-input grasslands, field margin management, hedges and ditches management, watercourse margin (riparian buffer) management, replacement of species-poor agricultural grassland with other plants
2 Multispecies swards (MSS)
3 Alternative farming systems—i.e., organic farming
4 Grazing of semi-natural rough grasslands (SNRG) and species-rich grasslands

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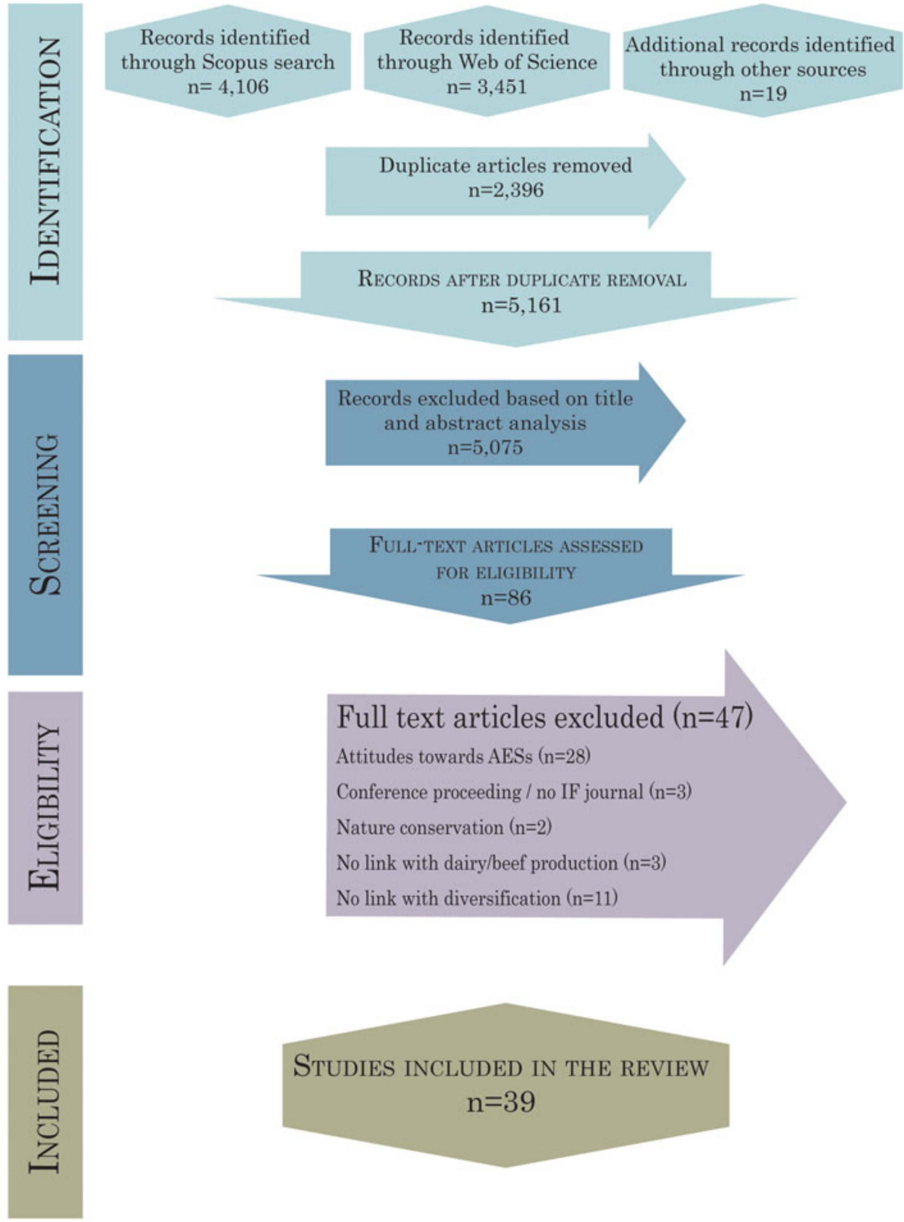

Fig. 1. Systematic review protocol employed during the current study including results of literature identification, screening, eligibility assessment and final study inclusion.

Table 2. Eligibility (inclusion/exclusion) criteria employed for literature screening

	Inclusion criteria	Exclusion criteria
Study type	Research papers	Reviews, book chapters, books, opinion papers, conference proceeding
Language	English	Other languages
Region	Humid temperate climate UK, ROI, NZ	Other regions
Type of production	Grass-based dairy and beef production	Non-dairy/beef production
Period	After 2000	pre-2000
Study design—diversification in action	Papers on diversification actions that affect biodiversity/environment and livestock performance/productivity/welfare	Papers that compare conventional systems, feeding regimes, conventional pasture management, off-farm diversification, sports/leisure facilities, accommodation services, hire/contract services, food processing and direct marketing
Study design—attitudes	Papers on farmers' attitude toward pro-environmental diversification	Papers on farmers' attitudes toward agri-environmental schemes/climate change/biodiversity loss

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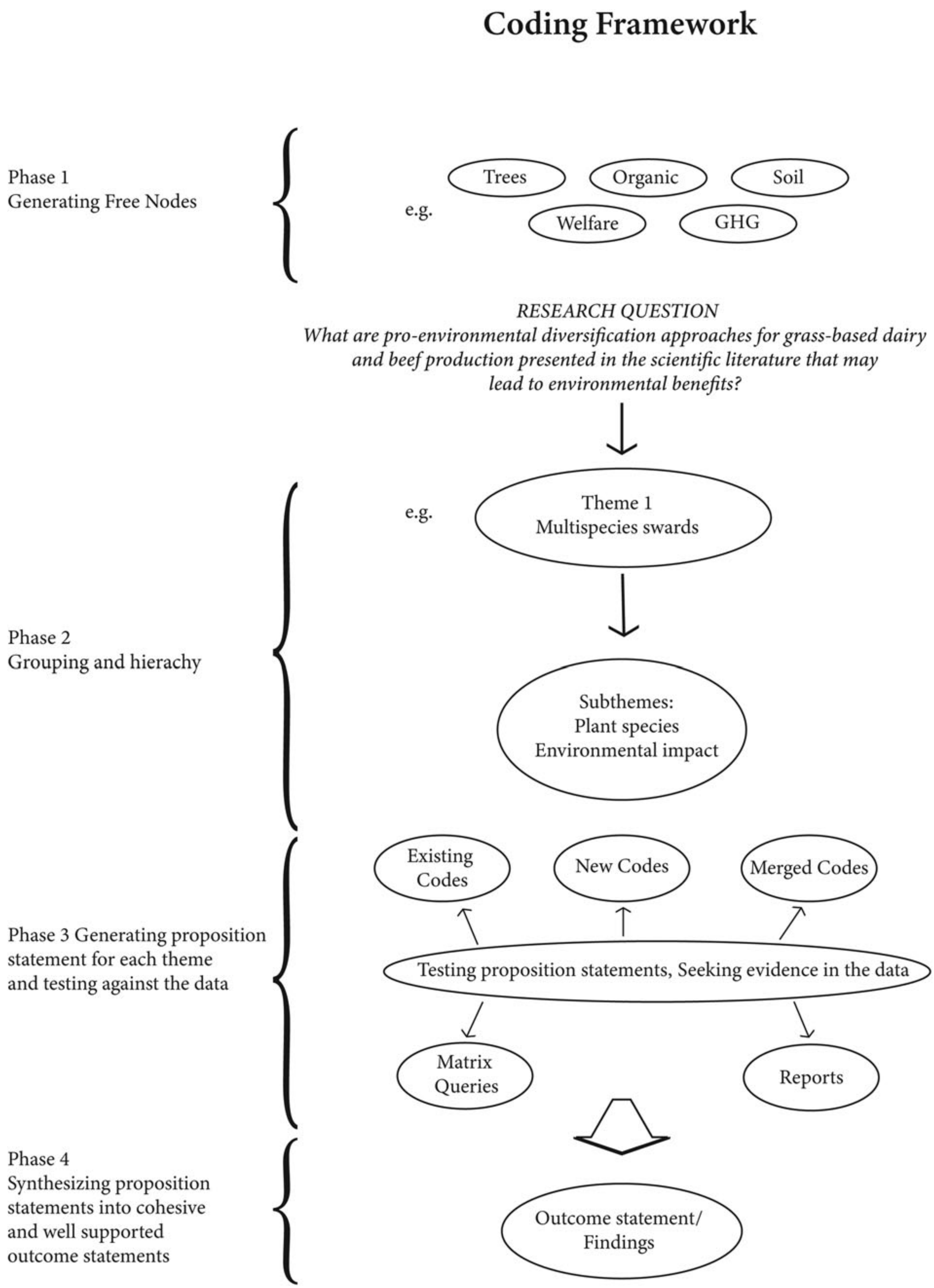

Fig. 2. Coding framework.

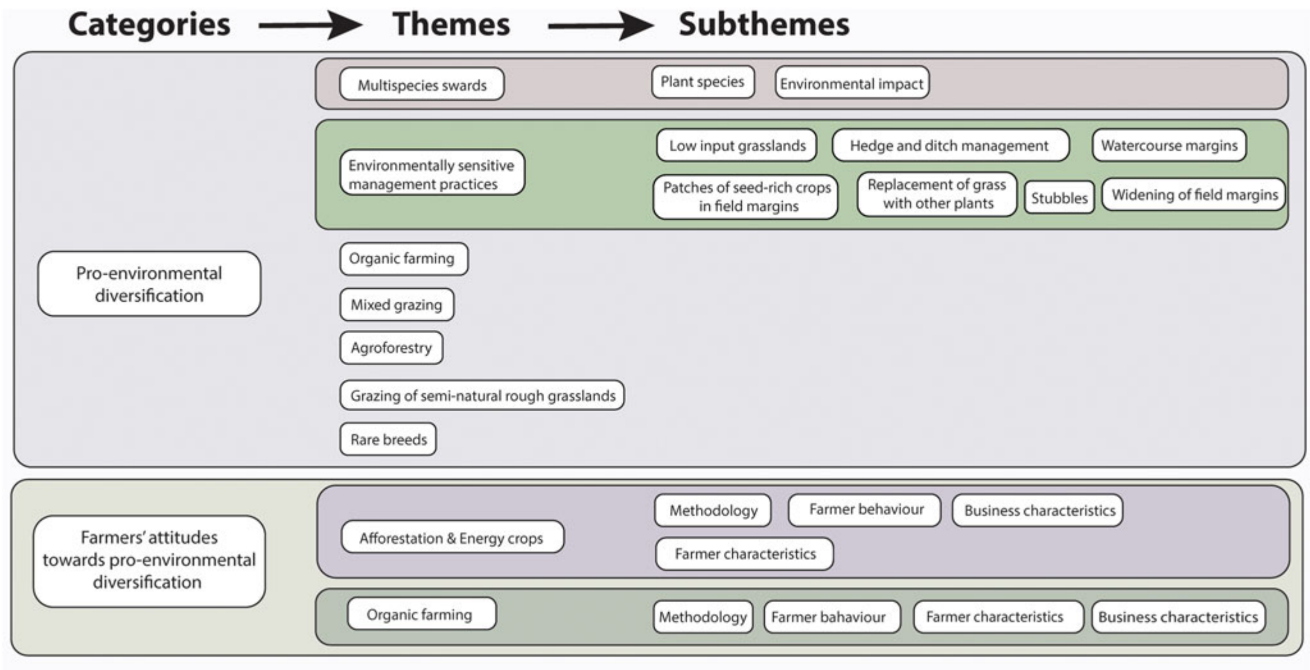

Fig. 3. Thematic map of coding hierarchy.

5 Mixed grazing, where two or more herbivorous animals graze the same land
6 Agroforestry
7 Rare/indigenous breeds

During thematic analysis, 12 distinct pro-environmental management practices potentially benefiting the environment, biodiversity, or animal welfare when implemented on dairy and beef farms were distinguished (Table 3). MSS ($n = 8$), ESMPs ($n = 7$) and organic farming ($n = 7$) were the most frequently studied diversification options (Fig. 5a). Analysis of the impact(s) addressed by each diversification option is presented in Figure 5b and Table 4. Overall, 58% of identified articles in 'pro-environmental diversification' category focused on the impact of diversification on biodiversity ($n = 18$), while 41% ($n = 13$) concentrated on livestock performance (Fig. 5b). However, no identified study addressed all five impacts (product quality, animal welfare, biodiversity, livestock performance, environment), while only studies on organic farming examined impacts on animal welfare.

Environmentally sensitive management practices

ESMPs are often undertaken by farmers to enhance the biodiversity status of their farms. In Europe, these actions are encouraged by AES, an important part of European agricultural policy (McGurk *et al.*, 2020).

Seven ESMPs were identified (Fig. 3), with boundary (ditches and hedgerow) management as the most frequently studied ESMP ($n = 4$). Five articles (Feehan *et al.*, 2005; Potts *et al.*, 2009; Peach *et al.*, 2011; Baker *et al.*, 2012; Curtis *et al.*, 2019), three from the UK and one each from NZ and ROI, investigated the impact of field margins ($n = 3$) and replacement of grassland with other plant species ($n = 2$) on biodiversity. The impacts of individual ESMPs on biodiversity are summarized in Table 4.

Two studies (Baker *et al.*, 2012; Curtis *et al.*, 2019) report that ESMPs, including stubble, patches of seed-rich crops, low-input heterogeneous grasslands, and field margins and corners, had a positive effect on invertebrate species and multiple granivorous birds by increasing their numbers; however, not all granivorous birds species reacted positively to these changes, with some species found to decline (Table 4). Conversely, both Davey *et al.* (2010) and Feehan *et al.* (2005) found no significant pattern across farmland bird species, carabid beetles population and plant species richness in response to ESMPs.

Environmentally sensitive management of hedgerows via increased connectivity, width, height and length had a positive impact on small mammal populations and specific granivore bird species; however, again, not all granivore birds reacted positively with goldfinch, tree sparrow and yellowhammer exhibiting a decline in numbers (Gelling *et al.*, 2007; Baker *et al.*, 2012), yet again, Davey *et al.* (2010) and Feehan *et al.* (2005) reported no significant impact between boundary management and numbers of farmland birds, carabid beetles and plant species richness.

The effect of replacing species-poor agricultural grassland with other plants on invertebrate and bird populations was studied twice in the UK (Potts *et al.*, 2009; Peach *et al.*, 2011). The study by Peach *et al.* (2011) provided strong evidence that including cereals intended for silage in intensive livestock systems can offer practical conservation measures for seed-eating farmland birds. However, the authors noted that early harvest of cereal crops for silage could be harmful to breeding attempts of late-nesting species.

Potts *et al.* (2009) studied the abundance of bumblebees and butterflies on grasslands on which modified management practices such as no summer disturbance or raised mowing height were applied, and on the fields where grassland was replaced with various plant species including under-sown spring cereal and a diverse conservation mix with kale, mixed cereals, linseed and legumes. Replacement of grass aimed to attract a diversity of invertebrates rather than feed livestock. Indeed the results confirmed that replacing grass with cereals and conservation mix

Fig. 4. Bar chart displaying frequency of article categories by year (A) and by country (B).

attracted significantly more invertebrates than grass-based treatments. Treatment that combined kale, cereals, linseed and legumes attracted more diverse bumblebees and butterflies than under-sown spring cereal treatment.

Multispecies swards

Seven studies were conducted in NZ and one in the UK, all of which focused on utilizing MSS for dairy production (Table 5). The main studied aspects were associated with the effects of MSS on livestock performance, milk production/composition and nitrogen excretion. Even though MSS, by their nature, increase diversity of plants and potentially encourage more biodiversity on the farm, this factor has not been studied in identified papers which addressed grass-based dairy and beef production in ROI, the UK and NZ.

Plant species most frequently added to researched swards included plantain ($n = 7$) and chicory ($n = 5$), with one study (Hammond *et al.*, 2014) examining the effects of a wildflower mixture (Table 5). Decreased nitrogen concentrations in urine from cows fed mixtures containing herbs (also referred to as forbs in scientific publications) was noted in five papers (Totty *et al.*, 2013; Box *et al.*, 2017; Bryant *et al.*, 2017; Minneé *et al.*, 2017; Dodd *et al.*, 2019). However, Cheng *et al.* (2018) did not find any effect between the addition of chicory or plantain and urinary nitrogen. Two studies investigated the impact of MSS on methane emissions (Hammond *et al.*, 2014; Jonker *et al.*, 2019). Jonker *et al.* (2019) observed that adding lucerne, chicory and plantain to ryegrass/white clover swards had no effect on methane production. Conversely, Hammond *et al.* (2014) noted a significant decrease in daily methane emissions from cattle consuming a ryegrass—wildflower mixture. Three studies (Totty *et al.*, 2013; Box *et al.*, 2017; Dodd *et al.*, 2019) reported that the addition of herbs to pasture increased milk production compared to control treatments, while Jonker *et al.* (2019) and Minneé *et al.* (2017) did not find any change in yield following addition of forbs.

Table 3. Description of pro-environmental diversification measures identified during review process

Pro-environmental diversification measures	Description	Potential benefits	References
Stubbles retention	Retention of unploughed stubbles until at least mid-February	• Improvement in soil aggregation • Reduction in soil GHG emissions • Build-up of soil organic matter • Main source of weed seeds and grain for seed-eating birds	Baker *et al.* (2012); Peach *et al.* (2011)
Patches of seed-rich crops	Establishment of small patches (0.4–2 ha) of seed-rich crops in a >6 m filed margin that remain undisturbed until March	• Breeding season benefits for birds • Food and nesting habitat for insects which further benefits crop yields • Maintenance and reproduction of wild plant communities • Key habitat for numerous taxa of insects and birds • Refuge a habitat and a corridor for small mammals • Improve crop yields by providing natural pest control, pollination	Blary *et al.* (2021)
Low-input grasslands	Restrictions on chemical inputs on grassland and the maintenance of a heterogeneous sward	• Foraging and breeding habitat for birds, insects • Maintenance and reproduction of wild plant communities • Reduced use of fertilizers and pesticides	Baker *et al.* (2012)
Filed margin management	Input reduction of grass margins of width 2–6 m adjacent to pastoral and arable fields	• Maintenance and reproduction of wild plant communities • Food and nesting habitat for insects which further benefits crop yields • Refuge a habitat and a corridor for small mammals	Blary *et al.* (2021); Main *et al.* (2021)
Hedges, ditches management	Hedges—restrictions on the cutting of hedgerows and sets minimum dimensions to be maintained Ditches—kept open and restricts the cutting and grazing of adjacent vegetation	• Foraging and nesting habitats for wildlife fauna • Retention of wildlife habitats • Food and nesting habitat for insects which further benefits crop yields • Maintenance and reproduction of wild plant communities • Refuge a habitat and a corridor for small mammals	Baker *et al.* (2012); Gelling *et al.* (2007)
Watercourse margins management	Exclusion of cattle from watercourses	• Reduction in nitrogen, phosphorus and sediment run-off • Improvement of riverbank stability • Improved vegetation cover and biodiversity • Livestock biosecurity benefits through a decrease in the risk of the transmission of bovine viral diarrhea (BVD), bovine tuberculosis (TB) and Johne's disease	Kilgarriff *et al.* (2020)
Replacement of species-poor agricultural grassland with other plants	Grassland is replaced with various plant species, including under sown spring cereals and conservation mixes	• Breeding season benefits for wildlife fauna • Maintenance and reproduction of wild plant communities • Key habitat for numerous taxa of both flora and fauna • Improve crop yields by providing natural pest control, pollination	Baker *et al.* (2012); Peach *et al.* (2011); Potts *et al.* (2009)
Unimproved grasslands	Not agriculturally improved or cultivated for several hundreds of years	• Maintenance and reproduction of wild plant communities including protected species • Can represent pastoral value to farmers and grazers • Offer good quality hey and silage	French (2017)

(*Continued*)

Table 3. (*Continued.*)

Pro-environmental diversification measures	Description	Potential benefits	References
Multispecies swards	Grazing swards that beside ryegrass and clover include herb species such as chicory (*Cichorium intybus* L.) and ribwort plantain (*Plantago lanceolata* L.)	• Reduced use of fertilizers • Reduced urine nitrogen concentration and nitrate leaching from cattle consuming heterogeneous swards • Increase consumption of phytochemicals and potentially reduce the use of antibiotics and anthelmintics, improve animal health and increase average daily gains. • Improved resilience—often incorporate drought-resistant plant species	Grace *et al.* (2019)
Semi-natural rough grassland (SNRG)	SNRG grazing is practiced on marginal land, usually on uplands and helps maintain high biodiversity of plant species. Cattle grazing behavior is characterized by generally lower selectivity than sheep or goats; thus, they are considered particularly helpful in SNRG management	• When the numbers of wild ruminants are low, domesticated ruminants play an essential role in the ecological management of these areas • Can represent pastoral value to farmers and grazers • Cattle consume relatively willingly poor-quality forage such as *M. caerulea* or other invasive grasses, consequently maintaining balance in floristic and structural diversity of SNRG • Introduction of grazing increases floristic diversity, while abandoned grasslands exhibit very low diversity • Nesting and breeding season foraging habitat for wildlife fauna	Fraser *et al.* (2014); Mohammed *et al.* (2020); Rysiak *et al.* (2021)
Mixed grazing	Mixed grazing is a livestock management system where two or more large herbivores graze together, sharing the resources	• Differences in feeding behavior of different herbivore species lead to complementary pasture use • Better utilization of the sward and improved animal performance	D'Alexis *et al.* (2014); Fraser and Rosa García (2018); Mahieu *et al.* (2020)
Rare native breeds	Rare indigenous breeds represent dual purpose, low input animals, well suited for both milk and meat production	• Dual purpose animals • Native breeds of cattle are often highly fertile, extremely maternal and long-lived, often resistant to diseases that cause problems in mainstream breeds • Milk and beef from native cattle breeds are considered to be more nutritious with higher amount of bioactive components • Inclusion of rare livestock breeds promote agrobiodiversity and actively encourage conservation of genetic diversity • Native breeds represent living heritage	Kuczyńska *et al.* (2012a, 2012b); Marsoner *et al.* (2018)
Organic farming	Organic farming is an alternative farming system and, by its nature, very often represents mixed crop-livestock production where diversity is its crucial component. This system does not allow artificial pesticides, fertilizers and GMOs	• Ceases use of synthetic fertilizers and pesticides • Promotes crop rotations • Focuses on soil fertility and closed nutrient cycles • Enhances floral and faunal diversity • Improved animal welfare	KilBride *et al.* (2012); Langford *et al.* (2009); Lund (2006); Mäder *et al.* (2002); Wagner *et al.* (2021)
Agroforestry	Intentional incorporation of trees into crops or pasturelands. Silvopasture is one of the agroforestry practices that combines specifically livestock production with forestry	• Provides essential ecosystem services such as carbon sequestration, improved soil health and water quality • Plays a critical role in food security, pollinator/ wildlife habitat and green infrastructure efforts • Helps to diversify income streams to private landowners and communities	Bettles *et al.* (2021)

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Heat map A

Diversification	Country		
	New Zealand	Republic of Ireland	United Kingdom
ESMP	1	1	5
Mixed grazing	0	0	4
Multispecies swards	7	0	1
Organic farming	0	3	4
Rare breeds	0	0	3
SNRG	0	0	5
Inclusion of trees	2	0	0
Attitudes			
Afforestation and energy crops	0	3	3
Organic farming	0	3	0
Total number of papers	10	10	25

Heat map B

Diversification	Impact												
	Product quality	Animal welfare	Biodiversity					Livestock Performance			Environment		
			Biodiversity total	Birds	Invertebrates	Plants	Small Mammals	Total Livestock Performance	Beef	Dairy	Soil	Water	GHG
ESMP	0	0	7	4	3	1	1	0	0	0	0	0	0
Mixed Grazing	6	0	4	2	1	2	0	3	3	0	0	0	1
Multispecies Swards	0	0	0	0	0	0	0	8	0	8	0	0	8
Organic Farming	0	3	4	1	2	3	0	0	0	0	0	0	0
Rare breeds	1	0	2	1	1	1	0	3	3	0	0		1
SNRG	1	0	3	1	1	2	0	3	3	0	0	0	2
Inclusion of trees	0	0	1	0	0	1	0	0	0	0	2	1	0
Total number of papers	7	3	18	7	7	9	1	13	5	8	2	1	10

Fig. 5. Heat maps displaying frequency of diversification measures and attitudes by country (A) and their impact on product quality, animal welfare, biodiversity, livestock performance, environment (B). Colors and numbers correspond to number of papers identified.

Organic farming

Seven studies of organic farming on dairy farms were identified—four from the UK and three from ROI. Three studies explored the impact of organic agriculture on animal welfare, with four focusing on biodiversity. Results indicate that animal welfare indicators were generally higher on organic farms as compared to conventional operations where lactating animals had to have access to grazing over the summer (Table 6). Certified organic farms were also characterized by a lower culling rate due to health problems and experienced fewer pre-identified health-related issues than cows on farms that were not certified organic (Langford *et al.*, 2009; Rutherford *et al.*, 2009). Moreover, Kilbride *et al.* (2012) reported that participation in organic certification schemes significantly reduced the risk of non-compliance with animal welfare regulations (Langford *et al.*, 2009; Kilbride *et al.*, 2012).

All studies examining the impact of organic farming on biodiversity ($n = 4$) reported significantly higher plant diversity than that found on pasture-based conventional (not organic) farms, with positive impacts on insect abundance and evenness also described (Gabriel *et al.*, 2010; Power and Stout, 2011; Power *et al.*, 2012; 2013). Gabriel *et al.* (2010) identified 10×10 km landscapes containing high or low number of organic farms, i.e., organic hot-spots, which were characterized by >15% of available land used for organic farming and organic cold-spots characterized by <5% of available land used for organic farming. The authors explored the impacts of land use at multiple spatial scales (field-level to regional) on biodiversity, with biodiversity surveys indicating a higher abundance of plants, arthropods and butterflies in both organic fields and organic hot-spots than in conventional plots or organic cold-spots.

Mixed and semi-natural rough grasslands grazing

Mixed grazing is a livestock management system where two or more large herbivores graze together, sharing the resources (Fraser and Rosa García, 2018; Mahieu *et al.*, 2020). This practice offers potential benefits for animal productivity and performance, species diversity within animal production systems and wildlife (D'Alexis *et al.*, 2014; Mahieu *et al.*, 2020). Differences in feeding behavior of different herbivore species lead to complementary pasture use and have been associated with better utilization of the sward and improved animal performance (D'Alexis *et al.*, 2014).

SNRG grazing can be practiced on marginal land, usually uplands. The productivity of SNRGs is generally lower than those of permanent improved pastures. However, currently, in Europe, these ecosystems are one of the most important providers of multiple services such as provisioning services (e.g., wild foods, crops), regulating services (e.g., carbon storage, pollination) and cultural services (e.g., recreation, aesthetic values) (Nowak-Olejnik *et al.*, 2020). When the numbers of wild ruminants are low, domesticated ruminants play an essential role in the ecological management of these areas. Cattle grazing behavior is characterized by generally lower selectivity than sheep or goats; thus, they are considered particularly helpful in SNRG management (Fraser *et al.*, 2014; Mohammed *et al.*, 2020). Furthermore, cattle consume relatively willingly poor-quality forage such as *Molinia caerulea* or other invasive grasses, consequently maintaining balance in floristic and structural diversity of SNRG (Fraser *et al.*, 2014).

Seven studies were identified on mixed grazing ($n = 4$) and SNRG ($n = 5$), with two papers researching the implementation of both practices. Out of seven studies, only two explored the combined impact of SNRG and mixed-grazing on animal performance, and just one investigated the effect of SNRG on meat quality. All studies originated from the UK. The results on mixed grazing referred to the British upland grazing systems.

Study outcomes indicated that incorporating suckler cows and calves into sheep-only systems improved total production per unit

Table 4. Impact of different diversification measures on biodiversity and environment

Pro-environmental diversification	Factors studies	Impact	Authors, year
Stubbles[a]	Birds population	Positive impact on the population growth rates of multiple granivorous species, i.e., corn bunting, goldfinch, linnet, grey partridge, reed bunting, skylark, yellowhammer	Baker *et al.* (2012), Peach *et al.* (2011)
		No impact on farmland bird species	Davey *et al.* (2010)
		Negative impact on goldfinch	Baker *et al.* (2012)
Patches of seed-rich crops[a]	Birds population	Positive impact on multiple granivorous species (corn bunting, reed bunting, skylark, tree sparrow, yellowhammer)	Baker *et al.* (2012)
		Lack of positive impact on farmland bird species	Davey *et al.* (2010)
		Negative impact on chaffinch, tree sparrow	Baker *et al.* (2012)
Low-input grasslands (incl. heterogeneous swards)[a]	Birds population	Positive impact on chaffinch, lapwing, linnet, skylark, yellow wagtail	Baker *et al.* (2012)
		Lack of positive impact on farmland bird species	Davey *et al.* (2010)
		Negative impact on chaffinch, lapwing, meadow pipit, reed bunting, yellow wagtail	Baker *et al.* (2012)
	Plants	Unimproved grasslands (UG) contained multiple species of grasses, forbs and legumes, 59% of which were not found on other site types. Species richness on conservation grasslands (CG) was lower and covered 37% of the species found on UG. As expected, improved grasslands included only a few species of plants and were dominated by ryegrass and clover	French (2017)
	Nutritional quality	Forage from species-rich grasslands contained up to 27% more protein, 56% more phosphorus, 106% more potassium and 183% more calcium than cereals and conventional hay and met the nutritional requirements of beef cattle, sheep and horses	French (2017)
Filed margin management (such as widening, input reduction 2–6 m adjacent to arable/pastoral field)[a]	Birds population	Arable margins—positive impact on corn bunting, dunnock, linnet and turtle dove Grassland margins—positive impact on chaffinch, dunnock, greenfinch and whitethroat	Baker *et al.* (2012)
		Arable margins—negative impact on bunting, goldfinch, yellow wagtail Grassland margins—negative impact on corn bunting	
	Invertebrate	Lack of significant effect on carabid beetles	Feehan *et al.* (2005)
	Plant species richness	Lack of significant effect on plant species richness	Feehan *et al.* (2005)
	Invertebrate	Positive impact on several native spiders, pollinators and mite species Negative impact on exotic slugs species	Curtis *et al.* (2019)
Hedges and ditches management[a]	Birds population	Positive impact on bullfinch, house sparrow, reed bunting, song thrush	Baker *et al.* (2012)
		Negative impact on goldfinch, tree sparrow, yellowhammer	
		Lack of positive impact on farmland bird species	Davey *et al.* (2010)
	Plants	Lack of significant effect on plant species richness	Feehan *et al.* (2005)
	Carabid beetles	Lack of significant effect on carabid beetles	Feehan *et al.* (2005)
	Small mammals	Improved connectivity had positive impact on wood mice abundance Hedgerow gappiness had negative impact on ban	Gelling *et al.* (2007)

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Table 4. (*Continued.*)

Pro-environmental diversification	Factors studies	Impact	Authors, year
		voles Increased hedgerow width, height and length had positive impact on all small mammals	
Water course margins (fencing)[a]	Plants	Lack of significant effect on plant species richness	Feehan *et al*. (2005)
Replacement of species-poor agricultural grassland with other plants[a]	Invertebrate	Replacing grass with cereals and conservation mix attracted significantly more invertebrates than grass-based treatments. The conservation mix attracted more diverse bumblebees and butterflies than the under-sown spring cereal treatment	Potts *et al*. (2009)
	Birds	Positive impact of barley crops on seed-eating birds	Peach *et al*. (2011)
Mixed grazing	Birds	Positive impact on pipit territories	Evans *et al*. (2006)
	Methane emission	Estimated total emissions across the summer grazing period were expressed relative to the growth rates achieved—sheep only system was characterized by higher amount of methane per unit liveweight gain	Fraser *et al*. (2014)
Semi-natural rough grazing (SNRG) *vs* PP grazing	Birds and insects	Introduction of cattle to SNRG had positive impact on the abundance of birds and butterflies	Fraser *et al*. (2014, 2013)
	Plants	Semi-natural rough grazing increased plant diversity on marginal land	
Replacement of modern crossbred cattle with a traditional breed	Birds and insects	No impact on birds and butterflies	Fraser *et al*. (2014)
	Methane emission	Negative impact	
Organic *vs* conventional farming	Plants	Positive impact on total number of plant species	Gabriel *et al*. (2010); Power *et al*. (2013, 2012); Power and Stout (2011)
	Insects	Lack of positive impact on number of insect taxa	Gabriel *et al*. (2010); Power and Stout (2011)
		Positive impact on bees abundance and evenness, and hoverfly evenness	
		Lack of impact on bees richness; hoverfly abundance and richness	
	Birds	Negative impact on diversity of farmland birds	
Agroforestry	Water quality	Decrease in sediment export (by 76%), phosphorus loss (by 62%) and fecal coliform levels (by 43%) The aquatic fauna indicator showed a positive trend and increased to 82 *vs* 78% pre-change	Dodd *et al*. (2008)
	Plant	Plant diversity on the pastures significantly increased	
	Soil	Poplar pastures had higher pH and produced more throughout 11 months than open pastures	Guevara-Escobar *et al*. (2002)
		No effect on organic carbon, total nitrogen, phosphorus, sulfur, soil hydraulic characteristics, microporosity, water aggregate stability and bulk density	

[a]Actions identified as environmentally sensitive management practices (ESMPs).

area of permanent pasture and improved lamb performance without compromising cattle performance (Fraser *et al*., 2007, 2013, 2014). Highest collective lamb and calf live weight gains were recorded where sheep and Limousin-crossbred cattle grazed permanent pastures at a ratio of 6:1, with cattle subsequently removed to semi-natural vegetation for ten weeks. Live weight gain for mixed grazing of cattle and sheep was 216 *vs* 142 kg ha^{-1} for sheep only grazing (Fraser *et al*., 2014). While suckling calf growth rates were lower on SNRG than improved pasture, their growth rate was still reported as being commercially viable —calf final weight was 207 kg for Limousin calves raised on permanent pasture only and 201 kg for Limousin calves removed to SNRG for 10 weeks (Fraser *et al*., 2013).

Studies also suggested that increased weight gains of animals in the combined SNRG and mixed-grazing systems were associated with decreased methane emissions, estimated based on

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Table 5. Overview of the studies reviewed in the paper—multispecies swards

Author	Main objectives	Experimental design	Plant species incorporated/ mixed species treatments	Effect on N excretion and CH4 emission	Effect on milk production
Dodd *et al.* (2019)	Urinary N concentration; milk solids production	4 dietary treatments were tested in 2 experiments: 1. Summer experiment 2. Spring experiment Both experiments consisted of—7 days covariate period, 12 days adaptation period, 7 days measurement period *Animals*: 60 multiparous lactating cows	1. RG + LC—pasture mix1 2. RG + LC + PL—pasture mix2 3. TF + LC—pasture mix3 4. TF + LC + PL—pasture mix4	No significant difference in UN concentration between treatments 1–3; UN concentration of cows grazing pasture mix4 was significantly lower than from remaining pastures in both summer and spring ($P < 0.01$)	Milk volume of cows grazing pasture mix4 in summer was 26% greater than the other three treatments ($P < 0.05$) 12% decrease in milk fat for cows grazing PL mixtures during summer ($P < 0.05$) and 3% in spring ($P < 0.05$)
Minneé *et al.* (2017)	Dry matter intake; milk production; digestion	5 dietary treatments were tested in 1 indoor 22-day experiment conducted in summer. Experimental period consisted of 4 days adaptation period to the facility, 5 days adaptation period to the diet, measurements were conducted during days 9–14 and 17–22. To prevent lameness on days 15–16 cattle were grazed outdoors and were offered cut chicory or plantain treatments *Animals*: 42 multiparous, lactating cows	1. RG + WC—forage mix1 2. RG + WC + CH 20%—forage mix2 3. RG + WC + CH 40%—forage mix3 4. RG + WC + PL 20%—forage mix4 5. RG + WC + PL 40%—forage mix5	UN concentration was lowest for forage mixes 2, 3 and 5 ($P < 0.010$) UN was reduced with increasing amount of CH or PL in the diet	Milk production, milk fat and protein concentration was similar for all diets There was a trend for reducing milk protein content with increased amount of forb in the diet ($P = 0.043$). Milk lactose concentration was increased ($P = 0.042$) in cattle on diets containing forb, but there was no effect of proportion of forb in the diet on lactose content. There was no difference in the composition of milk between cattle on forages with CH or PL
Cheng *et al.* (2018)	Live weight gain; animal behavior; urinary N excretion	5 dietary treatments were tested in two experiments: 1. Autumn experiment The experiment consisted of 25-day experimental period and 28-day carryover period 1. Spring experiment The experiment consisted of 17-day experimental period, 35-day carryover period Acclimation period for both experiments was 7 days *Animals*: each trail used 60 heifers	1. RG + WC—pasture mix1 2. 50% RG/WC + 50% CH—pasture mix2 3. 75%RG/WC + 25% CH—pasture mix3 4. 75% RG/WC + 25% PL—pasture mix4 5. 50% RG/WC + 50% PL—pasture mix5	There was no significant difference in UN between treatments neither in autumn nor in spring	Not studied

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Table 5. (*Continued.*)

Author	Main objectives	Experimental design	Plant species incorporated/ mixed species treatments	Effect on N excretion and CH4 emission	Effect on milk production
Jonker *et al.* (2019)	CH4 emissions; milk production	2 dietary treatments were tested in summer *Animals*: 30 Friesian × Jersey cows in their 6th month of lactation Methane emissions were estimated using the GreenFeed automated head chamber system which offered feed to attract the animals. One unit was placed with each herd during adaptation and measurement periods, and access was possible at all times, except during milking	1. RG + WC—pasture mix1 2. RG/WC + LC + CH + PL—pasture mix2	There was no significant difference in CH4 production (g day^{-1}) between treatments	Milk composition was not affected by diet
Box *et al.* (2017)	Milk production; urinary N concentration	3 dietary treatments were tested in 2 experiments 1. Early lactation—spring 2. Late lactation—autumn 3-day adaptation period, 7-day experimental period *Animals*: A group of 36 lactating dairy cows were blocked into three groups of 12 cows	1. RG + WC—pasture1 2. PL—pasture2 3. 50%RG + WC + 50%PL—pasture 3	The concentration of UN was lowest for pasture2, intermediate for pasture3 and highest for pasture1 ($P < 0.001$). Daily N output was 30 and 40% lower for cows on pasture2 than remaining pastures in the late and early lactation experiments respectively	Milk volume (L) and milk solids yield was greatest ($P < 0.05$) for pasture2 and 3 in the late lactation. No treatment differences in the early lactation. In both experiments, pasture mix3 altered milk composition. In the late lactation experiment, milk fat percent was lower and lactose percent was higher for pasture3 compared with pasture1. In the early lactation experiment, milk protein percent was lower for the pasture2 than for pasture 1. Milk urea N was lowest ($P < 0.005$) for pasture 2 in both experiments
Bryant *et al.* (2017)	Milk production; nitrogen excretion	6 dietary treatments were offered to replicate groups of cows and tested in 3 experiments. Randomized block design with 3 blocks was used 1. Spring experiment 2. Summer experiment 3. Autumn experiment All experiments consisted of 7-day covariate period, 4-day adaptation period, 5-day experimental period *Animals*: In spring and summer, there were six lactating cows in each group ($n = 72$). In autumn there were four lactating cows per group ($n = 48$)	1. RG + WC—pasture mix1 2. HS-RG + WC—pasture mix2 3. TF + WC—pasture mix3 4. RG + WC + PG + CH + PL + RC—pasture mix4 5. HS-RG + WC + CH + PL + L—pasture mix5 6. TF + WC + PG + CH + PL + LC—pasture mix6	The lowest UN concentrations were recorded for pasture mixes 4, 5, 6 in spring and pasture 4 in summer ($P < 0.05$). In general addition of forbs into binary mixtures resulted in decrease of UN concentration	Milk yield, the proportion of fat, protein and lactose in the milk was not affected by treatments. Addition of forbs, red clover and bromegrass in a multispecies mixture, compared with the binary control ryegrass, increased milk solid yield only when red clover exceeded 35% of the DM (i.e., in summer). A binary mixture of tall fescue and white clover resulted in significantly higher milk yields than the binary control ryegrass, but addition of forbs, lucerne and bromegrass in the multispecies tall fescue mixture resulted in lower milk solid yield. Binary tall fescue treatments had higher MUN than any other treatments in spring and summer

Totty *et al.* (2013)	DMI; milk yield; N partitioning	3 dietary treatments were tested in complete randomized block design study in autumn The experimental period consisted of 5-day acclimation period + 5-d experimental period *Animals*: 12 lactating cows were allocated in each experimental group	1. RG/WC—pasture mix1 2. HS-RG/WC—pasture mix2 3. HS-RG + WC + CH + PL + L—pasture mix3	Urinary N excretion was lower from the cows fed pasture mix3 than those fed 2 other mixes ($P < 0.05$)	The cows grazing the pasture mix3 had an increased milk yield ($P < 0.05$). However, no differences were observed in milk solids yield for the 3 treatments
Hammond *et al.* (2014)	Digestion; energy utilization; N excretion; methane emissions	4 dietary treatments were tested in 2 experiments. Cows were fed indoors Experiment 1—4 forage treatments were fed indoors as haylages to 4 heifers in 4 × 4 Latin square design over 5 months with 5 week periods. 4 days acclimatization, 4 weeks adaptation. In week 5, animals were staggered in pairs into two individual respiration chambers for 5 days Experiment 2—3 of the forage treatments used to make silage in experiment 1 were grazed for 6 months (May–October): pasture mix1, pasture mix2 or pasture mix4 were grazed over 6 months *Animals*: 12 growing heifers, managed by strip grazing each sward for 28 days, in a sequence of flowers, clover then ryegrass. Within each treatment paddock, heifers were allowed 2 weeks for diet adaptation followed by a 2-week methane measurement period which comprised of two 4-day methane measurements using the sulfur hexafluoride (SF6) tracer technique	1. RG—pasture mix1 2. RG 70% + RC30%—pasture mix2 3. RG 80% + T 20%—pasture mix3 4. RG 40% + wildflower mixture: *Rumex acetosa*, *Leucanthemum vulgare, Achillea millefolium, Centaurea nigra* and *Plantago lanceolata*—pasture mix4	Heifers fed pasture mixes1 and 3 emitted more methane (224 g day^{-1}) than heifers fed pasture mix3—200 g day^{-1} ($P < 0.05$) and flowers—190 g day^{-1} ($P < 0.01$) In experiment 2 methane production (g day^{-1}) was similar for pasture mixes1 and 2 (203), and was lower ($P < 0.001$) for heifers consuming pasture mix4 (159). When expressed as methane yield (g kg^{-1} DM intake), heifers grazing flowers had the lowest ($P < 0.05$) methane yield (19.5) compared to two other treatments (22.4)	Not studied

RG, ryegrass; WC, white clover; LC, lucerne; PL, plantain; TF, tall fescue; CH, chicory; HS-RG, high sugar ryegrass; PG, prairie grass; RC, red clover; L, lotus; T, trefoil; UN, urinary nitrogen.

Table 6. Animal welfare indicators for organic and conventional farms

	Organic	Non-organic	*P*	References
Age heifers first calve (months)	27.3	25	<0.05	Langford *et al.* (2009)
Time calves spend with dams (days)	2.4	1	<0.05	Langford *et al.* (2009)
Cows culled with reference to health records (%)	19.6	26.3	<0.01	Langford *et al.* (2009)
Cases of endometritis in one year (% herd), with reference to health records	6.1	10.8	0.05	Langford *et al.* (2009)
Cases of milk fever in one year (% herd), with reference to health records	7.8	14.9	0.05	Langford *et al.* (2009)
Percentage of herd affected by lameness	36.5	31.9	NS	Langford *et al.* (2009)
	Lower	Higher	0.012	Rutherford *et al.* (2009)
Grazing intensity (mean LU ha^{-1a})	1.5	2.5		Power *et al.* (2013)

[a]Livestock unit per hectare.

gross energy intake (Fraser *et al.*, 2014). Richmond *et al.* (2014) compared methane emissions from beef cattle grazing on SNRG uplands and improved lowland pastures. Lower mean daily methane emissions were associated with cattle grazing on SNRG; however, these animals reached finishing weight later; thus, their overall lifetime emissions were higher than those on improved lowland pastures. In terms of beef quality, it was shown that carcasses of SNRG-grazed animals were of inferior quality compared to those from animals fed on permanent pasture; SNRG-grazed beef was characterized by higher vitamin E content compared to beef obtained from permanent pasture (Fraser *et al.*, 2009).

Agroforestry

Two studies from NZ examined inclusion of trees on cattle farms. It was reported that land-use change and integration of trees onto farmland resulted in several economic and environmental benefits, including improved water quality characterized by a significant decrease in sediment export (−76%), phosphorus loss (−62%) and fecal coliform levels (−43%). Additionally, plant diversity within pastures significantly increased (+25%) (Dodd *et al.*, 2008). Further results indicate that the inclusion of trees in pastures increased their productivity, accelerated soil formation and decreased erosion (Guevara-Escobar *et al.*, 2002).

Rare breeds

The utilization of rare breeds was explored in three studies from the UK. Results from two studies demonstrated that a rare breed—Belted Galloway (BG) calves exhibited lower live weight gains in the mixed cattle/sheep system with cattle grazing SNRG over 3 months summer period than Limousin calves (0.85 *vs* 1.17 kg day^{-1}). However, in this type of system, BG cows were characterized by higher performance, with live weight change +0.3 *vs* −0.225 kg day^{-1} for Limousin cows (Fraser *et al.*, 2013, 2014). In the case of 9-month-old Walsh Black (WB) and Charolais bulls, it was reported that both genotype and pasture had a significant effect on measured growth rates, which were the highest for WB on permanent pasture. In the case of 14- and 20-month-old bulls, only pasture type significantly affected live weight gains with higher growth rates encountered on permanent pasture. No between-breed differences were observed when cattle grazed grassland dominated by invasive hill grass species such as *M. caerulea* (Fraser *et al.*, 2009). The results did not confirm that native cattle breed attracted more wild fauna (e.g., birdlife) than conventional cattle at similar stocking densities (Fraser *et al.*, 2014).

Attitudes toward diversification

Nine papers reporting on attitudes toward diversification options were identified and primarily focused on afforestation, energy crops and comparison of attitudes between organic and non-organic farmers toward the environment, profit and on-farm biodiversity (Table 7).

Attitudes toward afforestation and energy crops

Six studies pertaining to farmer attitudes toward afforestation ($n = 4$) and energy crops ($n = 3$) were identified, with one paper researching both aspects. Two papers from ROI concentrated on afforestation, one focused on energy crops, while UK studies focused on forestry ($n = 1$), forestry and energy crops ($n = 1$), and two papers focused solely on energy crops (Table 7).

Results indicated that farm size (too small) and land quality (too good) are the main barriers to switching from 'traditional' agricultural systems to forestry (Duesberg *et al.*, 2014; Howley *et al.*, 2015). Furthermore, farmers did not find forestry as 'satisfying' as livestock farming (Convery *et al.*, 2012; Duesberg *et al.*, 2013; Howley *et al.*, 2015), with substantial payments within forestry schemes not seen as being appropriately compensatory for the loss in non-pecuniary benefits associated with more traditional agriculture (Convery *et al.*, 2012; Howley *et al.*, 2015). The relatively quick land use cycling associated with agricultural land compared to that under forestry and farming lifestyle were identified as two main benefits of traditional farming (Duesberg *et al.*, 2013; Howley *et al.*, 2015). Moreover, Irish farmer resentment toward forestry was shown to be associated with historical reasons such as previous oppression by English landlords, tenant farming and the Great Famine. These rationales may explain Irish farmers' relationship with 'good agricultural land', which they believe should be used for food production rather than forestry (Duesberg *et al.*, 2013).

Farmers were reported as being more willing to increase renewable energy production than plant forestry (Sutherland *et al.*, 2016). In the UK, engagement in renewable energy was more likely on profit-oriented farms, while afforestation was rarely seen as an economic diversification strategy (Sutherland *et al.*, 2016; Hopkins *et al.*, 2017). In Ireland, the primary reason to switch to energy crops was associated with farmers demonstrating a lack of confidence in their enterprise (Augustenborg *et al.*,

Table 7. Overview of the studies reviewed in the paper—attitudes toward different diversification options

No.	References	Country	Method	Attitudes toward	Participants
1	Duesberg *et al.* (2013)	ROI	Semi-structured interviews	Afforestation	62 farmers
2	Howley *et al.* (2015)	ROI	Survey	Afforestation	799 farmers
3	Hopkins *et al.* (2017)	UK	Telephone survey	Afforestation	2416 Scottish farmers
4	Sutherland *et al.* (2016)	UK	Telephone survey	Afforestation and bioenergy	2416 Scottish farmers
5	Convery *et al.* (2012)	UK	Semi-structured interviews	Bioenergy	Upland farmer group; lowland farmer group Combined group; 36 participants in total
6	Augustenborg *et al.* (2012)	ROI	Survey	Energy crops/bioenergy	172 farmers completed the survey
7	Power *et al.* (2013)	ROI	Survey	Farm biodiversity	9 organic dairy farmers; 8 conventional dairy farmers
8	Läpple *et al.* (2012)	ROI	Survey	Environment, risk, profit motivation, information gathering	341 beef organic farmers; 50 ex-organic beef farmers, 164 beef conventional farmers
9	Läpple (2010)	ROI	Survey	Organic farming	341 beef organic farmers; 41 beef ex-organic farmers, 164 beef conventional farmers

2012). Identified studies also showed that Scottish farmers already engaged in afforestation and energy crop production did not plan to abandon these activities and were more likely to consider further expansion (Sutherland *et al.*, 2016; Hopkins *et al.*, 2017). Moreover, it was concluded that young, organic farmers who are well educated, receive subsidies, have off-farm income and started farming relatively recently demonstrated more enthusiasm for agri-environmental diversification and showed more interest in AES participation, woodland expansion and renewable energy production than other farming cohorts (Sutherland *et al.*, 2016; Hopkins *et al.*, 2017).

Attitudes toward organic farming

Three papers from Ireland evaluated organic and non-organic (conventional) beef farmer characteristics, their attitudes toward the environment and factors influencing leaving the organic farming scheme. A comparison of farm and household characteristics revealed that conventional farms are typically larger and are characterized by higher stocking densities than organic and ex-organic farms. Organic farmers were more likely to have an off-farm income, were typically younger, better educated and more likely female (Läpple, 2010, 2013).

It was shown that having achievements such as 'best livestock and pastures' was more important among conventional than organic farmers; however, production-oriented behaviors and attitudes—'a farmer conscientious running of the farm towards business success' were comparable across both groups (Power *et al.*, 2013). Furthermore, the approach to the environment, biodiversity and nature was similar for organic and conventional farmers. However, organic farmers were more likely to introduce environmentally oriented behaviors such as habitat management and were more 'environmentally informed' (Läpple, 2013; Power *et al.*, 2013). Organic and ex-organic farmers were less risk-averse than conventional farmers and more eager to learn new techniques and acquire new knowledge (Läpple, 2013). Additionally, farmers with significant environmental concerns were less likely to leave organic schemes than those who joined the scheme mainly for economic reasons. Conversely, farmers with off-farm incomes were more likely to leave organic farming, while those with higher stocking densities were more likely to remain. The lack of organic market outlets was highly correlated with the decision to leave these schemes (Läpple, 2010).

Discussion

According to the Intergovernmental Science Policy Platform on Biodiversity and Ecosystem Services, 1 million plant and animal species are currently threatened with extinction (Jaspers, 2020). Moreover, GHG emissions are still increasing globally, with the projection that the carbon budget set to meet the Paris Agreement target of 2°C will be exhausted before 2050 (Baiardi and Morana, 2021). Consumer awareness of climate and biodiversity crisis continues to increase, leading to change in dietary habits and many questioning the sustainability of Western diets (Clonan *et al.*, 2015). In high-income societies, it is well-recognized that climate change and biodiversity loss are twin disasters and need to be addressed urgently (Baiardi and Morana, 2021).

Agroecosystem diversification is considered an important tool in combatting the negative impact of agriculture on biodiversity and climate change (Kronberg and Ryschawy, 2019). The present review identified several overarching (i.e., thematic) pro-environmental diversification measures for cattle production, frequently linked to the diversity of land and landscape use and, consequently, financial performance.

Environmentally sensitive management practices, mixed grazing and SNRGs

ESMPs comprise a suite of relatively simple actions often undertaken by farmers to enhance the environmental credential status of their farms. Identified studies branded seven practices—stubble retention, patches of seed-rich crops, low-input grasslands, field margins, boundary management, watercourse margins and

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replacement of species-poor grasslands with other plants—as ESMPs. Based on qualitative analysis, it may be concluded that ESMPs positively impact biodiversity, particularly granivorous birds, albeit not in all contexts or situations. Presently, most grass-based dairy and beef farms are characterized by a lack of arable crops. Consequently, the absence of spring-sown cereals and winter stubbles results in a deficiency of nesting habitats and winter supply of seeds and grains (Peach *et al.*, 2011). Thus, inclusion of conservation mixes (e.g., seed-rich plants and/or crops) into an agricultural landscape predominated by grasslands enable provision of winter food for granivorous birds and would seem to be an effective method for attracting more bird species in decline onto farmlands (Peach *et al.*, 2011; Baker *et al.*, 2012).

Nonetheless, several barriers limiting the success and uptake of ESMPs have been identified. Implementation of meaningful biodiversity mitigation strategies depends on the scale at which these measures are applied (Baker *et al.*, 2012). Despite frequently positive responses of birds to ESMPs, overall populations of examined species continue to decline, with a significant increase in the uptake of selected ESMPs thus required to assist in reversing this trend (Baker *et al.*, 2012). Furthermore, changing land use for grassland to arable, even though beneficial for granivorous birds, is often linked with the increased release of carbon dioxide from the soil, reducing its organic matter levels caused by tillage. Reducing or eliminating primary tillage operations, known as no-tillage, can improve soil aggregation and reduce GHG emissions (Hati *et al.*, 2021). Nevertheless, recent studies on implementing this practice on farms not certified organic in north-western Europe present conflicting results on its environmental benefits; thus, more research is needed to understand better the trade-offs of no-tillage practice (Skaalsveen *et al.*, 2019).

Moreover, since many research funders and programs provide funding for a maximum of 4–5 years, the time required to observe biodiversity changes represents another (inherent) limitation. Several authors have stated that study periods are typically too brief to observe the long-term impacts of proposed diversification and amended management practices (Davey *et al.*, 2010; Baker *et al.*, 2012). For example, a 9-year study by Baker *et al.* (2012) reports that ESMPs positively affect granivorous bird species (Table 4). However, an earlier study surveying bird population changes over a considerably shorter time period (3 years) found no significant trend across farmland bird species in response to ESMPs (Davey *et al.*, 2010). Replacement of grassland with conservation mixes seemed to have a relatively rapid positive impact on invertebrate populations; however, these authors also noted year-on-year variability, with highest positive impacts found during year 2 of the 4-year study (Potts *et al.*, 2009). Furthermore, a paucity of baseline biodiversity data that would help long-term monitoring and improve pro-environmental actions also presents a significant knowledge gap for researching the impact of ESMP (Feehan *et al.*, 2005; Davey *et al.*, 2010; Berg *et al.*, 2019).

According to several studies identified in the current review, SNRG and mixed grazing would seem to offer 'win-win' solutions for biodiversity conservation, enhancing animal productivity and reducing GHG emissions (Fraser *et al.*, 2007, 2013, 2014; Richmond *et al.*, 2014). However, the implications of these systems have only been studied by two research teams, both from the UK and both limited to mixed grazing of cattle and sheep. Sequential grazing systems, including sequential grazing of ruminants and monogastric, have not been studied to date, albeit a growing interest among extensive, small-scale pasture-based dairy and beef farmers to integrate poultry into crop, expressed mostly through social media farming groups and other internet channels, is recognized. Hilimire *et al.* (2013) have demonstrated that poultry integration to crop agroecosystems increases soil fertility and crop growth. Furthermore, poultry included into pasture systems consumes weeds and insects, potentially improving the management of crop pests and controlling fly/parasite problems (Bare and Ziegler-Ulsh, 2012). However, peer-reviewed scientific evidence testing this hypothesis was not identified as part of the current review.

Multispecies swards

MSS offer relatively low input-high impact potential to diversify plant species within pastures, attract more fauna, decrease chemical usage, including fertilizers and reduce nitrogen excretion from cattle. Potentially, MSS can also improve animal health, beef and milk quality and methane emissions (Richmond *et al.*, 2014; Dodd *et al.*, 2019; Grace *et al.*, 2019). Most of the identified research on MSS (87.5%) originated from NZ; however, the topic is now also increasingly studied in the ROI and the UK. Examples of ongoing projects that explore the utilization of MSS for cattle, among others, include SMART SWARD and HEARTLAND projects from Ireland and The Diverse Forages Project from the UK (Cummins *et al.*, 2021; McCarthy *et al.*, 2021a, 2021b).

Studies on MSS included in this review primarily focused on animal performance, basic milk composition and GHG emissions. Conversely, product quality in terms of bio-active components, impact on biodiversity and animal health and welfare were not addressed. Furthermore, studies were limited to dairy cows and did not include beef cattle; however, to the best of authors' knowledge, a UK-Irish study has been initiated in this area. More information on the impact of MSS on biodiversity, animal welfare, chemical fertilizer and herbicide use, and plant nutritive value over time, through long-term grazing studies, is required to improve current knowledge on their applications and limitations (McCarthy *et al.*, 2020).

Organic farming and native breeds

The EU Commission's Farm to Fork and Biodiversity Strategies aim for 25% of agricultural land to be under organic farming by 2030 (European Commission, 2020). NZ has also committed to achieving carbon neutrality by 2050 and is introducing changes within the agricultural sector to attain this long-term goal (Yang *et al.*, 2020). According to the Research Institute of Organic Agriculture and the International Federation of Organic Agriculture Movements, 1.5% of global farmland is currently organic, with Oceania and the European Union representing the highest spatial shares of organic agriculture—9.6 and 8.1%, respectively. The UK, ROI and NZ organic shares of entire agricultural land are relatively low by EU standards at 2.6, 1.6 and 0.8%, respectively (FiBL & IFOAM—Organics International, 2021).

Results from the current review would seem to confirm that organic systems on grass-based dairy farms have a positive impact on biodiversity and animal welfare compared to conventional, non-organic systems (Langford *et al.*, 2009; Rutherford *et al.*, 2009; Gabriel *et al.*, 2010; Power and Stout, 2011; Power *et al.*, 2012). However, research on this topic is limited, with just seven studies identified over the 20-year review period. Research on the impact of alternative grass-fed milk and beef production systems, including organic agriculture, on product quality, animal productivity and performance, GHG emissions and soil or water quality were not identified. According to Niggli *et al.* (2017), current research funding dedicated to organic agriculture represents less than 1% of private and public R&D budgets. Consequently, innovation in the organic sector is mainly driven by farmers without significant input from researchers or farm advisors. Prior to a full appraisal of its potential role in producing sustainable, biodiversity and climate-friendly grass-based milk and beef is possible, more research on the impact of organic systems on the environment, biodiversity, animal welfare and product quality is required.

In contrast to intensive dairy and beef production, which is based on a limited number of high-output cattle breeds, organic farming is often associated with native, low-input breeds well adapted to the local environment. Moreover, according to The Second Report on the State of the World's Animal Genetic Resources, 'Livestock diversity facilitates the adaptation of production systems to future challenges and is a source of resilience in the face of greater climatic variability […] coping with climate change, new disease challenges, and restrictions on the availability of natural resources' (FAO, 2015). The report goes on to state that changing market demands will require a diverse range of animal genetic resources.

Notwithstanding the recommendations of FAO Genetic Resources Commission, just three studies, all of which were undertaken in the UK, sought to measure the impact of native breeds (BG and WB) on animal productivity and biodiversity; beef quality and GHG emissions were studied only once (Fraser *et al.*, 2009, 2013, 2014). The product quality from native Irish breeds such as Kerry, Dexter and Irish Moiled cattle and their role in biodiversity conservation remains unknown. Meanwhile, demand for organic produce from 'old' native breeds has been linked to positive consumer perception, with respondents believing that these products do not contain chemical residues and contain more nutrients than their non-organic equivalents (Kuczyńska *et al.*, 2012b). A recent meta-analysis conducted by Srednicka-Tober *et al.* (2016) reports that organic meat is characterized by a higher proportion of n-3 PUFA than non-organic meat. Several studies have also confirmed significant differences in the chemical composition and improved nutritional quality of organic milk and dairy products compared to their non-organic equivalents (Bergamo *et al.*, 2003; Belletti *et al.*, 2009; Butler *et al.*, 2011; Kuczyńska *et al.*, 2012a). The higher proportion of *n*-3 PUFA in milk and meat has been associated with grass-based diets, which are central to organic farming standards. Further studies are required to establish the difference, if any, in the composition of organic meat and milk relative to grass-fed products that are not certified organic, as these issues have not been addressed in the scientific literature to date.

Agroforestry

Agroforestry represents another emerging agricultural system that remains understudied in ROI, the UK and NZ. Intercropping or polyculture offers multiple advantages and is considered an important future solution to restoring on-farm biodiversity (Nerlich *et al.*, 2013). However, agroforestry systems are still rare in temperate maritime climates as both mean air temperature and sunlight intensity are considered too low for two- or three-layer plantings.

Just two studies from NZ sought to provide evidence on the effects of tree plantations on pastures. Nevertheless, by using appropriate tree density, this system has been found suitable for ruminant production in the temperate oceanic climate of Ireland and showed advantages such as reducing nutrient leakage, increasing biodiversity and creating spatial heterogeneity in the canopy and soil (McAdam *et al.*, 2006). According to McAdam *et al.* (2006), incorporating agroforestry into pasture-based ruminant production improves sustainability and contributes to the growth of rural economies (McAdam *et al.*, 2006). However, the establishment of silvopasture requires several years before cattle can be (re)introduced. Therefore, studies and solutions for different stages of implementation of this system are needed. Furthermore, every farm's environment and micro-climate differ; thus, a one-size-fits-all solution is unlikely. Building and strengthening farmer–researcher networks and collecting data from multiple farms will be critical to future research in agroforestry (Niggli *et al.*, 2017).

Economic implications of pro-environmental diversification

It is anticipated that the inclusion of pro-environmental diversification and reduction of chemical inputs will decrease feed production, lower animal productivity and, consequently, farmer income (Zhou *et al.*, 2020; Brown *et al.*, 2021; Kragt *et al.*, 2021); however, these concerns were seldom addressed in identified literature. Two studies conducted a cost analysis of proposed diversification actions, with results indicating that the inclusion of trees on the pastures and replacement of grass silage with cereal silage had either a positive or neutral effect on overall production and farmer income (Dodd *et al.*, 2008; Peach *et al.*, 2011). According to Niggli and Riedel (2020), reports on polycultures implemented in different parts of the world indicate that these systems are characterized by 40–145% higher yields than monocropping. Similarly, conservation grazing and utilization of SNRG in summer allow for the production of winter feed in the form of silage or hay from permanent pastures, adding to the profitability of this practice (Fraser *et al.*, 2013).

Moreover, most biodiversity-rich land represents wetlands, moorlands, woodlands, hedgerows and areas of low agricultural value. Thus, according to Delaby *et al.* (2020), biodiversity protection does not have to affect farm productivity and profitability adversely. Unpublished findings from a series of interviews undertaken by the current authors and conducted with Irish, UK and French farmers who initiated diversification approaches indicate that pro-environmental diversification can offer solutions to generate additional income on the farm. For example, inclusion of wildflower strips and field margins provide valuable feed for bees that can produce honey; tree plantations can generate income from timber, fruits and thinning. More case studies demonstrating the financial benefits of pro-environmental diversification reaching beyond financial incentives are needed to improve current understanding of the economic consequences of these actions for both individual farmers and society.

Farmer's attitudes toward pro-environmental diversification

The intention to balance food production, environmental preservation, consumer satisfaction and adequate income generation for farmers has been highlighted in political and civil society debates (Brunori *et al.*, 2019). However, research on farmer attitudes toward available diversification options was limited to biomass production in ROI and UK and organic beef production in ROI. No studies on attitudes among NZ farmers to diversification

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were identified. Additionally, there was a notable lack of research on conventional dairy farmer attitudes and behavioral barriers toward the organic dairy farming system.

Likewise, while a reasonable body of evidence regarding attitudes toward afforestation and bio-energy crops was identified, no relevant peer-reviewed research in the regions defined by the current study on ESMPs and agroforestry was found. Rois-Díaz *et al.* (2018) examined motivations among European farmers to undertake agroforestry, with the authors observing that negative attitudes were linked with concerns around reduced farm productivity. Non-organic farmers, in particular, may be less inclined to adopt agroforestry (incentivized or otherwise) due to the perceived trade-off of a reduction in arable land parcels. As agroforestry does not necessarily result in curtailment of productive land and can increase farm-net margins, where implemented appropriately, a lack of knowledge has previously been cited as a primary barrier to pro-environmental diversification in this instance (Isaac *et al.*, 2007). Evidence suggests that attitudes toward pro-environmental diversification may also be associated with farmer ethos and professional background. For instance, European farmers with an educational and/or professional background in nature conservation have repeatedly been demonstrated to display a more positive disposition toward agroforestry and conservation agriculture (Casagrande *et al.*, 2016; Rois-Díaz *et al.*, 2018).

Moreover, problems associated with afforestation and agroforestry are also linked to the irreversibility of land-use change from agricultural to forestry. This factor was considered as a barrier for Irish farmers who planned to leave an inheritance of traditional agricultural practices to their children and was ranked as the second most significant barrier to participation in afforestation projects (Connolly and Kinsella, 2006; McDonagh *et al.*, 2011). Furthermore, the irreversibility of investments in conservation and agroforestry schemes has been globally recognized as a hindrance to the uptake of these schemes (Schatzki, 2003; Wiemers and Behan, 2004; Behan *et al.*, 2006). Thus, policymakers should address the importance of the flexibility of AES when designing new schemes (Vidyaratne *et al.*, 2020).

The small number of studies identified via the current review concerning farmer motivations is mirrored in the broader literature examining agricultural diversification. Investigations of farmer motivations to implement ESMPs tended to focus on the benefits of AES membership as opposed to personal motivations for including pro-environmental measures on their farm. In light of the increasing prominence (and necessity) for both on- and off-farm diversification methods and the ever-expanding functional role of farmers (e.g., ecosystem service providers, direct food vendors), identification of the motivations underpinning conventional, organic and pro-environmental agricultural practices represents an important research agenda for the future of farming (Giller *et al.*, 2021). As farmer decisions to revert from organic and sustainable agriculture to conventional agriculture have generally been based on economic reasons, recurring issues such as farm scale, land requirements and market proximity must be addressed in monetary as well as political terms (Sahm *et al.*, 2013).

Conclusions

Given the importance of environmental sustainability within dairy and beef production, holistic studies investigating management practices that can potentially decrease GHG emissions and strengthen both biodiversity and the provision of ecosystem services on dairy and beef farms are urgently needed. Moreover, evidence-based studies pertaining to the economic and social impacts of pro-environmental diversification are urgently required. The current review focused on research from temperate, high-income island countries characterized by widespread grass-based beef and dairy production; this approach was employed to effectively recognize specific knowledge gaps within this particular system. Outcomes of the presented analyses highlight that pro-environmental diversification represents multiple disciplines that encompass agricultural sciences, food sciences, environmental sciences, sociology and economics. However, results are frequently fragmented, focusing on only one or two impacts. For example, ESMPs have been studied mainly from a biodiversity perspective, leaving animal welfare, GHG emissions and animal productivity unexplored. This might result from the nature of the funding available for the research; however, studying the solutions from only one perspective (agriculture/ecology/food science) often does not cover the entire spectrum required for meaningful transformation. Addressing all three pillars of sustainability, namely social equity, economic viability and environmental protection, is thus crucial to generate positive, acceptable change among farmers and consumers. Researching several impacts concurrently would show diversification trade-offs more comprehensively. However, this approach requires funding for long-term research (>8 years), which is not provided by most funding agencies.

Including farmers in the scientific process and fostering interdisciplinary systemic approaches would significantly benefit the design of solution-oriented agroecological studies. Farmers, together with policymakers and consumers, play an important role in redesigning the food systems of the future. However, top-down measures are frequently limited to financial incentives and forgo educational, communicative interventions. The knowledge of farmers' values and motivations pertaining to pro-environmental diversification is limited. As such, it is challenging to validate existing claims about farmer acceptance and motivations toward pro-environmental diversification. Meanwhile it has been documented that many farmers display a genuine inclination to farm in harmony with nature and may be compliant to adopt environmental management measures where pre-existing values and motivations are appropriately addressed (Mills *et al.*, 2013).

Development of practical solutions for farming based on circular economies and custodianship should be prioritized by advisory and scientific bodies. Accordingly, increased financial support from public funding institutions and the private R&D sector is required. Furthermore, additional strategies are necessary to increase consumer awareness of the environmental impact of intensive grass-based dairy and beef systems on biodiversity and climate change to motivate their sustainable choices and behaviors.

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