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Learning from innovative practitioners: Evidence for the sustainability and resilience of pasture fed livestock systems

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There is an urgent need for transformational change in agriculture to address current and future issues caused by climate change, biodiversity loss and socio-ecological disruption. But change is slow to come and is hindered by a lack of transdisciplinary evidence on potential approaches which take a systems approach. The research described here was co-developed with the Pasture Fed Livestock Association in the UK to objectively evidence their practices. These include producing pasture-based meat from livestock fed on pasture and pasture-based forages alone. This approach sits alongside wider aims of fitting their practices with the ecological conditions on each individual farm to facilitate optimal production and working collaboratively through a forum for sharing knowledge. The research provides strong indications that the PFLA approach to livestock production is resilient and viable, as well as contributing to wider public goods delivery, despite variability within and between farms. It also reveals that learning and adaption of practice (through farmer experience) is central to farming using agro-ecological approaches. This fluidity of practice presents challenges for reductionist approaches to "measuring" agricultural innovations.

KEYWORDS

innovative practitioners, holistic assessment, pasture fed livestock, sustainability, resilience, grassland

1. Introduction

Can livestock farming be at the leading edge of transformational change in our food systems? Grassland systems are known to be able to provide many ecosystem services including biodiversity, erosion control, climate regulation (Dumont et al., 2019) and the preservation of cultural landscapes (Beudou et al., 2017) alongside food production on a worldwide basis (O'Mara, 2012). Pasture-fed livestock farmers in the UK, who seek to promote the virtues of producing pasture-based meat (from livestock fed 100% on herb, legume and grass rich pasture and pasture-based forages alone),[1] have been working together as part of the Pasture Fed Livestock Association (PFLA) to produce quality products whilst also delivering environmental goods for over a decade. With the pressures of a highly publicized global environmental lobby on the climate impacts of meat and dairy production (Rojas-Downing et al., 2017; Happer and Wellesley, 2019; Willett et al., 2019) and enduring low profitability in the UK beef and sheep sectors (Defra et al., 2020) livestock farming for many is more a question of survival than of prosperity. Other stresses on grassland farming systems include the emerging impacts of BREXIT (Ojo et al., 2021) and demands to increase tree cover through policy initiatives like Net Zero (HM Government, 2021). PFLA farmers and supporters (including butchers, retailers and consumers) strongly advocate the pasture fed farming system as one which can promote the delivery of a wide range of public goods including; food security, protection of landscape and heritage, efficient energy and water use, high animal welfare, nutritional quality of products and farm business resilience. PFLA farmers are aiming for what they call "optimum production" rather than "maximum production"—where "optimum" means working toward a "fit" with the ecological conditions on each individual farm (P. F. L. A., and Plantlife, 2021). Their aims reflect prominent "sustainability" and "multi-functionality" discourses in agro-ecological research (see Herren et al., 2020) which identify the need for a transformational change in farming to focus on the number of people that can be fed healthily and sustainably per unit of land/input, rather than on agricultural output alone (Benton and Bailey, 2019). The PFLA aims also reflect current UK government post-BREXIT agendas which seek to reward the delivery of public goods from farming (Klaar et al., 2020).

Resilience in agriculture and food systems is a broad concept, but there is agreement of its key characteristics, some of which relate to the "goods" purportedly delivered by PFLA systems. These include the following responses to perturbation to maintain system functions including; (i) absorbing or buffering, (ii) adapting to change, and (iii) "transforming" or "re-orienting" the food system to a new configuration (Folke et al., 2010; Ashkenazy et al., 2018). Bruce et al. (2021) suggest that farm level resilience could include a combination of maintaining financial viability, levels of food production, on-farm biodiversity, value of breeding stock, quality of water and soil, landscape impact, animal welfare, welfare of the farming family and maintenance of social capital. Ashkenazy et al. (2018) summarize five main strategies for resilience; (i) valuing traditions and local capacities; (ii) promoting economic diversification; (iii) utilizing technological innovation and cost efficiency; (iv) increasing cohesion between different social groups; and (v) optimizing the use of public support. Although these aspects of resilience may vary in their emphasis on different social, environmental and farm business elements, there are broad themes emerging that can be used to characterize resilient farm systems.

Despite an acknowledged need for transformation in agriculture, change away from intensively managed, high input agricultural systems is slow to come. The sustainable intensification agenda continues to support the belief that technological innovation can resolve the clear trade-off between producing more, whilst reducing ecological damage (Terry et al., 2020; Pulina et al., 2021). On the other hand, recent work has pointed out that in some areas "sustainable de-intensification" will also need to be part of a future agricultural agenda (Struik and Kuyper, 2017). Long embedded vested interests for agri-business in maintaining the status quo (Schram and Townsend, 2021), private sector control over agri-food systems (Busch and Bain, 2004), concerns about the capacity to feed a growing population (Willett et al., 2019) and questions of legitimacy around evidence of alternative approaches, all contribute to this stagnation. Factors preventing change at the farm scale may include farmer insecurities about cutting losses on infrastructural investments for higher intensity systems (slurry tanks, sheds, machinery, animal breeds) and a variety of social issues. These include slow succession and lack of turn-over in the farming community and farmer isolation and insecurity about change, particularly on small family farms (Winter and Lobley, 2016). However, recent changes in social capital in agriculture (Pretty et al., 2020), have resulted in many individual producers making the choice to come together with others to address the issues facing their industry collectively. Collaborative approaches such as the Innovative Farmers groups, first launched in 2012 (Innovative Farmers, 2022), and others focused around or funded through agri-environment schemes (Thomas et al., 2020) have blossomed in the UK in recent years. Innovative Farmers have launched over 135 field labs in the past decade. The PFLA (formed a decade ago in 2011) represents a body of farmers who have chosen to join with others for support, learning and validation for livestock farming methods which rely on pasture with minimal (if any) inputs (Vetter, 2020). Evidence indicates that producer movements, such as the PFLA, across the world may play pivotal roles in supporting landscape multi-functionality through agroecological farming practices (Altieri and Toledo, 2011; Hart et al., 2016) as part of a socio-ecological revolution in agriculture (Norton, 2016). However, in order to inform on whether PFLA practices can play such a role in Great Britain, evidence is needed on their viability and resilience and the extent to which they are associated with the wider delivery of the public

1 "Pasture-fed" in this sense is distinct from labels such as "grass fed" that may require a minimum proportion of pasture-based feed and/or a minimum number of grazing days.

goods that they aim to promote. This research sought to provide evidence about this socio-ecological innovation in agriculture for PFLA farmers themselves and for others with an interest in the resilience of the UK food system (Tendall et al., 2015; Zurek et al., 2020).

Holistic approaches to measure multiple aspects of performance across a large sample of farms are resource intensive and difficult (Trabelsi et al., 2016; Gosnell et al., 2020; Song et al., 2020). A particular challenge with this research was to consider the difference between scientific and farmer practitioner ways of accruing and using knowledge, with scientific knowledge being based on a culture of objectivity (and often information collected over short time-scales) and farmers' knowledge being constructed *via* their own knowledge systems (Morris, 2006) over much longer time frames. In documenting and observing practitioner practices and their drivers and effects, the approach taken here seeks to produce rigorous, repeatable and objective evidence without affecting or controlling PFLA farmer practices. The research aimed to observe the messy reality of practices in the real world, particularly where such practices deviate from scientifically based industrial practices where assumptions are that X input $= Y$ production benefit. Others have highlighted the difficulties of producing traditional rigorous science relating to farming practices. For example, Gosnell et al. (2020) highlight the highly contested scientific evidence related to Holistic Management (HM) practices, as employed by to up to 10,000 cattle ranchers on an estimated 40 million acres across four continents. Gosnell et al. (2020) provide a novel explanation for the controversy, i.e., that it is grounded in epistemic differences between disciplines associated with agricultural science, and that these differences in knowledge-making rule out any chance of resolution. They conclude that the way to resolve such differences is to research HM socio-ecological systems in partnership with ranchers in more integrated ways.

The research described here adopted such an approach in seeking to evidence the practices of PFLA farmer members. In particular, PFLA members were interested in how their innovations might ensure continuing production of public goods and minimize dis-benefits from livestock systems into future generations. A transdisciplinary approach was taken, involving the producers themselves and an interdisciplinary research team adopting natural and social science methodologies for measuring the performance of the system. The research sought to identify the impacts of PFLA membership on soils and vegetation, on the wider delivery of environmental goods, on the economic viability of enterprises and on the social viability of livestock farming through understanding farmer values and motivations. Methods were designed to shed light on the hypothesis that pasture fed livestock systems are resilient and viable and deliver high levels of public goods. Evidence from associated work on meat quality on a small sample of farms in our study is also presented.

FIGURE 1
Locations of PFLA member farms included in the study.

2. Methods

A total of 56 PFLA member farms across GB were included in the research (Figure 1), all were livestock farmers and the majority (53) farmed either beef, or beef and sheep together; two of the remaining three farmed sheep only. Farmers also had other enterprises with 16 farmers classing their farms as mixed. Twenty-four of the farms were certified PFLA producers (under their Pasture for Life, PfL scheme), seven were provisionally certified and the remainder were members with plans to become certified in the near future. Farms were located across GB (below 400 m altitude), with the majority in England, five in Scotland and three in Wales (Figure 1). The majority of PFLA farms were also either certified organic (26) or farmed largely according to organic principles (13), with a smaller number undergoing conversion (3), the remaining farms used conventional practices including fertilizer use (14). Methods are described in brief for the Public Goods Tool here, more details are provided in Supplementary material S1. These methods therefore included several components: A (section PG Tool data collection)—the use of the Public Good Tool (PG tool) (Paraskevopoulou et al., 2020), a multi-criteria analysis-based sustainability assessment protocol; B (section Soil and vegetation sampling)—Soil and

Vegetation Sampling; C – (section Qualitative interviews) Qualitative interviews on farms; D (section Meat quality)—Assessment of meat quality in relation to 4 different farm system types in the UK. Data for A and B were collected in 2018 and for C (and D) in 2019.

2.1. PG tool data collection

Trained assessors collected data for the PG Tool through interviews with each farmer. Responses to a series of over two hundred questions relating to a recent (2016 or 2017) specific business year (as defined by the farmer) covering multiple farm criteria were recorded within an Excel workbook. A PG Tool dataset was completed for 54 farmers.

The PG tool fulfilled two roles in the research, one to encourage and facilitate farmers in understanding more about the multiple impacts of their businesses (not described here) and a second to provide data for scientific analysis. Summarized PG data for all farms is provided for reference in Supplementary material S1. Raw data provided by farmers (on costs, animal numbers, prices received etc.) was used for analysis of farm viability. Other quantitative/categorical data were used in multivariate analyses as described in the joint analysis of multiple criteria (section Joint analysis of multiple criteria).

2.2. Soil and vegetation sampling

Soil and vegetation were sampled using methods from the Countryside Survey (CS) (see Emmett et al., 2008; Maskell et al., 2008; Wood et al., 2017), in a grazed field identified randomly within the holding pre-visit. In each field a large (200 m^2) randomly positioned plot (marked pre-visit) was sampled for plant species presence and cover recorded in a series of nested quadrats alongside vegetation height and plot locational information. A single soil core (15 cm depth and 7 cm diameter) was taken from within each sampling plot. Soil cores were tested for a range of properties in line with soil analysis protocols from CS (Emmett et al., 2008). Measured properties on soils included: bulk density, soil C, total N, pH, Olsen and total P. Adoption of common protocols enabled comparisons with existing CS datasets (Norton et al., 2022, under review). Soil and vegetation samples were carried out on all 56 farms and were taken regardless of the timings of management practices on the fields, as is the case for samples in Countryside Survey.

2.3. Qualitative interviews

A social scientist carried out two semi-structured interviews with farmer(s) on a sub-sample of 17 PFLA farms during 2019. Interviews were aimed at assessing the social, motivational, learning and innovatory aspects of farming according to PFLA principles. Whereas the first interview probed the farmers' motivations and the learning and social networks involved in farming under PFLA principles, the second interview was designed to give free rein to the farmer to show, and discuss further, the nature of day-to-day farm practices that support the distinct PFLA method of farming—whereby the raising of ruminant livestock is based exclusively upon pasture. Both interviews lasted around 1 h and were recorded on a digital ZOOM recorder. Recordings were later transcribed verbatim and transcripts anonymised.

2.4. Meat quality

In a preliminary study conducted in 2019, aimed at considering the potential impacts on consumer health of different UK production systems, beneficial fatty acid profiles of steaks from 4 systems: non-organic, organic, certified pasture-fed (PFLA) and conservation cattle were assessed as part of a separate study, see Butler et al. (2021). The steaks from certified PFLA farms came from two of the farms included in our study in the year in which they were visited for social science interviews. Whilst these cannot be taken as representative of the PFLA system as a whole, they are included here to provide some (limited) evidence of the connection between livestock systems and the quality of the food produced.

3. Data analysis

3.1. PG tool

Analysis focuses on the use of quantitative data collected using the PG tool for economic variables (3.2) and on the use of selective quantitative and categorical variables as described in section Joint analysis of multiple criteria (Joint analysis of multiple criteria). The PG Tool is used to collect data on multiple aspects of farm performance including detailed data on all enterprise types (e.g., livestock numbers, feed and fertilizer inputs, meat prices per kilo, medicine use, etc.) as well as data on fuel use, waste management, water management, animal welfare, agri-environment schemes and much more (see Supplementary material S1, S2 for further details).

3.2. Economic

The economic analysis used data from the PG tool to benchmark PFLA enterprises against comparable beef and sheep enterprises from concurrent UK Farm Business Survey (FBS) data (FBS, 2018). The functional units of analysis in terms of output were output or cost (in £) per suckler cow or ewe, respectively. Values for PFLA farms were calculated for all farms and for the top, middle and bottom thirds.

3.2.1. Farm enterprises

Average results are given for suckler beef (38) and sheep (24) enterprises as these were the most common enterprise type within the PFLA sample. We do not, however, make a distinction between organic and non-organic (PFLA) in the following analysis, but comparisons with organic (non PFLA) are included for lowland sheep. This was the only system for which the FBS provides an organic benchmark. Similarly, we do not make a distinction between upland (uncommon in the PFLA sample) and lowland enterprises but FBS data using these categories is included for comparison.

3.2.2. Enterprise outputs

The FBS benchmarking tool provides average output (per head of cow or ewe) and removes net livestock depreciation and transfers in and out (i.e., replacement costs) to calculate enterprise output. Many of the PFLA farms are involved in direct marketing through online, farm shop or farmers' market sales (24 out of 54 shop and/or market). Processing and marketing costs were removed from the output to calculate enterprise output for the PFLA farms.

3.2.3. Enterprise variable costs

The PG Tool collects enterprise level cost data covering: bought-in forage, vet and medicine and other (bedding, ear tags, etc.). Forage production costs (seed, fertilizer and crop protection (where used), fuel and other) are included as an enterprise within the arable section of the PG Tool and need to be apportioned to livestock enterprises. As with forage area, this apportionment was done on the basis of the relative numbers of livestock units.

3.3. Soil and vegetation data

The following metrics derived from the vegetation plot data and associated soil cores were used in the joint analysis (below): total species richness (numbers of plant species recorded), % cover of forb (herbaceous flowering plant) species, vegetation height and loss on ignition (LOI) as a measure of organic matter (carbon) in soil.

3.4. Qualitative interviews

NVivo qualitative data analysis software, version 12, was used for coding and interpretation of interview transcripts.

3.5. Meat quality

See methods as described in Butler et al. (2021). Meat was subsampled for intramuscular (IMF) and subcutaneous fat (SCF).

3.6. Joint analysis of multiple criteria

Quantitative and categorical data collected through the PG tool; economic variables (A) and soil and vegetation sample data (B), were used in cluster analysis to investigate the hypothesis that pasture fed livestock systems are resilient and viable and deliver high levels of public goods, and to identify and highlight differences between farms in their delivery. Heatmap cluster analysis was used with complete linkages after Paretoscaling using R 3.5.3 (Lucent Technologies, NewZealand) involving the use of an algorithm to produce a dendrogram of all farms. Initial cluster analysis was carried out using all environmental and economic metrics (Supplementary material S2). Subsequently data were narrowed down to identify relationships between key economic and environmental criteria, helping to highlight where farmers tended to perform more or less well, related to; (1) the length of PFLA membership (years) (Memb) and (2) the level of agri-environment scheme participation (Ag-env) (low to high) and 3) the total amount of subsidy received as % of total income (subsidy).

4. Results

4.1. Economic data

4.1.1. Suckler cows

PFLA farms in the middle third (based on an ordering of farms in terms of enterprise gross margin) had a higher number of cows on average than the Farm Business Survey (FBS) benchmark; the top and bottom performers were more similar to FBS farms. There was also a notable difference in terms of forage area between PFLA and FBS farms with PFLA farms having more forage than FBS farms. The gross margin calculations at the per cow level are shown in Figure 2A) benchmarked against both "all" lowland and upland conventional suckler beef farms from the FBS database and against the top 25% ("high performers") of FBS farms. The overall average gross margin per cow for the PFLA farms was considerably higher than for

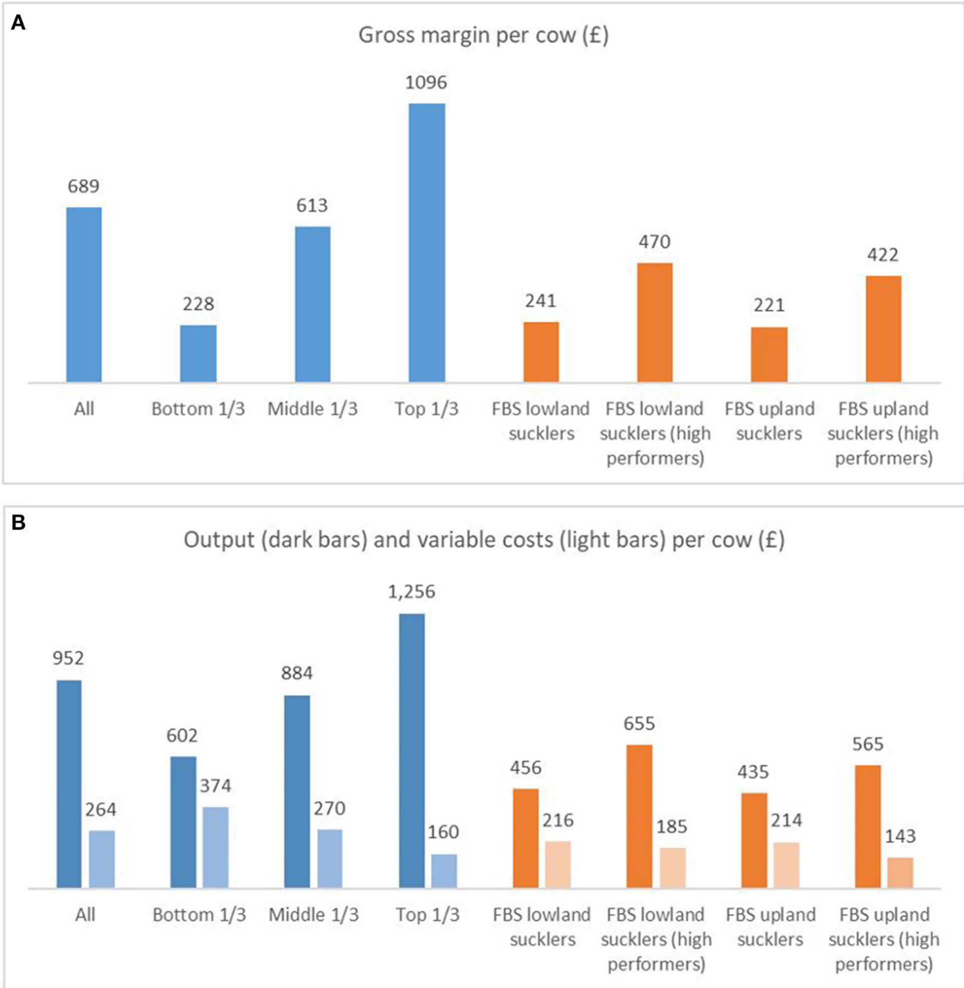

FIGURE 2
Economic performance of PFLA beef sucker enterprises (blue) compared to Farm Business Survey data (orange) for the same year, **(A)** gross margins per suckler cow, **(B)** output and variable costs per suckler cow. All values are in £, specific values are given at the top of each bar.

FBS farms (Figure 2A). On average, the performance of the bottom 33% of PFLA was comparable to the average across the FBS sample.

In terms of output (Figure 2B), the PFLA farms outperformed the FBS benchmarks except when comparing the lowest performing PFLA farms with the top FBS farms. Replacement costs were much lower for the top performing farms in both PFLA and FBS farms. Marketing and processing costs were much higher for the top performing PFLA farms (this data is not available for the FBS) indicating that these farms are more likely to be involved in direct selling (farm shop, online, farmers' markets). We assume that the higher returns from direct selling (higher prices, greater proportion of value added) are reflected in higher output figures.

Variable costs were generally lower for the top performing PFLA and FBS farms, and proportionally lower for the majority of PFLA farms, excepting those in the bottom third of performers. Specifically, fodder production costs were higher for lower performing PFLA farms (only farms not yet fully registered as PFLA producers feed fodder other than grass). Bought in feed costs were generally lower in PFLA farms (no concentrates or non-grass fodder are fed in pasture fed systems), but did not offset the increased costs of fodder production for the bottom third of PFLA farmers.

4.1.2. Sheep

Of the 24 farms with sheep enterprises in the PFLA sample, 5 were classified as upland (using a definition of above 250 m). The economic data at the per-ewe level includes the FBS benchmark data for lowland, upland (Less Favored Area, LFA) and lowland organic

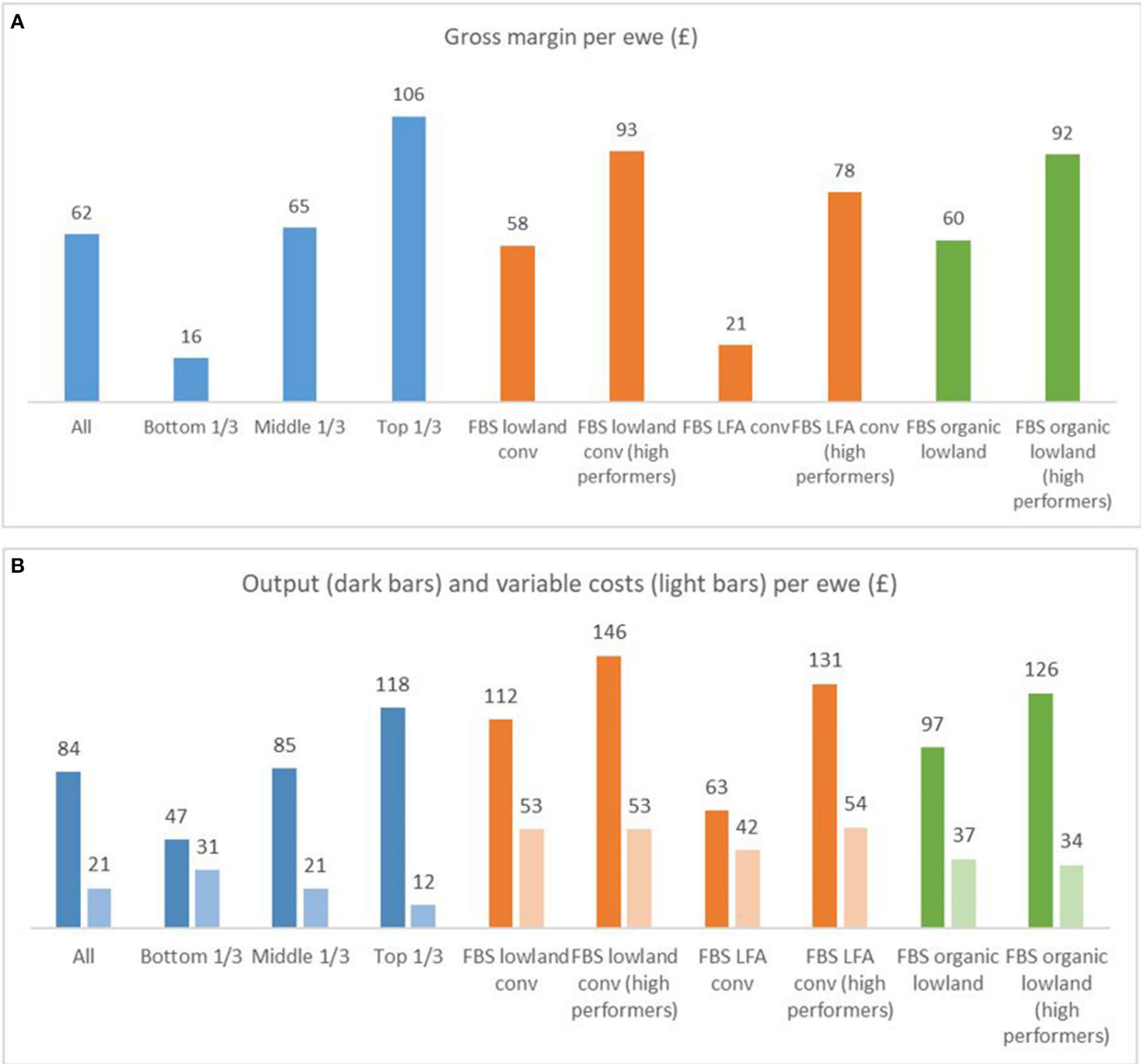

FIGURE 3
Economic performance of PFLA sheep enterpr ises (blue) compared to Farm Business Survey data (orange) including organic (green) for the same year, **(A)** gross margins per ewe, **(B)** output and variable costs per ewe. All values are in £, specific values are given at the top of each bar.

breeding ewe producers (Figure 3). In terms of gross margin per ewe, the average PFLA farm marginally outperformed the lowland and organic FBS averages and the top third of PFLA producers were ahead of the top lowland FBS producers (both conventional and organic). The bottom third of PFLA farmers performed considerably less well than average conventional and organic farmers and slightly less well than sheep producers on LFA (Figure 3A).

Output per ewe for the average PFLA producer was closer to that for organic producers or those on LFA than it was to the FBS benchmarks for lowland conventional producers (Figure 3B). Only the top third of performers achieved outputs comparable with these producers. However, there were clear differences with respect to variable costs, with PFLA farms having much lower costs than either conventional or organic producers in the FBS sample, which led to increased gross margins for PFLA farmers (Figure 3). Although forage production costs were higher across the PFLA sample than the FBS, these were more than offset by lower bought-in feed costs. Within the PFLA sample variable costs per ewe declined as performance increased.

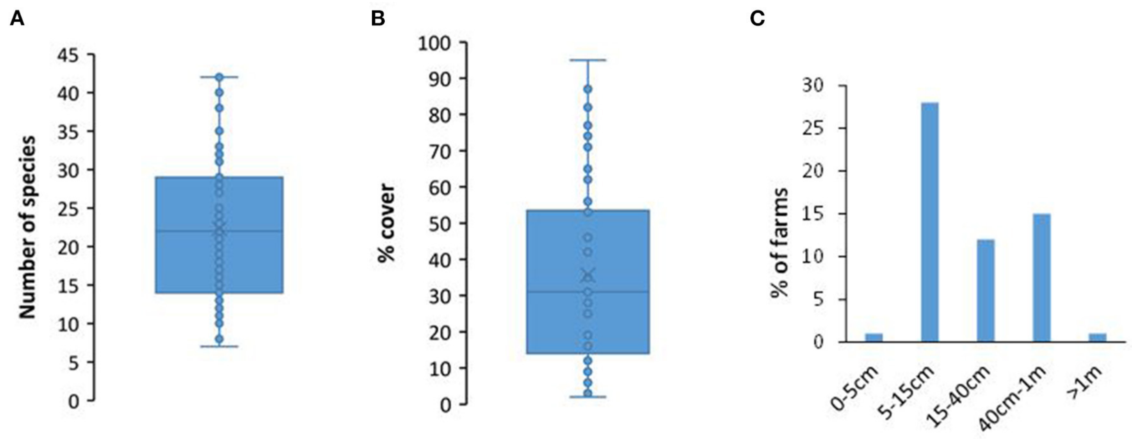

FIGURE 4
Vegetation metrics for quadrats on PFLA farms: **(A)** box plot of total species richness across all farms showing mean, upper and lower quartiles and outliers, **(B)** box plot of % cover of forbs showing mean, upper and lower quartiles and outliers, and **(C)** bar chart of % farms with different vegetation height categories.

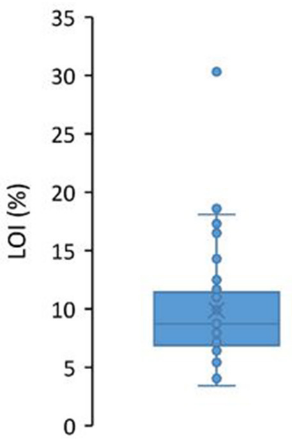

FIGURE 5
Box plot of loss on ignition (% of organic matter) for soil cores (0–15 cm) from PFLA farms showing mean, upper and lower quartiles and outliers.

4.2. Soil and vegetation

Results for total plant species richness, forb (herbaceous flowering plant) cover and average height of vegetation are shown in Figure 4. These data have been compared with nationally representative randomly located samples of grassland data from close to a thousand survey plots across GB in Norton et al. (2022) to investigate any broad scale differences between the "populations" of fields. Both numbers of species and the cover of forb species were highly variable across PFLA farms. Grassland height (in a limited range of categories) was somewhat less variable, but at least half of farms included grass over 15 cm high. Vegetation height and forb cover was on average greater in PFLA grassland than on grassland in the CS sample of grasslands. Loss on ignition (LOI) (Figure 5) was mainly concentrated at between 5 and 20%, one outlier farm, located in the peatlands of the Lincolnshire Wolds, had soils containing almost double the levels of soil carbon as found on all other farms.

4.3. Qualitative interviews

It is a commonplace to suggest that farmers are profit motivated, see Brown et al. (2021). However, discussions with the 17 PFLA farmers interviewed in 2019 revealed that these farmers are motivated to do more than simply make a profit. Farmers narrated a complex bundle of factors (including, for example, business failure, past farm practices, a commitment to the future of the farm, a desire to build up the physical resilience of the farm and a critical stance toward post-war industrial agriculture) as incentivising them in different ways to make the decision to farm according to PFLA principles. That is, to feed beef cattle entirely on grass and forage crops, to "kick the habit" of feeding cattle grain, and to strive toward producing food "in a more natural way" (PFLA, 2016), and, as the PFLA certification standards stipulate, delivering "environmental goods rather than just avoiding environmental harm" (PFLA, 2020).

PFLA farmers expressed the desire to achieve "optimum" rather than "maximum" production, where the notion of an optimum is not numerically-based but value-based. Optimum production in a grass based system that is trying to "close the loop" between inputs and outputs means "how to use the grass that we've got, better" (Farm 06 Interview), as one farmer put it. Farmers suggested they were, for example, "taking a slightly more active approach to grassland" (Farm 08 Interview). This often involved learning new methods of grazing and learning how to gauge grass productivity against the grazing needs of their cattle. We have described elsewhere how many PFLA livestock farmers seem to be on a "grazing journey" whereby they gradually change their grazing strategies, tending toward a version of "mob-grazing" that suits the particular requirements of their pastures and their stock (Wagner et al., 2022). Farmers are learning through practical, bottom-up experimentation, for example, by bale-grazing over the winter months: "The cows stay out and we move an electric fence to the bales with what we call "stored up grazing" (grass left tall for winter)... the bales are amongst it and then every day you go and move the fence.... cheap as chips!... the birds find some seed and ... the cows are happy" (Farm 05 Interview). The farmer describes this as an experiment which he carried out with a view to "proving" that it could be beneficial, not just for the cattle and the pastures, but also for his bottom line and for wildlife. All of the 17 PFLA interviewees described detailed examples of small-scale, yet (for them) consequential, innovations and experiments—a "tweaking and tinkering" with the farm system aimed at providing multiple goods.

This "tweaking and tinkering" implies a particular kind of focused care (Mol et al., 2010) but it is also a *social* activity. Membership of the Pasture Fed Livestock Association meant that this farmer could share this experiment with other members through the PFLA "Google Group"—a simple e-mail list generating up to 20+ messages per day. This group was described as "totally helpful" (Farm 03 Interview), "trustworthy" (Farm 07 Interview), and as having a strongly cooperative ethos: "Totally equal, the newest person with five acres is as equal as anybody else" (Farm 05 Interview). It is clear that social goods—such as learning, generosity to others, and trust—are generated through this flow and exchange of on-farm trials, results and experiences, (see Vetter, 2020).

The interviews also revealed that adopting pasture fed farming practices on beef farms involves collaboration with the cattle themselves. The cattle are part of the ongoing experimentation and farmers often remarked whether the cows were "happy" (Farm 01, 03, 05, 12 Interviews). Farmers are working in a new, often daily, rhythm and routine with their animals as they fine-tune their grazing methods and judge the quality and quantity of pasture and the health of their stock. They are also innovating by re-thinking their breeds and breeding strategies on the farm, taking into consideration a range of factors such as winter hardiness, ability to achieve a good finish on grass, ability to thrive on less rich grazing, and fat content and taste of the meat for their customers.

Hence, innovations concern grazing and stocking strategies, but are also social and shared, involving collaboration with the animals themselves. Interviews showed that farmers are intensely interested in the cascade of effects that some of these innovations are having on the farm. These ranged from a re-calibration of time and labor "It's not more work, it's less work" (Farm 14 Interview), to a tangible appreciation of the wildlife benefits of grazing approaches and longer grass swards, through observation of the benefits on animal health and lower veterinary bills, to a lessening of weed species. Many interviewees noted their reduced reliance on, and need for, physical infrastructures and infrastructural capital on farm (Farm 04 Interview, Farm 14 Interview), as pastures provide both the site and the forage upon which the cattle are fed. At the heart of all of the innovation going on was the quest for what Clark calls the "sweet spot" in pasture fed rearing of cattle (Clark and Scanlon, 2019) whereby both ecology and economy are calibrated toward a kind of equilibrium. At this equilibrium, profit margins are more important than profitability and multiple gains—in terms of social capital, learning, and a positive sense of purpose, autonomy, agency and the future—can be achieved. It is clear from the 17 interviews carried out in 2019 that these multiple gains involve carefully calibrated trade-offs and value judgements on the part of the farmers. PFLA farmers are motivated to find such an equilibrium and are supporting each other to produce a diversity of goods rather than a single profit outcome.

4.4. Meat quality

Results for meat sourced from 2 of the PFLA farms in our sample showed that ratios for linoleic acid: α-linolenic acid, omega-6:omega-3 and SFA:PUFA in pasture-fed sirloins were only 27, 55, and 70% (respectively) of those in non-organic beef. Intramuscular fat from pasture-fed meat had twice as much omega-3 and 1.9× the long chain omega-3 concentrations compared with non-organic meat, with a ratio of omega-6:omega-3 only 38% of that in non-organic meat (Butler et al., 2021). These results indicated that the nutritional quality of beef from the pasture fed production systems (sampled for other criteria here) exceeded that from other production systems.

4.5. Joint analysis of multiple criteria

The heatmap cluster analysis of the environmental and economic criteria revealed apparent clustering into three broad groups (Figure 6, clusters i–iii), The first cluster (i) included farms with a high level of agri-environment scheme participation, and high values for the environmental indicators relating to grassland and soil quality (grass height, species richness, forb coverage and soil organic matter). Cluster (i) also included farms with the highest values for "PFLA membership years" suggesting a possible link between

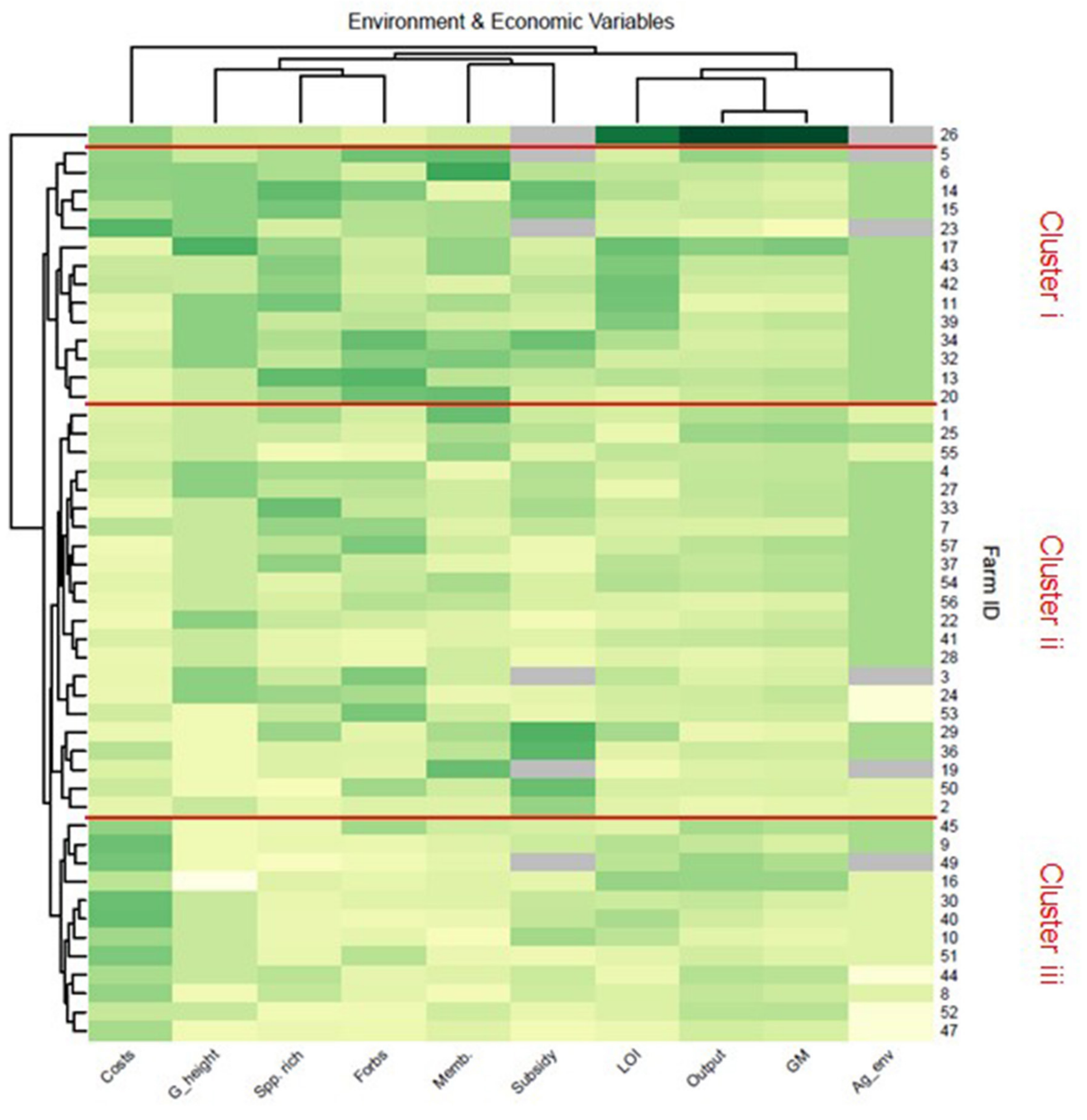

FIGURE 6
Heatmap of variables within the Economic and Environmental categories collected as part of the PG tool and field data collection. Farms are clustered by color where they have similar values (i.e., farms with higher values have darker colors across all columns). Variables include; Costs, variable costs per livestock unit; G_height, height of grassland; Spp. rich, species richness; Forbs, forbs coverage; Memb, duration of PFLA membership in years; Subsidy, total amount of subsidy received as % of total income; LOI, Loss On Ignition (derived soil organic matter %); Output, financial output per livestock unit; GM, Gross margin per livestock unit; Ag_env, Level of agri-environment scheme participation (1–3).

duration of membership and environmental performance. Significant positive correlations between agri-environment scheme participation and PFLA membership years ($R = 0.38$. $P < 0.01$) and total species richness and level of scheme participation ($R = 0.49$, $P < 0.01$) lend support to this. Additionally, two-thirds of farms in cluster (i) had low variable costs, suggesting that these farms were the most economically efficient in terms of the "value for money" associated with their higher environmental performance. Farm 26 was excluded from the first cluster as an outlier due to very high values for soil organic matter (LOI) and, financial output (Output) and the farm-level Gross Margin (GM).

Cluster (ii) is typified by farms with low production costs, high levels of agri-environment scheme participation, highly variable performance for the environmental values, and lower membership years, whilst Cluster (iii) includes farms with lowest values for the environmental indicators, and membership years. Cluster (iii) also included farms with the highest variable costs, although this cluster also included some of the highest values for overall output and Gross Margin(s). Despite soil organic matter (LOI) exhibiting a slight positive correlation with species richness (correlation $= R = 0.29$, $P = <0.05$, ~5–6 farms in cluster (iii) also had medium-high levels of soil organic matter, when compared with the overall PFLA sample.

5. Discussion

This study sought to evidence the potential for Pasture Fed Livestock farming to transform ruminant livestock systems and specifically to shed light on the hypothesis that pasture fed livestock systems are resilient and viable and deliver high levels of public goods. For the farmers in the study, resilience of their systems incorporates economic viability alongside the continuing production of public goods and minimized dis-benefits from their systems for future generations.

Our data was collected using transdisciplinary approaches across social, environmental and economic aspects of over 50 PFLA farms representing a broad range of soil types and locations, including a variety of enterprise mixes and incorporating farmers with differing levels of expertise and experience in PFLA approaches. Despite this inherent data messiness, our research reveals strong indications that on average the PFLA approach to livestock production is resilient and viable and does contribute to public good. It also reveals that farmers within this relatively novel movement (just over a decade old) are continually learning and adapting their practices, through both their own experiences, and those of others across the PFLA. In this process, farmers report improvements in their practices and the public goods resulting from them as they continue to learn more about their land and their animals and the relationships between them. The importance of this experiential learning, when working with agro-ecological approaches, echoes calls in the US for a more ecologically skilled farming workforce to address the loss of expertise in farming that has resulted, in part, from the use of inputs as well as from effects of wider land use and social change (Carlisle et al., 2019).

Objective evidence from our research supports the fact that longevity of PFLA membership is associated with higher levels of species richness in grassland swards as well as higher levels of participation in agri-environment schemes (Figure 6). Relationships with soil carbon (loss on ignition) were more variable, although many of those who had been members for longest tended to have higher levels of soil carbon (Figure 6). Economic evidence revealed that whilst some farmers do less well (particularly those with high variable costs) PFLA farmers are at least on a par with non-PFLA livestock farmers, and that those producing beef sucklers seem to perform better than FBS averages. Economic outcomes link to lower input costs, including no livestock feed and low use of mineral fertilizers, for the majority of farms (42 of the 56 farms were organic, in conversion or farmed according to organic principles). They also link to more direct marketing and short supply chains within the PFLA sample, in which twenty-four farmers either had a farm shop or sold direct at farmers markets or online. Patterns for economic performance showed high variability when related to non-economic variables, with the exception of costs which tended to be lower in clusters i) and ii) (Figure 6).

The aligned study by Butler et al. (2021) showed that indicators of meat quality, such as the ratio of omega-6:omega-3, as found in beef steaks from the 2 PFLA farms included in our study, were considerably lower (and thereby healthier) than those in non-organic meat (Butler et al., 2021). However, these two farms (45 and 50) were in clusters ii) and iii) (Figure 6) pointing to the fact that whilst these farms may deliver high meat quality, delivery of other public goods as measured by our research is not as high as for other farms in the study. Indeed, our findings show that PFLA farms are inherently variable both within and between farms in terms of their delivery of public goods. Hence, some farms may deliver particular goods well, but not others, and farms may be more or less good in terms of overall delivery. Indeed, some PFLA farmers (perhaps particularly those in cluster iii) (Figure 6) may not be farming in ways that deliver high levels of public goods or are viable or resilient. Farmers may be limited in their public good delivery by soil type and natural resources in their locations (e.g., to enable them to enter agri-environment schemes), the supply chain of which they are a part, or by lack of farmer experience, i.e., farmers that are only in the early stages of learning how to farm within ecological system boundaries (Carlisle et al., 2019; Clark and Scanlon, 2019).

Our results indicate the vital role of innovation in Pasture Fed Livestock approaches at both an individual and a group level. Other work has shown the importance of such grassroots initiatives in providing access to resources such as skills, knowledge or networks (Rossi, 2017; Skrzypczyński et al., 2021). Work by Wood et al. (2014) suggested that farmer knowledge exchanges were expressions of their social solidarity. The PFLA is an innovation providing social solidarity for like-minded farmers who seek to embrace approaches for producing high quality food in "natural ways". The PFLA Google group is a modern platform for the kinds of interpersonal discussions between colleagues where innovation may be driven by uncertainty and experimentation around knowledge that were recognized in medicine as long ago as the 1950's (Coleman et al., 1957). The farmers involved in this research show great willingness to learn and adapt their systems in ways that benefit them, their livestock and their environments.

Clear indications of potential resilience for PFLA approaches for farming were observable with respect to the characteristics proposed by Ashkenazy et al. (2018) and Bruce et al. (2021). In economic terms the best performing farms have diversified to include shorter supply chains including capturing a greater proportion of the value of their products, they are also more efficient in terms of variable costs. There are indications of better environmental performance, both in terms of measured outcomes and engagement with public support schemes. And, there are observable social benefits, both in terms of farmers' individual motivations and perceptions, and active peer-to-peer engagement which fosters learning and innovation. The correlation between length of PFLA membership and economic and environmental outcomes demonstrates the benefits of this social engagement in underpinning greater resilience. Farmers' social responses to the ecosystems which they manage are likely to be fundamental to learning how to bring about the necessary shifts in livestock systems which can help toward more resilient and sustainable outcomes for livestock agriculture [Gosnell et al., 2020, see also Winter and Lobley (2016)].

The need for systems approach toward developing sustainable and resilient agricultural systems has long been recognized (Ikerd, 1993). Reductionist scientific approaches have limited our ability to provide evidence which can support transformational change in agriculture. The "new era" anticipated by Nerbonne and Lentz (2003) and further advocated by others (Gosnell et al., 2020; Wezel et al., 2020) in which farmers and researchers build new knowledge together using holistic, transdisciplinary approaches remains in its relative infancy. In this work we have sought to take such an approach, and in doing so, have provided insights into the opportunities for moving toward ruminant livestock systems, which are viable, resilient and important for the delivery of public goods.

Data availability statement

Soil and vegetation data are available at: https://doi.org/10.5285/78ca9a01-107b-4f33-8561-9c3e64db7e02. Anonymized datasets for other measured parameters are available on request to the corresponding author.

Ethics statement

The studies involving human participants were reviewed and approved by Lancaster University Ethics Committee. The patients/participants provided their written informed consent to participate in this study.

Author contributions

LN wrote the manuscript with contributions from CW, AM, and LS. Data collection and analysis were carried out by LN, MW, AM, LM, LS, and CW. ChW provided input throughout. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fsufs.2022.1012691/full#supplementary-material

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