Contribution of High Nature Value farming systems to sustainable livestock production : A case from Finland

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Contribution of High Nature Value farming systems to sustainable livestock production: A case from Finland

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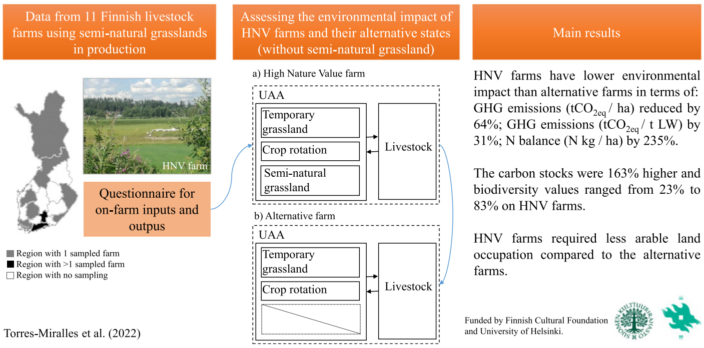
HIGHLIGHTS

- High Nature Value farmlands maintain semi-natural habitats in the boreal region.
- High Nature Value farming systems in Finland reduce nutrient loses at the farm.
- Use of semi-natural grasslands in Finnish production reduces GHG emissions per UAA.
- The use of semi-natural grasslands frees arable land for other non-animal purposes.
- High Nature Value farming systems maintain unique biodiversity and stock carbon.

GRAPHICAL ABSTRACT



HNV farms have lower environmental impact than alternative farms in terms of: GHG emissions (tCO_{2eq} / ha) reduced by 64%; GHG emissions (tCO_{2eq} / t LW) by 31%; N balance (N kg / ha) by 235%.

The carbon stocks were 163% higher and biodiversity values ranged from 23% to 83% on HNV farms.

HNV farms required less arable land occupation compared to the alternative farms.

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ABSTRACT

Sustainability of livestock production is a highly contested issue in agricultural sustainability discourse. This study aimed to assess the environmental impact of farms using semi-natural grasslands in Finland, or so-called High Nature Value (HNV) farms. We estimated the environmental impact of 11 such farms, including greenhouse gas emissions (GHG), nitrogen (N) balance, land occupation, and carbon storage. We also accounted for unique biodiversity, defined in this study as communities that are dependent on semi-natural grasslands. We compared these to the alternative states of the farms, specifically a hypothetical farm with the same production output but without access to semi-natural grasslands. GHG emissions at the farm level (tCO_{2eq}/ha) in HNV farms were 64% lower than on the alternative farms; GHG emissions at the product level (tCO_{2eq}/t LW) and N balance (N kg/ha) were 31% and 235% lower, respectively. The carbon stocks were 163% higher at farm level. Biodiversity values, indicated by the share of semi-natural grassland in management, ranged from 23% to 83% on HNV farms. Six out of eleven farms would need to increase their arable land occupation by an average of 39% of arable land to fulfil their needs for animal feed if they did not utilize semi-natural grassland. This study contributes to growing evidence that HNV farming systems can support sustainable production by minimising arable land occupation, reducing nutrient loses, and increasing carbon storage while maintaining unique biodiversity.

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1. Introduction

Livestock production is associated with both negative and positive environmental impacts, ranging from land area and water use to biodiversity and greenhouse gas (GHG) emissions (Willett et al., 2019). However, environmental impact evaluations of livestock typically focus mostly on GHG emissions resulting from production processes and are aggregated over a wide variety of farming systems (e.g. de Vries and de Boer, 2010; Herrero et al., 2013; Poore and Nemecek, 2018). Only recently research has included extensive systems in an attempt to capture the overall benefits, such as nutrient cycling or biodiversity conservation, in addition to rural development roles linked to livestock production (e.g. Bragaglio et al., 2020; Ripoll-bosch et al., 2013; Ryschawy et al., 2017).

In the largest global review of life cycle assessment (LCA) for agricultural products (Poore and Nemecek, 2018), the performance of extensive livestock systems is overshadowed as most studies are based on intensive farming systems. Further, as intensive systems generally have lower emissions and land occupation values per product output than pasture-based and extensively managed systems (Bragaglio et al., 2020; de Vries and de Boer, 2010; Pelletier et al., 2010), most environmental assessment research on livestock in Europe is focused on lowering such impacts through production intensification. Whereas such systems (for example intensive broiler production or pig fattening) may have limited biodiversity or other non-production benefits (ibid), other extensive systems support them.

Few studies in the literature include the lowest possible trade-off situation, that is, specific production systems with the lowest overall adverse impact and the greatest benefits within their biogeographical context (Del Prado et al., 2021; IPCC, 2018). Further, most studies have focused on mountainous areas, Iberian dehesas or montados, while boreal regions remained unexplored (Jordon et al., 2020; Moreno et al., 2018). Therefore, there is a considerable need for a more holistic and nuanced treatment of livestock production systems, which also includes positive environmental impacts of livestock production, particularly in LCA studies (Battaglini et al., 2014; Moreno et al., 2018; Ripoll-bosch et al., 2013). This study explored a potential lowest trade-off situation through a specific focus on High Nature Value (HNV) farmlands. HNVs are “areas where agriculture is a major land use and where it supports, or is associated with, either a high species and habitat diversity and the presence of species of European conservation concern” (Andersen et al., 2003). HNV farmland has been used as an indicator for assessing sustainability in terms of biodiversity and other ecosystem services (Andersen et al., 2003; Gardi et al., 2016; Paracchini et al., 2008). The main differences between mainstream production systems and HNV farming systems are the use of permanent semi-natural pastures and low external inputs to a varied degree (from major to low dependence) instead of the use of cultivated grassland for production (Keenleyside et al., 2014).

Semi-natural habitats, mainly grasslands, result from long-term extensive ruminant grazing or mowing without added fertilizers or other inputs. Due to moderate human disturbance over thousands of years, semi-natural grasslands are characterised by their exceptional small-scale plant diversity (Wilson et al., 2012), high shares of indigenous and endemic species (Bruchmann and Hobohm, 2010), and red-listed species (Eriksson and Cousins, 2014). The diversity of frequently endangered invertebrates and fungi is also high (Pöyry et al., 2009; Pykala, 2003; Van Teeffelen et al., 2008). Such pastures and their biodiversity have experienced a drastic decline due to a double threat of abandonment and intensification, leading to their designation as critically endangered habitats as assessed by the EU (Halada et al., 2011; Henle et al., 2008). In Finland, semi-natural grasslands represent the single most biodiverse land use on farmland with unique and highly threatened communities (Mäkeläinen et al., 2019).

In the boreal region, intensification of grassland production transformed most of the semi-natural areas into cultivated grasslands, with a subsequent decline in biodiversity (Herzon et al., 2021; Lampinen et al., 2018). Most of the remaining semi-natural pastures survive in coastal areas or on forested land, land that is otherwise unsuitable for arable cropping. A proportion of the semi-natural grasslands are legislatively protected as part of the national Natura 2000 networks. The remaining areas are estimated to remain at levels of only a fraction of a percent of their historic areas at the beginning of the 20th century (Eriksson and Cousins, 2014; Luoto et al., 2003). Extensive ruminant grazing, as part of production or for agricultural subsidies, is currently the main management tool that preserves semi-natural grasslands (Raatikainen et al., 2017).

The aim of this study was to assess the environmental sustainability of livestock production on HNV farms in Finland when compared with mainstream production systems. Such sustainability assessments have not been previously performed in the boreal region. We hypothesised that HNV farms would have similar or higher environmental impacts compared to mainstream production farms, while also maintaining unique biodiversity compared with the mainstream farms. We first assessed the sustainability of 11 HNV farms in relation to environmental criteria such as unique biodiversity, Nitrogen (N) balance, carbon storage, GHG emissions, and land occupation. We then created alternative states for these 11 farms (i.e., retaining the same level of production but without semi-natural grasslands) and compared their performance to that of the actual HNV farms.

2. Materials and methods

2.1. Selection of High Nature Value farms and data collection

We invited farmers to participate in the study through social media (i.e., farmers association's group pages; approximately 1600 farmers registered). From these, 15 farmers contacted us. We selected 11 farms that corresponded to beef and sheep HNV farming system type I (i.e., farms that utilize semi-natural vegetation for grazing, haying, or both) and excluded equine farms from this study. The HNV farms (6 beef cattle, 2 sheep, and 3 sheep and cattle farms) were situated in nine out of nineteen regions in Finland. The selected farms differed from mainstream livestock production, namely due to the inclusion of semi-natural grasslands in production. Although farmers completed the questionnaire by themselves, we also provided assistance by telephone in most cases. Primary data collected covered the main aspects of grazing livestock, such as breeds, numbers of animals by age groups, grazing intensity, field use, manure management and yield, and other relevant practices on the farms. Based on such primary data, literature, and expert assessment, we modelled the most critical parameters such as liveweights, growth rates, or forage intakes that had the greatest potential to influence the model (see Appendix A).

2.2. Environmental impact assessment

The environmental impact assessment was based on 5-year average data of livestock production in HNV farms. We applied the LCA-based Carbon Calculator (CC) from the Joint Research Centre of the European Commission (Tuomisto et al., 2015) to assess the environmental impact of the farms. The scope used in the CC was from cradle to farm gate. The data included in the carbon calculator corresponded to primary data collected from questionnaires and additional required calculations, such as energy requirements or forage intakes.

2.2.1. Assumptions and other parameter calculations for HNV farms

We used the best available estimates from a diversity of national statistics databases. Averaged yields of the main feed crops, barley and oats, were based on average Finnish production yields of the last 4 years by respective region (Natural Resources Institute of Finland, 2021). We used farmer-reported protein feed purchases. We considered yields of 6.3 t DM/ha for red-clover pastures based on Lehtonen and Niskanen (2016) and 1.8 t DM/ha for semi-natural grasslands based on Saastamoinen et al. (2017). Semi-natural grasslands in production were included in the total Utilised Agricultural Area (UAA) accounted for on each farm as pastures and other field crops. To avoid double counting in the UAA, we included cover crops as a percentage of legumes and adapted the corresponding yield for the field. We assumed 34% of legumes in grass-clover silage fields and 21% of legumes in semi-natural grasslands (Riesinger and Herzon, 2008).

To assess the amount of forage intake originated from the semi-natural grasslands, we based our calculations on the following five key parameters: live weight, age, growth rate and energy requirements for the animals, and metabolisable energy (ME) concentration of low-quality forage. The ME concentrations applied for semi-natural grasslands and pastures were 8 MJ/kg DM and 11.3 MJ/kg DM, respectively (Natural Resources Institute of Finland, 2021). We calculated growth rates based on live weight and age of the animals reported by the farmers for growing bulls, heifers, calves, and lambs considering the particularities of each breed. For any missing values in the questionnaires, we used estimated values from the literature (i.e. Huuskonen et al., 2017) and average values based on information from the questionnaires. No growth was assumed for suckler cows, adult bulls, ewes, and rams. The energy requirement values and dressing proportions applied were based on national estimations for cows, calves, growing bulls, and heifers separately (Luke, 2021). The livestock breed was accounted for to assess the energy requirements of each animal of the herd.

2.2.2. Alternative states of the HNV farms

We excluded the extent of semi-natural grasslands from our HNV-sampled farms to build the alternative states of each HNV farm. Based on feed intake requirements for livestock under mainstream Finnish production, we calculated the amount of arable land required in the alternative state to maintain the same herd number as the HNV farms. We compared the performance of HNV farms and the alternative farms (without semi-natural grasslands in production) (Fig. 1).

We used the best available national estimates of feed demand and arable land required by the respective livestock type under mainstream production and averaged input data in the form of fertilizers and pesticides (Luke, 2020). We kept the other farming practices, including grazing period, the same as in the HNV farms. As the alternative-state farms do not

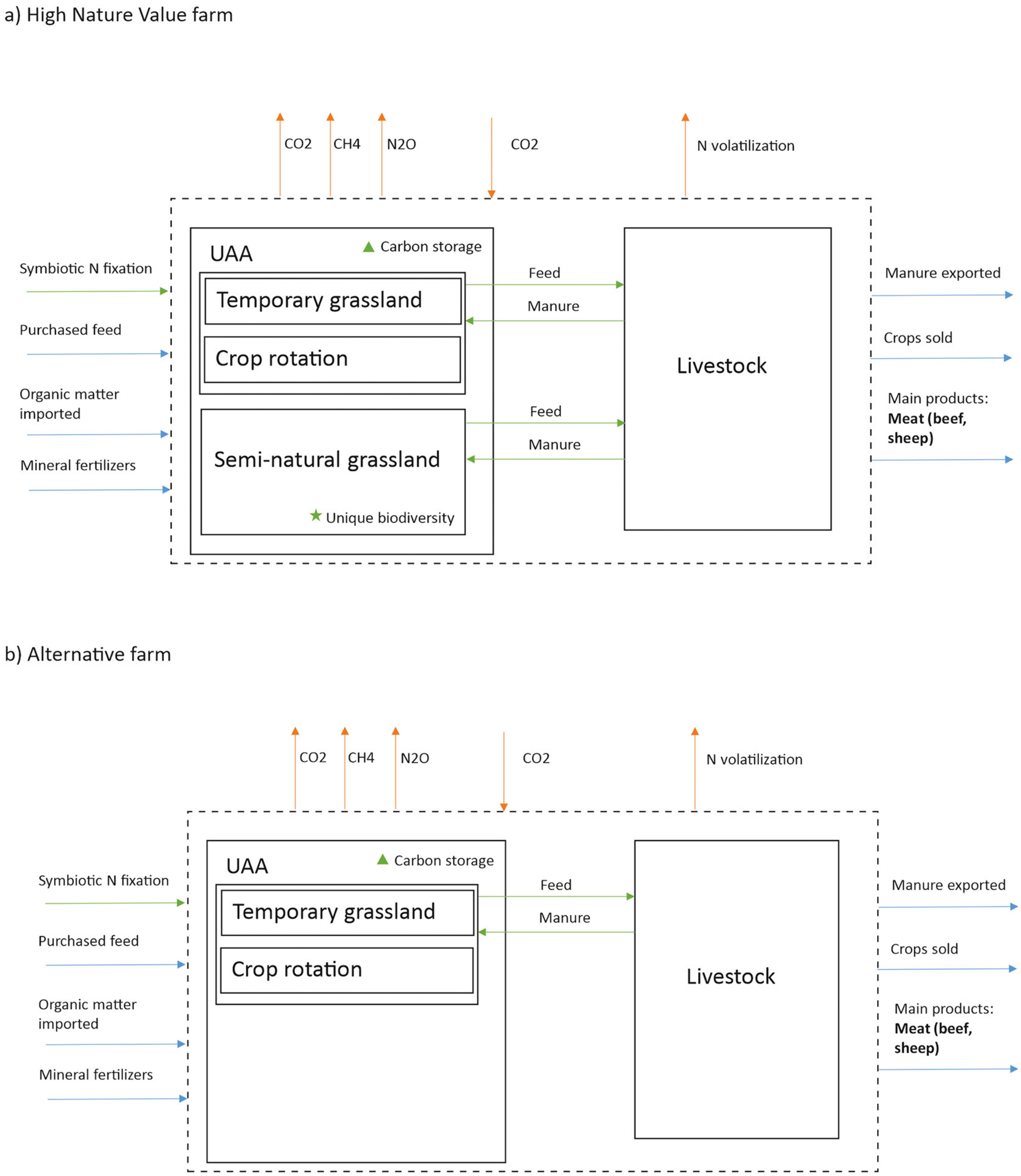

Fig. 1. Scope of analysis for HNV farms and their alternative states. Blue arrows represent inputs and production outputs, orange arrows represent emissions, and green arrows represent flows within the system. Dashed lines represent the system boundary. Linear squares represent Utilised Agricultural Area (UAA) according to the fields included and livestock husbandry.

have access to semi-natural vegetation, they have to re-organise their arable land and pasture (see farm descriptions in the Appendix A). We assumed that they would re-arrange their own crop field area; meet an increased demand for arable land either by buying or renting crop area for hay, silage, or cultivated pasture; and purchase cereals for feed if necessary. We used average national yields for all the scenarios implied in the study.

2.3. Environmental parameters

We calculated the following five environmental parameters in the CC: GHG emissions, N balance, arable land occupation, biodiversity, and carbon storage (Table 1).

2.3.1. GHG emissions

We calculated GHG emissions at farm and product level in the CC. The tool quantifies LCA-based GHG emissions following international standards, such as those of IPCC, FAO, European Reference Life Cycle Database (ELCD), Organisational Environmental Footprint (OEF) and Product Environmental Footprint (PEF), C footprinting (ISO, 2006a, 2006b, 2013; GHG Protocol (Standard, G.P., 2011); PAS2050:2011 by the British Standards Institution, 2011), and the EnviFood Protocol (Food, S.C.P., 2013). The system boundary applied in the CC was from cradle to farm gate. The included emissions were CO_2, CH_4, N_2O, and hydrofluorocarbons (HFC) from fuel use and burning crop residues, ruminant enteric fermentation and manure management, use of synthetic N fertilizers, and leakage. Emissions from production, transportation, and manufacturing of feeds outside the farm were also included. However, emissions from slaughtering, processing, and packaging were not included. N_2O emissions from volatilization, leaching, and runoff were incorporated. A more detailed description of the method is available in Bochu et al. (2013). Due to the exceptionality of using peat as part of the manure management system in the Nordic countries such as Finland, we added the corresponding emissions of peat to the total final value of GHG emissions per farm. We used peat density (200 kg/m^3) and its emission factor (860 kg CO_2eq/m^3) (Manninen et al., 2016). Four out of eleven farms used peat combined with straw for bedding material. The allocation method used was physical following the ISO 14044 (ISO, 2006b) and the Environmental Footprint guidelines.

2.3.2. Nitrogen balance

The rationale for calculating N balance for the total agricultural area in the CC was to quantify N inputs and outputs from the farms to assess their performance in N use efficiency. This is relevant because of the considerable losses of N from agricultural lands into the surrounding ecosystems in form of leaching or N_2O emissions. The tool assesses soil balance following the CORPEN committee methodology (CORPEN, 2006). For N inputs, we included symbiotic fixation, imported organic matter in manure and bedding straw, manure excreted (estimated), and mineral N fertilizers. N outputs covered N volatilization, organic matter outputs (manure and bedding straw), and N included in the forage and feed. We calculated N fixation separately following the methodology of (Koppelmäki et al., 2019) based on the formula from Anglade et al. (2015). The values used for BNF were 35.77 kg/ha for semi-natural grasslands (yield: 1085 kg DM/ha); 258.56 kg/ha for silage (yield: 6320 kg DM/ha); 285.38 kg/ha for forage (yield: 6320 kg DM/ha); 88 kg/ha for beans (average yield: 1978 kg DM/ha); 0 for cereals (average yield: 2183 kg DM/ha); 216.04 kg/ha for fallow fields (yield: 10578 kg DM/ha); and 5.20 kg/ha for cover crops (yield: 4500 kg DM/ha). We performed a Wilcoxon test to determine the differences between N balance CC calculations and our calculations.

2.3.3. Carbon storage

Carbon storage values were based on the estimate of annual carbon added to the soil per type of field for the total UAA of the farm, including semi-natural grasslands. The calculations were based on farming practices, land use factors for permanent grasslands, temporary grasslands and other annual crop temperate boreal moist fields, input level factor for grasslands (medium or high for improved grasslands), and land management factors for grasslands depending on the biome region (IPCC, 2006). Other relevant aspects, such as overgrazing or the botanical composition of pastures (spssC3/C4 ratio), were not included. In this study, we refer to the carbon storage as the potential or tendency of HNV farms for storing carbon due to the high variance and complexity of the parameter.

2.3.4. Biodiversity

Without having species data for the study farms, we used the semi-natural grassland area of the farms as an indicator of communities of species that are not found or have viable population on arable land, including cultivated grassland (Pöyry et al., 2009; Pykälä, 2005). While all farms have biodiversity associated with farmland to a varied degree (e.g., depending on the network of non-cropped areas and specific practices), only farms that manage semi-natural grasslands have the potential to have what we call here "unique biodiversity". The unique biodiversity was indicated as a percentage contribution of semi-natural grassland to the total UAA of a farm.

2.4. Analysis

Since the alternative farm states were built from the HNV farm data, they are not independent samples. Due to the matched pairs and a low number of sampled farms, we used a non-parametric Wilcoxon test to examine the differences between the HNV farms and their respective alternative state for each environmental parameter.

3. Results

3.1. Comparison between High Nature Value farms and their alternative states

There were significant differences in GHG emissions at the product level and at the farm level, carbon storage, and N balance between HNV farms

Table 1

Parameters, units, level of calculation, and description.

Parameter	Unit	Level	Description
GHG emissions[a]	$tCO_2eq\ ha^{-1}$ UAA	Farm	Sum of CO_2, CH_4, and N_2O emissions produced at the farm in tCO_2eq per hectare of utilised agricultural area (UAA). The alternative farms also include the emissions from the production of the purchased cereals.
GHG emissions[a]	$tCO_2eq\ ha^{-1}\ t\ meat^{-1}$	Product	Sum of emissions allocated to the meat (final product) resulting from the following processes: enteric fermentation, N_2O direct and indirect emissions from soil, manure management, machinery, purchased feed, and mineral fertilizers. The alternative farms also include the emissions from the production of purchased cereals
Nitrogen balance[a]	$N\ kg\ ha^{-1}$	Farm	Difference between total N inputs and total N outputs of the farm
Arable land occupation on HNV farms	ha	Farm	Sum of total hectares covered by cultivated grasslands, forage crops and other crops (excluding semi-natural grasslands) owned, rented, or shared and crop fields of the farm
Arable land occupation on alternative farms	ha	Farm	Sum of total hectares covered by cultivated grasslands, forage crops, and other crops (excluding semi-natural grasslands) owned, rented, or shared and crop fields (including the land area needed for purchased feed) required for maintaining the cattle and beef herd under national regionalised estimates
Biodiversity	% of total UAA	Farm	Percentage of semi-natural grassland from the total farm's UAA of each farm
Carbon storage[a]	tC	Farm	Total tonnes of C sequestrated in the soil from arable land and grasslands of each farm.

[a] Estimated using the Carbon Calculator (CC) from the Joint Research Centre of the European Commission (Tuomisto et al., 2015).

and their alternative state ($p < 0.003$). However, the two farming scenarios, HNV farms and alternative farms, resulted in a similar arable land occupation (Fig. 2).

HNV farms had lower GHG emissions at the farm and product level compared to their alternative states on average (64% and 31%, respectively). All farms showed higher emission values at the farm and product level in their alternative states. Although one farm sample presented particularly high values (682.79 and 979.62 tCO_2eq/t live weight for HNV farm and its alternative state; farm 5), these did not influence the average increase. The standard deviation and standard error of the HNV farms and their alternative state in terms of GHG emissions at the product level had higher values than those at the farm level (Appendix A).

The average N balance value in HNV farms was −46 N kg/UAA; the alternative states increased the value up to 70.8 N kg/UAA (Fig. 2), representing a 235% change between HNV and their alternative state. The alternative states of the farms presented wide variation in relation to N balance values. However, outputs remained higher than inputs for both HNV and alternative farms. The alternative state of farm 3 was an exception, with a value of 239.8 N kg/UAA. For the remaining farms, N balance values ranged from −78.6 N kg/ha to −6.3 N kg/UAA in HNV farms and 13.3 to 239.8 N kg/UAA in alternative farms.

There were significant differences between N fixation values estimated for HNV farms and the alternative farms in the CC and our own estimations ($p < 0.021$ and 0.004, respectively) (Fig. 3). CC values for the HNV farms

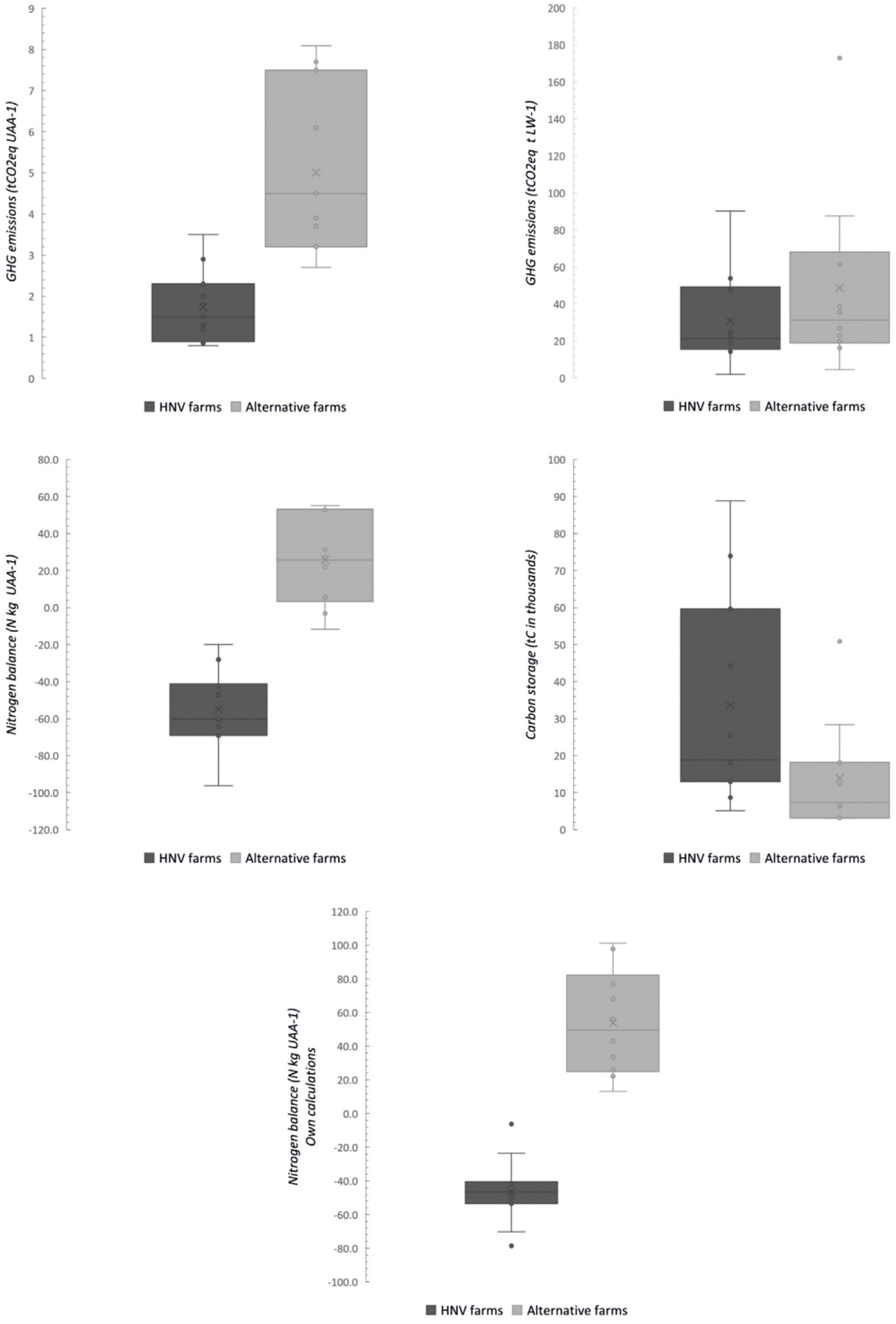

Fig. 2. Median, average, quartile, and outlier values for 11 High Nature Value farms (HNV farms) and their respective alternative farms without semi-natural grasslands (alternative farms) for five environmental indicators: GHG emissions at the product level (tCO_2eq/t LW) (excluding outlier from farm sample number 5) and at the farm level (tCO_2eq/UAA), N balance (N kg/UAA), carbon storage (t C/UAA), and arable land occupation (ha).

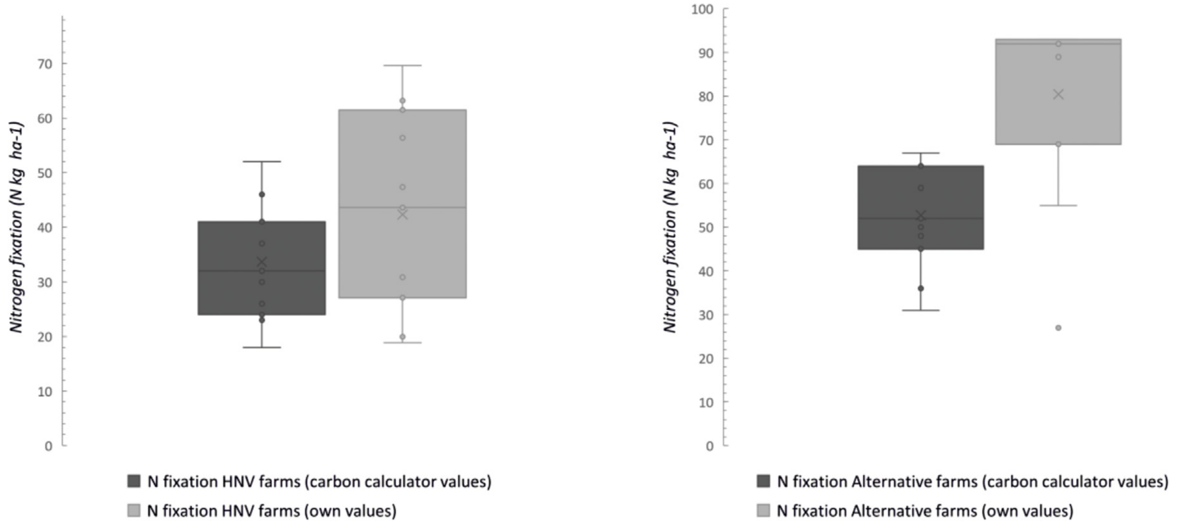

Fig. 3. Median, average, quartile, and outlier values for N balance values for 11 High Nature Value farms (HNV farms) and their associated alternative farms without semi-natural grasslands (Alternative farms).

mean 33.7 N kg/ha and for the alternative farms 52.7 N kg/ha, while our own estimations were average 42.3 N kg/ha and 80.5 N kg/ha, respectively.

The total tonnes of carbon (t C) storage were estimated to be 163% higher on the HNV farms compared to their alternative states. In relation to carbon storage potential, HNV values were twice those from their alternative states (Appendix A).

There were no significant differences for arable land occupation (Fig. 2). Six out of eleven farms would need to increase their access to arable land, imports of feed (e.g., cereal), or both to maintain their levels of production. In contrast, five out of eleven would reduce the required arable land for the same purposes (see Appendix A).

3.2. High Nature Value farms

The environmental impact among HNV farms was similar in GHG emissions at the farm level. However, such impact widely differed in the remaining parameters analysed (GHG emissions at the product level, N balance, carbon storage, and biodiversity) (Appendix A). The main processes that contributed most to total GHG emissions at the product level were enteric fermentation (43%), fertilization (22%), direct N_2O emissions from soil (12%), and fuel consumption (8%) (Appendix A). The sampled farms had two outliers (682.79 and 90.21 tCO_2eq/t LW for HNV farms 5 and 7, respectively) that increased the mean from 19.99 tCO_2eq/t LW (excluding the outlier values) to 90.26 tCO_2eq/t LW. Carbon storage estimations varied along different farms (range 5.1 to 88.9 t C, in thousands). Unique biodiversity values of the HNV farms averaged 48% (range 23% to 83%) (Appendix A).

3.3. Alternative states

Alternative states of the HNV farms had higher variances between the SD and SE along all parameters compared to HNV farms (Appendix A). The main processes that contributed to the total amount of emissions per product remained similar as the HNV farms with an additional process related to indirect N_2O emissions. The averaged contribution to the total was 29% for enteric fermentation, 29% for fertilization, 15% for direct N_2O emissions from the soil, 8% for fuel consumption, and 7% for indirect N_2O emissions (Appendix A). Carbon storage estimations ranged from 3.1 to 50.9 t C (in thousands). Unique biodiversity values were set to 0 for all the alternative states (Appendix A).

4. Discussion

In our study, HNV farms seemed to reduce nutrient loses, act as carbon sinks, and require less arable land for livestock production purposes, while maintaining unique biodiversity. We illustrated how the exclusion of semi-natural grasslands from production could make a farm more dependent on external inputs and increase its requirement for arable land intended for animal feed purposes. The need for increased external inputs results from modification in livestock diets and sourcing the feed from arable land instead of non-cropped semi-natural pasture, which overall contributes to higher GHG emissions at the farm level.

HNV farming systems tended to have low GHG emissions at the farm level compared to alternative farms (those of mainstream production). Such lower emissions were due to the larger carbon sinks (from high amounts of permanent plant coverage) and lower use of mineral fertilizers, amount of feed imports, and proportion of annual crops. However, the variation within GHG emissions at the product level was high among the farms due to differences in farming practices, livestock numbers, and proportion of semi-natural grassland. Farming practices are a key aspect that influences the overall environmental impact of livestock production, as most of the GHG emissions from a product chain occur at the farm gate (Garnett et al., 2017). For example, the HNV farm with the highest GHG emission value initiated its livestock production recently and retained the animals entirely without selling. Thus, that farm had the lowest yield (0.71 t of LW) compared to the remaining farms. This farm receives subsidies for managing semi-natural grasslands (70% of the total UAA of the farm) in production. Although such a system generates biodiversity benefits, it comes at a relatively high environmental cost in relation to other environmental parameters, such as GHG emissions.

Our results suggested that a reduction in GHG emissions should be addressed at the level of farming practices rather than production systems as a whole. A sectoral model for beef production in Finland, which used an alternative metric (GHG*) that reports the different effect between short- and long-term climate pollutants, revealed that the feedlot beef cattle system fed mainly by cereals would achieve a reduction in three GHG emissions when compared with the grass-based system (Lynch et al., 2020). However, we assumed that farming practices of the alternative state farms (without semi-natural grasslands) would remain the same except for mineral fertiliser input. N inputs would increase according to mainstream production to fulfil feed and land requirements for the same amount of livestock (Luke, 2020). Although changes would increase the intensity of production, the alternative states did not correspond to the most intensive possible indoor systems but remained relatively extensive. Still, the resultant GHG emissions were 14% greater in the corresponding alternative states when compared with the HNV farms. Here, we further demonstrated the challenge of describing and analysing extensive farming systems through an input-output system (Ripoll-bosch et al., 2013).

Carbon storage estimations exhibit large uncertainties in GHG inventory (Monni et al., 2007). Due to the complexity behind carbon storage calculations at different levels (Palosuo et al., 2016), we consider our carbon storage estimations as an indication of carbon stock rather than an ultimate value. HNV farms were likely to have a higher capacity for C storage, since they use permanent semi-natural grasslands in production, in contrast with farms with higher use of arable land. Results from semi-natural grasslands in Italy, France, and Hungary indicate their potential to act as a carbon sink (Soussana et al., 2007). However, such estimates cannot be directly applied to Finland due to differences in soil types and climates. Research is currently lacking on the function of semi-natural grasslands as carbon storage in boreal regions. Further research is also needed to quantify if such C storage potential compensates for the overall GHG emissions resulting from grazing, as natural systems appear to be in carbon equilibrium (Sanderson et al., 2004).

HNV farming practices, including low or zero applications of external inputs in the form of inorganic fertilizers or pesticides and the use of on-farm resources such as manure, have the potential to reduce nutrient loss by not exceeding N inputs. However, the average N balance values remained negative for HNV farms. Such values correspond to the difference between N inputs and outputs. Even though N outputs were higher than inputs in the HNV farms, N content in food from fields and animals had the greatest contribution to the final N output value. Losses in forms of leaching or gaseous emissions were not included in N outputs. However, the combination of the use of organic fertilizers, such as manure, and slow N mineralization caused by low temperatures in the Nordic countries results in low yields and low N plant availability (Dahlin et al., 2005; Röös et al., 2017) and contributes to the N deficit. Additionally, maintaining the N balance through legumes in cultivated grasslands may not be sufficient as shown in other farming models for Nordic countries (Karlsson and Röös, 2019). Average N inputs, through N fixing plants, were lower in HNV farms compared to their alternative states due to the use of cover crops and a higher proportion of legumes in cultivated grasslands than in semi-natural grasslands. The use of inorganic fertilizers in addition to the use of N fixing plants at the alternative farms results in a higher N volatilization rate (Bouwman et al., 2002).

Calculations in the Carbon Calculator appear to underestimate N values (as shown for N fixation) when compared to our own estimations based on regional N content data (Luke, 2020). In particular, the nutritional content of semi-natural forage varied depending on the species composition, morphological state of development, and part of the plant used for feed. Seasonality and geographical location are factors that interfere with nutritional content (Koidou et al., 2019). The neutral detergent fibber (NDF) concentration in semi-natural grasslands is higher than in cultivated grasslands, which are represented mainly as silage crops in Finland. Therefore, organic matter digestibility is lower than in cultivated grasslands (Luke, 2021). The CC might require some regionalisation of the data to provide more accurate estimates at regional level, even though the CC tool appeared to be robust when used for a wide sample of European farms (Tuomisto et al., 2015).

HNV farms, by including semi-natural grasslands in production, offer the additional value of freeing arable land to grow crops for direct human consumption or other uses (e.g., bioenergy production) (Karlsson and Röös, 2019; Koppelmäki et al., 2019). Although the total land occupation, including semi-natural grasslands and other natural permanent pastures, was similar on both farm types, HNV farms require less arable land due to their use of semi-natural grasslands. Most semi-natural grasslands are not suitable for arable cropping for human consumption purposes. This is due primarily to soil fertility constraints (e.g. Moog et al., 2002; Wahlman and Milberg, 2002) and difficult terrain; thus, this resource is specifically available for ruminant feeding purposes (Garnett, 2009; Röös et al., 2016). Combined with additional approaches, an optimised use of such a resource would further improve the overall efficiency of livestock production systems.

The proportion of semi-natural habitats currently unmanaged in Finland is estimated to be as high as 80% (Raatikainen et al., 2017). In the boreal regions, other countries have a similar proportion (Herzon et al., 2021). Although not all remaining habitats are suitable for modern cattle production (due to small sizes and fragmentation), there is a clear potential to reintroduce some production and also in integration with field pastures. Such integration delivers biodiversity maintenance while contributing to food production, unlike management of semi-natural habitats exclusively for conservation purposes. The overall environmental impact of such systems depends on a certain level of production, as illustrated here. Such production-conservation integration also lowers the overall conservation costs in contrast with other management options, such as semi-natural grasslands restoration (Oldén et al., 2016).

Semi-natural grasslands in particular achieve biodiversity conservation targets and act as reservoirs of genetic diversity in addition to supporting other ecosystem services, such as carbon stocking, water retention, soil erosion prevention, and aesthetic and cultural values (Herzon et al., 2022). We used the presence of semi-natural grasslands as an indicator of a specific and unique fraction of the overall biodiversity of a farm. By doing this, we do not imply that farms without semi-natural grasslands are devoid of biodiversity. Farms may also have high biodiversity due to other aspects, such as heterogeneity of farmland on various scales (e.g., diverse crops, variety of habitat patches, small field sizes, and networks of margins) (Sirami et al., 2019). However, incorporating biodiversity into multi-criteria assessments presents a particular challenge, largely due to the lack of a common framework and unifying metrics (Crenna et al., 2020; Winter et al., 2017).

The species-richness indicator for one or more taxa is most commonly used in the LCA method (Chaudhary and Brooks, 2018; Knudsen et al., 2017; Tuomisto et al., 2012). However, as the most recent attempt for holistic assessment, conventional LCA methods do not sufficiently consider a wide diversity of farming practices, biogeographical locations, and semi-natural habitat types. Moreover, some HNV farming practices may be suitable for one taxon (i.e., vascular plants) yet detrimental for other taxa (i.e., insects) and vice versa (Bonari et al., 2017). Our focus on semi-natural pastures can be justified by their exceptionally high level of endangered species in Finland, which is true also for many other countries in Northwest (EEA, 2016) and central Europe (Bonari et al., 2017). Future implementation of local biodiversity estimations or management regimes is necessary to improve accuracy in the metrics to assess environmental impacts (Jeanneret et al., 2014). Importantly, environmental assessments focusing mainly on GHG emissions with no consideration of other beneficial aspects (i.e., biodiversity) provide a misleading picture and lead to narrowly focused management recommendations that may result in further biodiversity loss (Reside et al., 2017).

Land management practices are crucial to maintain biodiversity independently of land use type or area type (regardless of protected status) (Hannah et al., 2005). The complexity increases when accounting for landscape composition meaning the share of hectares per land use type, which may determine the final impact on biodiversity (Kremen, 2015). The debate is centred around which approach is more effective to promote biodiversity, land sharing or land sparing (ibid). There are several biodiversity indices for potential or native vegetation in Europe that could be contrasted to those for human-managed land uses (Baker et al., 2016; Hayek et al., 2021). In the boreal region, forest is a native land use type. Under a scenario where semi-natural grasslands continue the ecological succession into forest, it is the management practices of such forest that will define the magnitude of biodiversity loss or gain, compared with the previous succession stage. Most of forests in the region are under heavy commercial use with low biodiversity levels (Siiskonen, 2007). Forest also being the predominant land use type has lower additional values for the overall biodiversity as compared to relatively uncommon semi-natural grasslands. Therefore, abandonment of extensive managed farmland is considered having an adverse impact on biodiversity (Herzon et al., 2022; Plieninger et al., 2014).

With a projected increase in future food demand (Campbell et al., 2017; FAO, 2011), food production places pressure on wildlife conservation (Martin et al., 2020). However, ideally, conservation practices would not reduce the amount of land in production (ibid), although yield may be affected. Relying on further intensification of food-production systems that may result in higher yield may reduce some environmental impacts (such as GHG emissions) but may also exacerbate others (such as loss of biodiversity or other ecosystem services) (Garnett et al., 2017; Tscharntke et al., 2012). When considering all plausible environmental impacts of livestock production systems, HNV farming systems contribute to the sustainability of food systems by freeing arable land for growing food for direct human consumption, enhancing carbon stock, provisioning of biodiversity, and reducing N loses while still producing animal-derived food (Bragaglio et al., 2020; Ripoll-bosch et al., 2013).

This study contributes to the currently limited knowledge on multi-criteria valuation of extensive farming systems. However, due to the lower productivity compared to intensive farming systems, reliance on HNV farming systems may require changes in current dietary patterns. Such changes should shift towards lower intake of animal products and higher reliance on plant protein sources following current dietary recommendations for more sustainable and healthy diets (Godfray et al., 2018; Willett et al., 2019). Further research to evaluate the production capacity and environmental impacts of HNV farming systems may clarify the extent to which HNV systems can supply sustainable animal-derived food.

5. Conclusion

Our results show that ruminant HNV farming systems are comparable in terms of environmental impacts with mainstream production; grazing systems based on cultivated forage dependent to some extent on external inputs. When producing animal-derived food, HNV systems, by including semi-natural grasslands in production, also maintain unique biodiversity, act as carbon sinks, tend to minimize GHG emissions and arable land occupation, and reduce N loses. This work points to further research. Better estimations of biodiversity on semi-natural grasslands (as compared to fields) are needed to more holistically assess the unique contribution of HNV farming systems within the overall environmental impact assessments. From the production perspective, the question remains to what extent HNV systems (with generally lower output than intensive systems) can provide animal products for future, more climate-friendly diets. Other plausible benefits of HNV farming systems, such as quality of animal products (regarding nutrient composition and taste) and carbon storage potential, have yet to be studied in northern climates.

CRediT authorship contribution statement

Miriam Torres-Miralles: Conceptualization, Methodology, Validation, Formal analysis, Writing – Original Draft and Review and Editing, Visualization, Funding acquisition.

Karoliina Särkelä: Methodology, Formal analysis.

Kari Koppelmäki: Methodology, Writing – Review and Editing, Visualization.

Marjukka Lamminen: Methodology, Writing – Review and Editing.

Hanna L. Tuomisto: Methodology, Writing – Review and Editing, Supervision.

Iryna Herzon: Methodology, Writing – Review and Editing, Supervision, Project administration.

Declaration of competing interest

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

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Appendix A. Supplementary data

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