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How to concurrently achieve economic, environmental, and animal welfare performances in French suckler cattle farms

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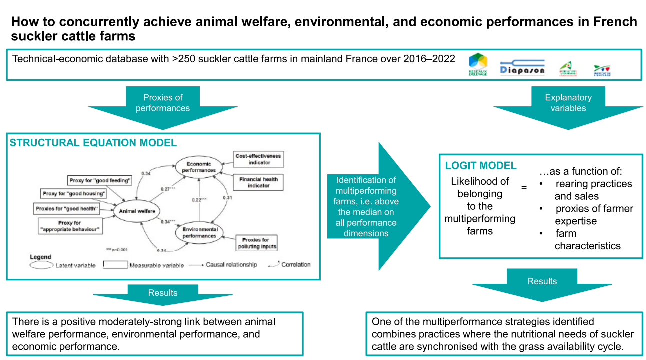
HIGHLIGHTS

- Society wants livestock farms to concurrently deliver animal welfare, environmental and economic performances.
- We investigate whether and how multi-performance is achievable based on technical-economic data of 250 suckler cattle farms.
- We use structural equation modelling to assess the concepts of animal welfare, environmental and economic performances.
- There is a positive moderately-strong link between the three performance dimensions.
- Combining practices that synchronise cattle nutritional needs with the grass growth cycle is a multiperformance strategy.

GRAPHICAL ABSTRACT



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ABSTRACT

CONTEXT: Society has a number of expectations around livestock farming that go beyond mere production and affordable food prices to now encompass high standards of animal welfare and environmental performance.
OBJECTIVE: Here we investigate whether and how it is possible to concurrently achieve good economic, environmental, and animal welfare performances on suckler cattle farms.
METHODS: We extracted economic indicators, proxies for animal welfare and environmental performances, and data describing farming practices and conditions from a technical-economic database featuring data collected from >250 French suckler farms over the period 2016–2022. We analysed the relationships between animal welfare performance, environmental performance and economic performance using a structural equation modelling (SEM) approach. We then used logit models to identify farming practices and conditions that promote 'multiperformance'.
RESULTS AND CONCLUSIONS: Farms that combine practices where nutritional needs of suckler cattle are synchronised with the grass availability cycle are more likely to multiperform. The synchronisation is managed by exploiting certain key animal characteristics (depletion and restoral of body reserves), choosing the right calving season, and selling animals well adapted to grass-feeding.

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SIGNIFICANCE: Combining two analytical models—one establishing the relationships between several performance dimensions and one establishing the relationships between multiperformance and farming practices—allows to bridge the gap between theoretical concepts and concrete farming measures on the topical issue of achieving multiperformance in more than two dimensions, where the literature is still scarce.

1. Introduction

What society values is not necessarily what society actually goes on to implement — a case in point is animal welfare. Based on the latest Eurobarometer survey, 94% of EU citizens think it is important to protect animal welfare and 84% want stronger protection for the welfare of farm animals (European Commission, 2015). However, in the 2023 State of the Union Address delivered on 13 September 2023, the president of the European Commission Ursula von der Leyen did not signal any move to update the animal welfare legislation (European Commission, 2023), despite previous plans to revise it by the end of 2023 (European Commission, 2022). As people face ongoing economic challenges with rising inflation, their priorities are shifting—and with them, political agendas—and these shifts appear to follow Maslow's hierarchy of needs (Maslow, 1943), where the most basic needs need to be met first. The same prioritization also arises with environmental issues. Although the IPCC Sixth Assessment Report (IPCC, 2023) underlines the growing urgency of climate action, people are more preoccupied by 'the end of the month' than by 'the end of the world', an opposition that politicians of all stripes readily exploit. Both animal welfare and environmental impacts are key issues for livestock farming, but this contradiction between the type of agriculture society says it wants and the type of agriculture it actually buys shows that society is not prepared to pay the extra costs that higher animal welfare and environmental standards may entail. This leaves livestock farmers in a stalemate. One way out of the stalemate is to find solutions that can improve both animal welfare and environmental performance without compromising economic performance, or whose additional costs are sufficiently compensated by current higher product prices or subsidies.

Economic results, environmental impacts and animal welfare are inter-related, but not in any straightforward way. Synergies may be possible under certain circumstances as some practices positively impact all three performance dimensions. As an example, reducing stress in farm animals makes them more efficient in terms of milk yield or liveweight gain per feed intake unit (see Coignard et al. (2014) and Hemsworth et al. (2000) for dairy cows, and Faucitano (2018) and Henningsen et al. (2018) for pigs), which in turn helps improve a farm's technical results and also reduces environmental impacts expressed per amount produced. Solutions to achieve this multidimensional performance—or 'multiperformance'—could thus rely on intensifying production, i.e. working on closing potential yield gaps (Godfray et al., 2010). However, high levels of production per animal risk eroding welfare, as seen in high-yielding cows that are more susceptible to mastitis (Coignard et al., 2014; EFSA, 2012). Intensification may also prove counterproductive in the long run from an environmental perspective (Tilman et al., 2002) and does not necessarily lead to a resource-use-efficient overall system (Struik and Kuyper, 2017). A combination of practices that promote economic performance, environmental performance and animal welfare performance is likely to be more successful than simply intensifying animal production.

Here we investigate ways of concurrently achieving multiple performances by studying suckler cattle farming in grassland areas. Suckler cattle farms that produce both beef and live animals attract criticism for their poor economic performance and high environmental footprint: in 2022, the average income for cattle farms in France was €26,580, which is less than half the national average for all farming systems (Agreste, 2023), and cattle farming alone is estimated to generate 8.5% of national greenhouse gas (**GHG**) emissions (Citepa, 2022). Furthermore, the French beef sector is moving to integrate animal welfare requirements into quality labels, such as *Label Rouge* (Interbev, 2022). Suckler cattle farming therefore has a need for solutions that bring multidimensional performance, but the literature on environmental, economic and animal welfare performances is scarce and focused on more intensive livestock systems, such as dairy cows (Brennan et al., 2021; van Calker et al., 2006; Zhu et al., 2023), pigs (Olsen et al., 2023) and broilers (Vissers et al., 2021). The results obtained on suckler cattle farms may not be generalizable to all livestock farms. However, we believe that such an investigation can, through its methodological contributions, help to conduct similar work in other productions.

Each dimension of performance—whether economic, environmental, or welfare-related—is a theoretical concept that cannot be measured directly and encompasses multiple factors. Animal welfare embraces comfort, good functioning thanks to appropriate diets, good health, freedom to express normal behaviours, and presence of positive emotions (Boissy et al., 2007; Botreau et al., 2007; Ofner et al., 2002). Indicators of environmental performance commonly quantify aspects such as GHG emissions, water and air pollution, use of limited natural resources (energy, water, phosphorous, land), and biodiversity (Doreau et al., 2018). Economic performances are split between economic indicators and financial indicators, where economic indicators are typically metrics of costs, profitability, or productivity and efficiency (Latruffe, 2009) whereas financial indicators assess solvency and liquidity issues.

The study of multiperformance requires a database that merges economic, environmental and animal welfare data on a large dataset of farms. To date, in France, there is no national database that combines all three sets of indicators. Technical-economic indicators harness the most extensive set of data, whereas studies on environmental or welfare-related performances most often rely on proxies. We therefore need to find suitable proxies for animal welfare and environmental performances in existing technical-economic databases.

Structural equation modelling (**SEM**) is an analytical framework used to quantify non-directly-observable concepts, whereby all coefficients in the model are determined statistically from a given dataset. SEM can also represent complex models with several simultaneously-estimated causal connections, and go on to calculate coefficients of correlation between concepts (Hair et al., 2021). SEM thus emerges as a compelling method to study the links between economic, environmental, and animal welfare performances.

The aim of this paper is to investigate whether and how it is possible to concurrently achieve good economic, environmental, and animal welfare performances on suckler cattle farms. We examine the relationships between these three performance dimensions via a SEM approach using performance proxies, which we extracted from a national technical-economic database. We then go on to explore the farming conditions that promote multiperformance.

2. Materials and methods

The approach used in this paper involves several steps (Fig. 1):

- a technical-economic database provides proxies for animal welfare (see section 2.1.1), environmental performances (see section 2.1.2) and economic indicators (see section 2.1.3), as well as explanatory variables describing farming practices and conditions (see section 2.1.4),

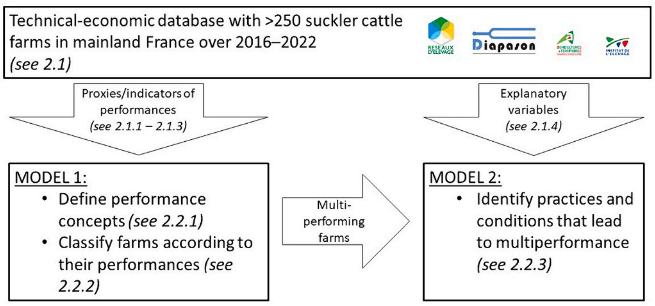

Fig. 1. Summary of the developed approach.

- a first model uses these proxies and indicators to define the concepts of the three performance dimensions (see section 2.2.1) and to classify farms according to their performances (see section 2.2.2),
- a second model combines this farm classification with the explanatory variables from the database to identify the practices and conditions that lead to multiperformance (see section 2.2.3).

2.1. Dataset

We used an unbalanced panel dataset counting 1289 observations made from 2016 to 2022 on 254 suckler cattle farms. This data was extracted from the French DIAPASON database managed by *INOSYS Réseaux d'élevage*, a livestock network operated by the French Livestock Institute and French Chambers of Agriculture (Institut de l'Elevage et Chambres d'Agriculture, 2014). Among the hundreds of variables proposed in the database, we only considered during our variable selection process those that were filled in by the large majority of farms. We kept all farms that had a complete dataset for the selected variables and were surveyed for at least 3 years in order to keep a certain degree of variability in the data. Farms in the sample were either cow–calf producers or cow–calf to finishing producers, and they were either specialised livestock or mixed crop–livestock farms. Cow–calf producers sell live animals to fattening farms. This concerns predominantly male animals as cow–calf producers often fatten their female animals themselves. The live animals are sold mainly as weanlings (at 7–9 months), but sometimes also as older weanlings (at 9–12 months) or young bulls (at 13–17 months). For France, the main market is Italy. Cow–calf to finishing producers sell off finished progeny for slaughter, i.e. they keep their animals from birth to slaughter. Mixed crop–livestock farms in our sample could have a large part of their revenue stemming from crop sales, but all farms had at least 30 livestock unit (**LU**). Farms that also reared other animals were discarded. The database targets farms that, from an economic perspective, rank in the top third of all farms that share the same production system,[1] which therefore biases the sample towards 'best-in-class'. As the aim of this paper is to identify multiperformance systems that work, the bias does not impact the study. The dataset contains technical data and information on each farm's production structure and economic and financial results, as well as certain contextual variables. Technical data includes detailed information on the farm system (related to reproduction, calving, feeding, housing) and certain indicators related to environmental performance. We selected proxies related to animal welfare performance, environmental performance, and indicators for economic performance. All monetary values were expressed in constant-deflator 2016 base-year euros, using the Consumer Price Index deflator (**IPC**) given by the French national statistics bureau (**INSEE**).

2.1.1. Selection of proxies related to animal welfare performance

To select proxies of animal welfare, we used the four principles established by Welfare Quality (2009), i.e. 'good feeding', 'good housing', 'good health', and 'appropriate behaviour'. Welfare Quality, which includes over 30 indicators, does not provide a specific protocol for suckler herds, and the measures defined for dairy cows or fattening cattle to check the four principles were not available in our dataset. Nonetheless, we identified proxies that were closely related to each principle, and made sure that each principle was informed by at least one proxy.

We identified 'average cow weight after calving' as a proxy of 'good feeding', as body weights are highly correlated to body condition scores (**BCS**) as used in the Welfare Quality protocol (2009). In the database, the average weight of cows after calving is estimated each year from the average weight of cull cows, via the following equations[2]:

For cows sold alive to fatteners:

$$\text{Cow weight at calving} = \mathit{Live\ weight} \times 1.08 \quad (1)$$

For finished cows sold for slaughter:

$$\text{Cow weight at calving} = \mathit{Carcass\ weight} \div \mathit{Carcass\ yield}_{breed} \times \mathit{Coefficient}_{breed} \quad (2)$$

where $\mathit{Carcass\ yield}_{breed}$ and $\mathit{Coefficient}_{breed}$ are breed-dependent: e.g. for Charolais cows, carcass yield is 53% and the coefficient is 0.88.

To account for year and breed effects, the variable was reduced and centred according to breed and year, then rescaled to the average weight and standard deviation of the entire sample.

We identified 'mean building costs per LU', i.e. depreciation, maintenance costs and rent, without water and electricity bills, as a proxy of 'good housing', assuming that newer and more expensive buildings would be more comfortable in terms of space per animal and adequate lying area (Adamie and Hansson, 2022).

We identified calf mortality, mortality of cattle other than calves, dystocia rate, abortion rate, mean calving intervals, and rate of 400-day-plus calving intervals[3] as proxies negatively related to 'good health', and pregnancy rate as a proxy positively related to 'good health'.

For the 'appropriate behaviour' principle, we identified estimated amount of feed grazed out of total amount of forage offered as a proxy for access to pasture. In the database, the variable is calculated each year as the difference between estimated consumption of forage dry matter (**DM**) per LU (4750 kg DM per year, the reference used by the French Livestock Institute) and amount of preserved forage distributed to animals.

2.1.2. Selection of proxies related to environmental performance

For environmental performance, impacts are generally deduced from activity data (IPCC, 2006) or information on inputs (Rega et al., 2022). Here, proxies of environmental performance were chosen from among variables characterising intensity of use of inputs, i.e. pesticides, nitrogen (**N**) balance, and total energy consumption. GHG emissions were not considered, as the database did not provide enough information to calculate them. To avoid distortions related to differences between production systems (mixed crop–livestock vs. specialised livestock farms), we calculated pesticide expenditures and N balance for forage area only. Pesticide expenditures were divided by the subindex 'pesticides' of the purchase price index for agricultural inputs (**IPAMPA**) of INSEE to represent a volume index. This index is expressed per hectare (**ha**) of forage. N balance was calculated as:

[1] The appreciation of whether a farm belongs to the top third is done by the agent collecting the data based on economic criteria such as gross operating surplus ratioed to total revenue or cash income per farmer.

[2] These equations were developed based on expert input from professionals and are used by sector professionals.

[3] As the target interval is 365 days (one calf per year), professionals consider a 400-day-plus interval as a sign of problems.

$$N\,balance(kg) = N_{fertilisers}(kg) \times \frac{Fertiliser\,expenditure\,for\,forage\,area\,(EUR)}{Total\,fertiliser\,expenditure\,(EUR)} + N_{manure\,imported}(kg) + N_{irrigation\,water}(kg) + N_{concentrated\,feed}(kg) + N_{purchased\,forage}(kg) + N_{purchased\,straw}(kg) + N_{other\,purchased\,feed}(kg) - N_{manure\,exported}(kg) - N_{forage\,sold}(kg) - N_{straw\,sold}(kg) - N_{liveweight\,sold}(kg) \quad (3)$$

Total energy consumption includes both the direct and indirect energy used for beef production. For mixed crop-livestock farms, the allocation between crop and beef production was done in the database according to Charroin and Ferrand (2010). Direct sources of energy comprise tractor fuels and lubricants, diesel fuel for farm vehicles, electricity in farm buildings or for irrigation, and estimated amounts of fuel and lubricants for outsourced work. We considered indirect sources of energy as energy used to manufacture and transport fertilisers, concentrated feed and purchased forage, which were calculated using fixed coefficients.[4] All energy components were converted into megajoules (**MJ**). N balance and total energy consumption are expressed per 100 kg liveweight.

2.1.3. Selection of indicators of economic performance

For economic performance, we selected 'gross operating surplus ratioed to total revenue' as an indicator of operational profitability (Fischer and Schornberg, 2007). The indicator is defined as:

$$Gross\ operating\ surplus\ ratioed\ to\ total\ revenue = \frac{(Total\ revenue - direct\ costs - animal\ puchases - overhead\ costs)}{Total\ revenue} \quad (4)$$

where *Total revenue* mainly includes sales, inventory changes and subsidies and excludes financial and exceptional income, d*irect costs* mainly include 1) for crops: fertilisers and other soil improvers, pesticides, and seeds, 2) for livestock: purchased feed and veterinary products, and o*verhead costs* mainly include energy and water expenses, machinery and building maintenance expenses, insurances, rents, wages, but excludes depreciations, interests and other financial expenses, remunerations of farm managers.

To avoid construing the term 'profitability' as 'capacity to generate profit' in absolute terms (Fischer and Schornberg, 2007), we preferred to refer to 'gross operating surplus ratioed to total revenue' as an indicator of cost-effectiveness to account for the central role played by 'costs' in the ratio. This ratio is commonly used in France and is very similar to the earnings before interest, taxes, depreciation and amortization (**EBITDA**) margin. Debt-to-asset ratio is an indicator of solvency that we selected to use here to reflect the farm's financial health. Farm and cash income per farmer were initially considered as indicators of income but were later discarded as they suffer high variability related to factors other than technical performance, such as tax optimisation. Unlike for animal welfare performance and environmental performance, we did not restrict economic performance to beef production but instead considered the entire farm's results and balance sheet in order to factor for opportunity costs between production systems. In order to evaluate the effect of crop production on the model parameters, we performed a sensitivity analysis varying the sample according to different thresholds for crop revenue ratioed to total revenue.

2.1.4. Explanatory variables related to practices, farmer expertise and farm characteristics

As explanatory variables for pathways to multiperformance, we considered practices related to feed, herd management, revenue sources and sales, as well as proxies for farmer expertise and farm characteristics and control variables that are external factors not influenced by farmer decisions. We calculated a covariance matrix integrating all the explanatory variables (Appendix, Table B1), and kept only one of the highly-intercorrelated variables (thresholded at a coefficient of correlation above 0.35[5]).

Regarding feed practices, we selected estimated amount of grazed feed, amount of corn silage feed and amount of grass silage feed out of total amount of forage offered. Amount of hay and wrapped haylage feed in total forage were discarded as they correlate with other feed variables of the model. We also discarded amount of concentrate feed in the total ration, as it correlates to feed costs.

Regarding herd management, we considered mean age at first calving, renewal rate, and calving rate in March–April.

Regarding revenue sources and sales, we considered crop revenue[6] ratioed to total revenue as well as percentage of sales (based on heads of livestock) for calves, weanlings, older weanlings, young bulls and heifers sold for fattening, and breeder stock. Percentages of sales for other categories of livestock were discarded as they correlate with other variables of the model, e.g. percentage of sales for cull cows correlates with renewal rate.

Regarding proxies for farmer expertise, we took years of work experience, which we estimated as the difference between survey year and year the farmer set up in business, as well as numerical productivity (number of weaned calves per breeding female) to account for breeder technical skills, and feed costs in constant-value euros per 100 kg liveweight (which included purchased feed and inputs, i.e. fertilisers and other soil improvers, pesticides, seeds, for self-produced feed) to account for management skills.

Regarding farm characteristics, we selected the variables LU and breed. We did not consider utilised agricultural area (**UAA**) and annual work units (**AWU**) as they are correlated with LU in our dataset. Likewise, we did not consider stocking rate and feed self-sufficiency as they are correlated with other variables already included in the model. As control variables, we included year and topographic location according to the less-favoured area (**LFA**) nomenclature of the European Union's Common Agricultural Policy (**CAP**) ('LFA' variable). For LFA, we also looked how it links to degree of specialisation and subsidies.

2.2. Modelling and statistical analyses

2.2.1. Structural equation modelling to analyse relationships between different dimensions of performance

We used **SEM** to causally connect the different dimensions of farm performance (latent variables) that are assessed based on observable variables (measurable variables), i.e. the proxies obtained from the

[4] 'INOSYS – Guide de suivi d'une ferme des réseaux d'élevage', November 2012 (internal document).

[5] This low threshold was chosen in order to keep a reasonable number of variables in the model.

[6] Crop revenue includes inventory changes and excludes production for own use.

database, and to go on to study the links between dimensions of performance. The dimensions of performance are: animal welfare performance (**AW**), environment performance (**ENV**), and economic performance (**ECO**).

SEM essentially encompasses two main approaches: covariance-based (**CB**) SEM, and partial least square (**PLS**)-based SEM. We opted for the PLS method for the following reasons (Hair et al., 2021): 1) our latent variables are defined in a formative way, i.e. the latent variables are considered as composite variables, where each proxy (measurable variable) represents a single aspect of the concept and the proxies combined together form the concept, 2) we look for unique values of latent variables to be able to relate them to explanatory variables that are not part of the model, 3) the PLS method allows to build complex models from a limited number of data.

In PLS-SEM, the connections between latent variables are represented by causal relationships and form the structural model. They are quantified using what are called 'path coefficients', which are calculated using partial least squares regression. The relationships between the measurable variables, i.e. our proxies, and their respective latent variables form the measurement models. The latent variables are calculated as a weighted sum of proxies (the formative way). The relationships between the latent and measurable variables are designated as 'weights' (Hair et al., 2021). We refer to the weighted sum of the latent variables as the 'score' of the respective performance dimension. We then calculated correlation coefficients between AW, ENV and ECO scores.

The parameters of the model developed here using our SEM approach ('SEM model') were calculated in R version 4.2.1 using the R package 'seminr' (R Core Team, 2022). The level of significance of the path coefficients and weights of the SEM model were determined with a bootstrap method (Hair et al., 2021). Proxies were kept in the model when their weight had a p-value less than or equal to 0.1. Abortion rate and dystocia rate were discarded based on this criterion. Mean calving interval and rate of 400-day-plus calving intervals were also discarded to increase the overall significance of the model, keeping pregnancy rate as the only indicator of reproduction.

2.2.2. Comparison of farms with high vs. low performances

Eight groups of farms were distinguished on the basis of whether their scores for AW, ENV and ECO were high (above the median of the whole dataset) vs. low (equal to or below the median). Groups 1, 2, 3 and 4 ('AW+' groups) scored high for AW, Groups 1, 3, 5 and 7 ('ENV+' groups) scored high for ENV, and Groups 1, 2, 5 and 6 ('ECO+' groups) scored high for ECO. Group 1 thus scored high in all three dimensions, and will be further referred to below as the 'Multiperforming' group. Groups performing poorly on a given dimension are referred to as 'AW–' groups, 'ENV–' groups or 'ECO–' groups.

We compared the means of performance proxies and other descriptive variables between the various groups by applying the pairwise Wilcoxon rank-sum test for clustered data from the R-package 'clusrank' (Jiang et al., 2020), with threshold for significance set at 0.1. As cluster, we set the farm identification number and used the 'Datta and Satten' (DS) method, which allows the same cluster to belong to different groups (Jiang et al., 2020). The method was run several times according to the relevant grouping for a particular comparison.

For each farm-year observation, we further calculated to which quantile their AW, ENV and ECO scores belonged to. We then computed the average quantile per relevant group and for each dimension of performance.

2.2.3. Econometric analysis

We used a random-effects panel-data logit model to assess the probability of a farm belonging to the Multiperforming group depending on its practices, its farmer expertise, and its farm characteristics. This model allows us to account for the panel structure of our data, as well as for unobserved heterogeneity. We used the xtlogit function of Stata (StataCorp, 2021). We compared this random-effects panel-data logit model to the standard logit model, where farm-year observations are considered as independent from each other, as we were unable to account for the panel structure in the SEM model and so we wanted to make sure that the results also hold under the assumption of independent farm-year observations. The models result in coefficients, whose interpretation is focused on their sign and not on their magnitude, as their magnitude is on a log-odds scale (Cameron and Trivedi, 2022).

We used the predicted probabilities of the panel-data logit model to further analyse the characteristics of the Multiperforming group, and in particular to identify the differences between the true positives (multiperformers correctly predicted by the model) and the false negatives (multiperformers not predicted as such by the model) using the pairwise Wilcoxon test (see section 2.2.2). To assess the quality of the model, we used a cutpoint where probability equals 0.5 to calculate sensitivity, i.e. the proportion of multiperforming-group farms correctly identified as multiperformers, and specificity, i.e. the proportion of non-multiperforming-group farms correctly identified as non-multiperformers, as well as the cutpoint-independent measure called 'area under the receiver operating characteristic (**ROC**) curve' by graphing sensitivity versus one minus specificity (Mandrekar, 2010).

2.3. Description of the sample

2.3.1. Variables in the SEM model

Based on the methods described above, the variables that were ultimately retained for the SEM model are: mean cow weight after calving adjusted for year and breed, mean building costs per LU, calf mortality, other-category mortality, pregnancy rate, and estimated amount of feed grazed out of total amount of forage offered for AW; pesticide volume index per forage area, nitrogen balance per 100 kg liveweight, and energy consumption per 100 kg liveweight for ENV; gross operating surplus ratioed to total revenue, and debt-to-asset ratio for ECO.

For the AW variables, the farm sample had a mean cow weight after calving adjusted for year and breed of 750 kg, ranging from 535 up to almost 1000 kg. Mean building costs averaged €75 per LU, ranging from close to zero for fully-depreciated older buildings with low maintenance costs up to €413 per LU. Calf mortality ranged from zero to over 25% of births. Mortality of other animals (i.e. other than calves) was nearly always below 1% but could be up to 9%. Mean pregnancy rate was over 90%. Grazed feed represented on average half of total forage in terms of DM (Table 1).

For the ENV variables, the pesticide index ranged from 0 to ten times the average. N balance was negative for some farms, meaning that more N was exported than imported, and reached >50 kg N per 100 kg liveweight for others. Energy consumption ranged by a factor of nearly 12 between farms (Table 1).

For the ECO variables, gross operating surplus rationed to total revenue averaged close to 32% and reached over 55% for the best performers. Debt-to-asset ratio averaged close to 36%, but some farms had higher debt than the value of their assets (Table 1).

2.3.2. Variables in the logit models and other descriptive variables

Regarding feed, the percentages of grazed forage and corn silage feed (Table 2) and preserved grass-based forage including grass silage feed were 54%, 8% and 34%, respectively, which correspond to the averages for cattle farms in France (Cordier et al., 2020).

Average renewal rate was around 24%, ranging from 5% to 44%. Mean age at first calving was around 35 months, ranging from 24 to 42 months, which are acceptable values according to Bovins Croissance (2020). Calving rate in March–April was 14%, which is below the 16.7%

Table 1
Description of the sample on the variables included in the structural equation model for the three dimensions: animal welfare performance (AW), economic performance (ECO), and environmental performance (ENV).

Dimension	Criteria	Variable	N	Mean	SE	Mean of the 1%-quantile[1]	Mean of the 99%-quantile[1]
AW	Good feeding	Adjusted mean cow weight after calving (kg)	1289	750	2	535	967
	Good housing	Mean building costs (€/LU)	1289	75	1.7	0	413
	Good health	Calf mortality (%)	1289	7.86	0.13	0	26.4
		Other-category mortality (%)	1289	0.876	0.043	0	9.363
		Pregnancy rate (%)	1289	91.8	0.2	57.5	100
	Appropriate behaviour	Estimated amount of feed grazed out of total forage offered (%)	1289	54.4	0.4	0.4	80.8
ENV		Pesticide index per ha forage area	1289	0.068	0.003	0	0.692
		Nitrogen balance (kg N/100 kg live-weight)	1289	13	0.2	−2.3	51.2
		Energy consumption (MJ/100 kg liveweight)	1289	2710	40	1140	12,950
ECO		Gross operating surplus ratioed to total revenue (%)	1289	32.2	0.3	5.1	56.4
		Debt-to-asset ratio (%)	1289	36.4	0.5	1.6	110.4

[1] To preserve full anonymity of participating farms, we present the averages of the 1%-quantile and 99%-quantile instead of min and max values.

Table 2
Description of the sample on the explanatory variables in the logit models and other descriptive variables.

	Variable	**N**	**Mean**	**SE**	**Mean of 1%-quantile** [1]	**Mean of 99%-quantile** [1]
Feed	Estimated amount of feed grazed out of total forage offered (%) [2]	1289	54.4	0.4	0.4	80.8
	Amount of corn silage feed out of total forage offered (%) [2]	1289	7.78	0.26	0	42.76
	Amount of grass silage feed out of total forage offered (%) [2]	1289	5.61	0.21	0	33.04
	Amount of wrapped haylage feed out of total forage offered (%)	1289	8.08	0.24	0	46.7
	Amount of hay feed out of total forage offered (%)	1289	20	0.3	0	72.6
	Amount of straw feed out of total forage offered (%)	1289	1.93	0.12	0	28.9
	Amount of concentrate feed out of total ration (%)	1289	11	0.1	1.5	30.9
Herd management	Renewal rate (%) [2]	1289	23.5	0.2	5.3	44
	Mean age at first calving (months) [2]	1289	34.8	0.1	23.8	42.1
	Rate of calving before 30 months (%)	1289	9.71	0.63	0	100
	Calving in Jan-Feb (%)	1289	17.8	0.5	0	83.1
	Calving in Mar-Apr (%) [2]	1289	14.1	0.4	0	83.8
	Calving in May-Jun (%)	1289	5.21	0.22	0	42.25
	Calving in Jul-Aug (%)	1289	9.5	0.43	0	80.67
	Calving in Sep-Oct (%)	1289	27.2	0.7	0	95.8
	Calving in Nov-Dec (%)	1289	26.2	0.7	0	92.2
Revenue, subsidies, sales	Beef revenue ratioed to total revenue (%)	1289	54.4	0.4	13.4	82.2
	Crop revenue ratioed to total revenue (%) [2]	1289	12.3	0.5	0	68
	Subsidies ratioed to total revenue (%)	1289	28.9	0.3	8.4	57.9
	Sales of calves (%) [2]	1289	8.34	0.55	0	90.32
	Sales of weanlings for fattening (%) [2]	1289	26.1	0.8	0	81.8
	Sales of older weanlings for fattening (%) [2]	1289	10.3	0.5	0	77.8
	Sales of heifers and young bulls for fattening (%) [2]	1289	1.53	0.17	0	47.42
	Sales of animals for slaughter excluding calves and cull cows (%)	1289	26.1	0.8	0	92.6
	Sales of cull cows (%)	1289	22.3	0.2	2.2	48.8
	Sales of breeder stock (%)[2]	1289	5.37	0.27	0	50.72
Farmer expertise	Work experience (years) [2]	1289	22.3	0.3	0.6	48.3
	Feed costs (€/100 kg liveweight) [2]	1289	73.8	0.9	20.3	231.6
	Numerical productivity (%) [2]	1289	87.1	0.2	49.7	105.4
Farm characteristics	Utilised agricultural area (UAA) (ha)	1289	168	2	39	418
	Livestock units (LU) [2]	1289	160	2	43	448
	Annual work units (AWU)	1289	1.85	0.02	0.99	4.48
	LU per AWU	1289	90.6	0.9	25.7	197.7
	Stocking rate	1288	1.52	0.02	0.49	7.45
	Feed protein self-sufficiency (%)	1289	85.5	0.3	34.9	100
	Feed energy self-sufficiency (%)	1289	89.8	0.3	40.4	100
	Breeds	1289	Aubrac, Blonde d'Aquitaine, Charolaise, Limousine, Gasconne, Parthenaise, Salers			
Control variables	Year [2]	1289	2016, 2017, 2018, 2019, 2020, 2021, 2022			
	Less-favoured areas (LFA) [2]	1289	Plain, Disadvantaged mountain simple, Piedmont, Mountain, High mountain			

[1] To preserve full anonymity of participating farms, we present the averages of the 1%- and 99%-quantiles instead of min and max values.
[2] Variables used in the logit models.

(=2/12) that would assume a uniform distribution throughout the year (Table 2).

Average crop revenue ratioed to total revenue was around 12%, ranging from farms with no crop production to farms where crops represented two third of revenue. Regarding sales of animal categories, the farms differed widely, although weanlings tended to represent the largest share (Table 2).

The farmers' work experience averaged 22 years. Numerical productivity averaged around 87%, ranging from 50% to 105%. Feed costs averaged €74 per 100 kg liveweight. Average LU, UAA and AWU were 160, 168 ha and 1.85 in the sample, whereas the French averages for cattle farms were 121, 111 ha and 1.38 in 2018 (Agreste, 2019), respectively; thus, the farms in the sample were larger in terms of absolute LU and UAA, but similar if expressed per AWU (Table 2).

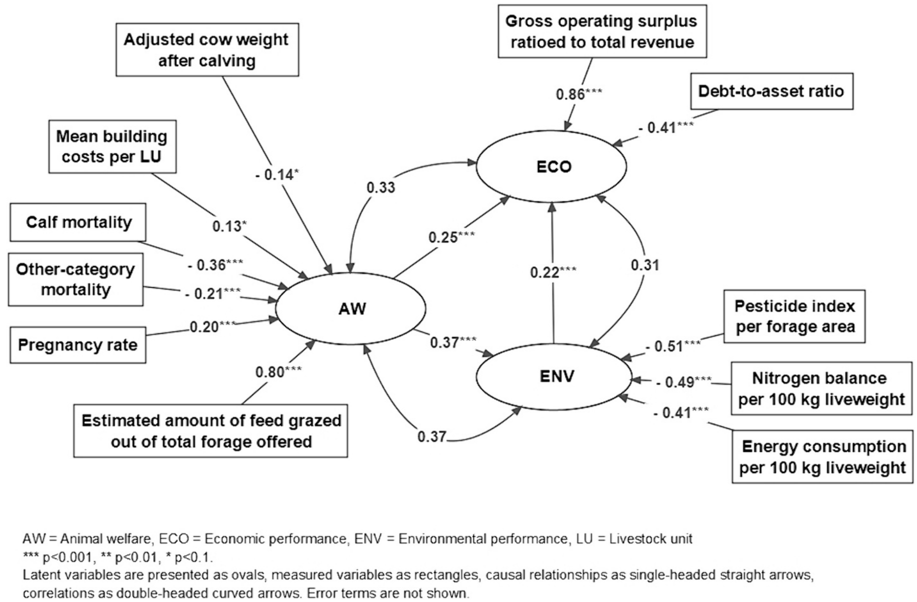

Fig. 2. Structural equation model relating the latent variables animal welfare performance (AW), environmental performance (ENV) and economic performance (ECO) to measured variables on 1289 suckler cattle farm–year observations over the period 2016–2022.

3. Results

3.1. Contribution of variables to the SEM model and connections between performances

The weights of proxies in the latent variables varied between years over the 2016–2022 period, but their signs remained stable, except for mean building costs per LU and other-category mortality for one year and adjusted cow weight for two years, although in these cases the weights were close to zero (Appendix, Fig. A1). The coefficients of correlation between performance dimensions also varied between years over the 2016–2022 period, but always remained positive at close to or above 0.3, except the coefficient of correlation between ENV and ECO in 2021 where the coefficient dropped to 0.11 (Appendix, Fig. A2). We therefore elected to keep the model based on the pooled data over all seven years.

Estimated amount of feed grazed out of total forage offered, pregnancy rate and mean building costs per LU were positively related to the latent variable AW, whereas calf mortality, other-category mortality and adjusted cow weight were negatively related to AW. Pesticide index per forage area, N balance per 100 kg liveweight, and energy consumption per 100 kg liveweight all had negative weights of similar magnitude in the latent variable ENV. Gross operating surplus ratioed to total revenue had a high positive weight in the latent variable ECO, whereas debt-to-asset ratio had a high negative weight in ECO (Fig. 2).

The three latent variables were positively correlated with each other, with a coefficient of 0.37 between AW and ENV scores, 0.33 between the AW and ECO scores, and 0.31 between ENV and ECO scores (Fig. 2).

Consistent with these correlations, the causal relationships between AW and ENV, between AW and ECO, and between ENV and ECO were all positive. As the path coefficients represent linear regression coefficients, increasing the AW score by 1 would impact the ENV score by 0.37 and impact the ECO score directly by 0.25 and indirectly (via the ENV score) by 0.08 (Fig. 2).

The weights of proxies in the latent variables and the path coefficients remained rather stable for samples with different thresholds for crop revenue ratioed to total revenue, except for the variable 'debt-to-asset ratio', whose weight drops as the proportion of crops in total revenue diminishes (Appendix, Fig. A3).

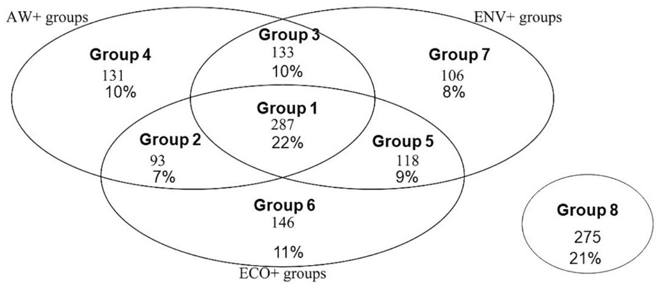

Fig. 3. Classification of farms according to their performance in the dimensions animal welfare performance (AW+ groups), environmental performance (ENV+ groups) and economic performance (ECO+ groups) based on scores calculated from the SEM model.

3.2. Description of groups using a performance classification based on the SEM model

The farms fell into 8 performance groups based on the scores calculated using the weights given by the SEM model. Of the 1289 farm–year datapoints (on average 180 farms per year over the 2016–2022 period), 22% fell into Group 1 – the Multiperforming group – featuring scores above the median in all dimensions, and 21% fell into Group 8 featuring scores below the median in all dimensions. The distribution into the other groups varied between 7% and 11% (Fig. 3).

Farms in the Multiperforming group on average ranked among the 27% best scores in each dimension, which is superior to farms focusing only on one or two of the respective performance dimensions (Tables 3–5).

The Multiperforming group did not differ from the other AW+ groups on AW proxies except for gross liveweight production per LU (lower) and estimated amount of feed grazed out of total forage offered (higher). AW+ groups differed from AW- groups on AW proxies for gross liveweight production per LU, mean building costs per LU, calf mortality, other-category mortality, pregnancy rate, and estimated amount of feed grazed out of total amount of forage offered. Calf mortality and other-category mortality were around twice as high in AW- groups than AW+ groups. Average pregnancy rates were about three percentage-points higher in AW+ groups than AW- groups (Table 3).

Table 3
Comparison of mean values for animal welfare performance (AW) proxies between the Multiperforming group (performing well on all dimensions), other groups performing well on AW (AW+ groups), and groups performing poorly on AW (AW- groups).

		Multiperforming group	Other AW+ groups	AW- groups
	Number of farms	287	357	645
	AW quantile	26.8 (13.7) a	32.5 (14) b	80 (14.2) c
Good feeding	Adjusted cow weight after calving (kg)[1]	740 (68) a	756 (80) a	750 (76) a
	Gross liveweight production (kg/LU)	320 (51) a	333 (61) b	345 (81) c
Good housing	Mean building costs (€/LU)[1]	82.7 (62.4) a	80.2 (70.9) a	68.6 (49.3) b
Good health	Calf mortality (%)[1]	5.88 (3.21) a	6.09 (3.15) a	9.71 (4.89) b
	Other-category mortality (%)[1]	0.483 (0.798) a	0.49 (0.841) a	1.26 (1.97) b
	Pregnancy rate (%)[1]	93.7 (5.4) a	93 (6) a	90.3 (8.9) b
	Mean calving interval (days)	378 (14) a	379 (16) a	382 (28) a
	Rate of 400-day-plus calving intervals (%)	18.9 (11.6) a	19.4 (13.1) a	20.6 (13.9) a
	Dystocia rate (%)	4.06 (9.2) a	3.83 (4.39) a	3.76 (5.03) a
	Abortion rate (%)	0.427 (0.946) a	0.496 (1.047) a	0.436 (1.11) a
Appropriate behaviour	Estimated amount of feed grazed out of total forage offered (%)[1,2]	63.5 (6.5) a	62.1 (7.2) b	46.1 (13.3) c

Standard deviations in brackets.
[1] Variables used in the structural equation model.
[2] Variables used in the logit model. a,b,c: values within a row with no common letter differ significantly (Wilcox-test: $p \leq 0.10$).

Table 4
Comparison of mean values for environmental performance (ENV) proxies between the Multiperforming group (performing well on all dimensions), other groups performing well on ENV (ENV+ groups), and groups performing poorly on ENV (ENV- groups).

	Multiperforming group	Other ENV+ groups	ENV- groups
Number of farms	287	357	645
ENV quantile	27.4 (13.8) a	32 (14.1) b	80 (14.2) c
Pesticide index per ha forage area[1]	0.023 (0.032) a	0.026 (0.034) a	0.112 (0.124) b
Fertiliser index per ha forage area	0.335 (0.244) a	0.32 (0.263) a	0.729 (0.459) b
Nitrogen balance (kg N/100 kg liveweight)[1]	7.87 (3.59) a	8.41 (3.86) a	17.9 (8.1) b
Energy consumption (MJ/100 kg liveweight)[1]	2060 (460) a	2240 (510) b	3270 (2060) c
Permanent grassland per UAA (%)	64.2 (25.2) a	54.8 (26.4) b	41.1 (23) c

[1] Variables used in the structural equation model. a,b,c: values within a row with no common letter differ significantly (Wilcox-test: $p \leq 0.10$). Standard deviations in brackets.

Table 5
Comparison of mean values for economic performance (ECO) indicators between the Multiperforming group (performing well on all dimensions), other groups performing well on ECO (ECO+ groups), and groups performing poorly on ECO (ECO- groups).

	Multiperforming group	Other ECO+ groups	ECO- groups
Number of farms	287	357	645
ECO quantile	26.2 (14.2) a	33 (13.4) b	80 (14.2) c
Gross operating surplus ratioed to total revenue (%)[1]	40.3 (6) a	37.7 (5.3) b	25.6 (6.6) c
Gross operating surplus (€/AWU)	57,100 (21400) a	62,300 (25100) b	46,300 (18500) c
Farm income (€/farmer)	27,800 (20500) a	34,300 (25400) b	14,800 (20000) c
Cash income (€/farmer)	36,400 (22600) a	41,300 (25400) b	19,300 (21800) c
Debt-to-asset ratio (%)[1]	27.4 (15.4) a	30.4 (14) a	43.7 (21) b
Capital intensity (€/AWU)	125,100 (48900) a	144,600 (55300) b	145,000 (49800) b

[1] Variables used in the structural equation model. a,b,c: values within a row with no common letter differ significantly (Wilcox-test: $p \leq 0.10$). Standard deviations in brackets.

The Multiperforming group had lower energy consumption per 100 kg liveweight and a higher ratio of permanent grassland to UAA than the other ENV+ groups. ENV+ groups differed from ENV- groups on all ENV proxies (Table 4).

Regarding economic performance, the Multiperforming group had a higher gross operating surplus ratioed to total revenue but a lower gross operating surplus per AWU and lower farm or cash income per farmer than the other ECO+ groups. In other words, the Multiperforming group managed to achieve high cost-effectiveness but at low levels of production, which fits with a lower capital intensity (Table 5). The ECO- groups perform worse than the Multiperforming group and the other ECO+ groups on all ECO proxies, and are also more capital-intensive than the Multiperforming group.

3.3. Probability of multiperforming based on a set of practices and farm(er) characteristics

The two variants of the logit model used to assess the probability of a farm belonging to the Multiperforming group – the panel-data logit model and the standard logit model – gave very similar outcomes, and so the results can be considered robust.

Regarding feed practices, the probability of belonging to the Multiperforming group decreased with amount of corn silage feed out of total forage offered, but increased with estimated amount of feed grazed out of total forage offered (Table 6). Thus, more grass-based feed improved the chances of performing well in all three dimensions.

Regarding herd management, older mean age at first calving

Table 6
Contribution and significance of farm practices and other explanatory variables in two logit models assessing the probability of belonging to the Multiperforming group.

	Variable	Panel-data logit[1] Coefficient	Standard logit[2] Coefficient
Feed	Estimated amount of feed grazed out of total forage offered (%)	0.141*** (−0.0181)	0.118*** (−0.0136)
	Amount of corn silage feed out of total forage offered (%)	−0.0781*** (−0.0276)	−0.0582*** (−0.0194)
	Amount of grass silage feed out of total forage offered (%)	−0.0124 (−0.0226)	−0.0204 (−0.0154)
Herd management	Renewal rate (%)	0.00112 (−0.0243)	0.000222 (−0.0181)
	Mean age at first calving (months)	0.105 (−0.0745)	0.102** (−0.0498)
	Calving in March–April (%)	0.0115 (−0.00979)	0.0075 (−0.00696)
Revenue/sales	Crop revenue ratioed to total revenue (%)	−0.0220* (−0.0115)	−0.0193** (−0.00808)
	Sales of calves (%)	0.0217** (−0.00952)	0.0175** (−0.00697)
	Sales of weanlings for fattening (%)	0.0154** (−0.0072)	0.0151*** (−0.00475)
	Sales of older weanlings for fattening (%)	0.0149* (−0.00811)	0.0118** (−0.0056)
	Sales of heifers and young bulls for fattening (%)	0.0288 (−0.0214)	0.0261** (−0.0123)
	Sales of breeder stock (%)	−0.0079 (−0.0154)	−0.0038 (−0.0108)
Farmer expertise	Work experience (years)	0.0347** (−0.0147)	0.0303*** (−0.00986)
	Numerical productivity (%)	0.128*** (−0.0203)	0.102*** (−0.014)
	Feed costs (€/100 kg liveweight)	−0.0521*** (−0.00751)	−0.0417*** (−0.00499)
Farm characteristics	Livestock units (LU)	−0.00247 (−0.00253)	−0.000978 (−0.00156)
	Breed = AUBRAC (base)		
	Breed = BLONDE D'AQUITAINE	−2.892** (−1.19)	−2.191*** (−0.838)
	Breed = CHAROLAIS	−2.047** (−1)	−1.544** (−0.641)
	Breed = GASCON	1.861 (−1.975)	1.31 (−1.209)
	Breed = LIMOUSIN	−1.747* (−0.959)	−1.267** (−0.607)
	Breed = PARTHENAISE	−0.234 (−1.836)	−0.012 (−1.193)
	Breed = SALERS	−1.245 (−1.043)	−0.931 (−0.657)
Control variables	Year = 2016 (base)		
	Year = 2017	0.385 (−0.361)	0.288 (−0.323)
	Year = 2018	−0.392 (−0.393)	−0.207 (−0.327)
	Year = 2019	−0.782** (−0.399)	−0.526 (−0.336)
	Year = 2020	−0.454 (−0.399)	−0.188 (−0.345)
	Year = 2021	0.0177 (−0.388)	0.102 (−0.35)
	Year = 2022	1.202*** (−0.41)	1.031*** (−0.368)
	Less-favoured area (LFA) = Plain (base)		
	LFA = Simple disadvantaged area	1.532*** (−0.439)	1.175*** (−0.333)
	LFA = High mountain	−2.051 (−1.751)	−1.602 (−1.07)
	LFA = Mountain	1.779*** (−0.582)	1.401*** (−0.394)
	LFA = Piedmont	1.447** (−0.679)	1.292*** (−0.438)
	Constant	−21.66*** (−3.951)	−18.68*** (−2.728)
	Observations	1289	1289
	Farms	254	

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.
[1] Model accounting for the panel structure of the data and for unobserved heterogeneity.
[2] Model considering farm–year observations as independent.

Table 7
Classification of farm–year observations with respect to their correct or wrong classification to the respective groups based on two logit models assessing the probability to belong to the Multiperforming group (Group 1).

	Panel-data logit[1]		Standard logit[2]	
	True positives	False negatives	True positives	False negatives
Group 1	171	116	177	110
	True negatives	False positives	True negatives	False positives
Group 2	84	9	83	10
Group 3	105	28	100	33
Group 4	126	5	124	7
Group 5	108	10	106	12
Group 6	143	3	143	3
Group 7	103	3	103	3
Group 8	275	0	275	0
Sensitivity[3]	59.6%		61.7%	
Specificity[3]	94.2%		93.2%	
Correctly classified[3]	86.5%		86.2%	
Area under ROC curve				91.5%

[1] Model accounting for the panel structure of the data and for unobserved heterogeneity.
[2] Model considering farm–year observations as independent.
[3] Cutpoint set at probability = 0.5.

increased the probability of belonging to the Multiperforming group (only in the standard logit model). Among revenue sources and sales practices, selling more young bulls and heifers for fattening (only in the standard logit model) and selling more calves and more weanlings (male and female) increased the probability of belonging to the Multiperforming group, whereas selling crops decreased this probability (Table 6). If we ran an alternative model using animals sold for slaughter (excluding calves and cull cows) rather than sold on for fattening, selling more animals for slaughter reduced the probability of multiperforming (Table B5 in Appendix). Thus, both models are consistent with each other.

Regarding proxies for farmer expertise, years of work experience, technical skill (approximated by numeric productivity) and management skill (approximated by keeping feed costs low) increased the probability of multiperforming.

Regarding farm characteristics, the hardy breed Aubrac was more likely to be among the multiperformers than high-performing breeds (Blonde d'Aquitaine, Charolais, Limousin). Compared to 2016, farms were less likely to multiperform in 2019 (only in panel-data logit model) but more likely to multiperform in 2022. The topographic location ('LFA') of the farms also had an effect on probability of belonging to the Multiperforming group; all non-plain areas except high mountains increased the chances of multiperforming compared to a plain-area localisation (Table 6).

Table 8
Comparison of mean values for practices, proxies for farmer expertise, and farm characteristics between the Multiperforming group (performing well on all dimensions) and the other groups, based on the panel-data model.

		Panel-data logit model		
		Multiperforming group True positives	False negatives	Other groups
	Number of farms	171	116	1002
Feed	Estimated amount of feed grazed out of total forage offered (%)[1,2]	65.2 (6.5) a	61 (5.7) b	51.8 (13.8) c
	Amount of corn silage feed out of total forage offered (%)[2]	1.78 (3.34) a	4.48 (6) b	9.18 (9.85) c
	Amount of grass silage feed out of total forage offered (%)[2]	2.82 (5.43) a	4.72 (6.6) b	6.2 (7.93) c
	Amount of wrapped haylage feed out of total forage offered (%)	7.75 (6.83) a	8.09 (6.49) a	8.13 (9.13) a
	Amount of hay feed out of total forage offered (%)	20.9 (8.5) a	19.5 (10.1) a	19.9 (13.1) a
	Amount of straw feed out of total forage offered (%)	0.852 (1.739) a	1.48 (2.26) a	2.17 (4.7) a
	Amount of concentrate feed out of total ration (%)	7.55 (3.1) a	9.59 (3.75) b	11.8 (5.3) c
Herd management	Renewal rate (%)[2]	21.6 (6.1) a	22.7 (5.5) ab	24 (6.7) b
	Mean age at first calving (months)[2]	35.2 (1.6) a	35.2 (1.6) ab	34.7 (2.6) b
	Rate of calving before 30 months (%)	6.22 (16.55) a	5.7 (14.96) a	10.8 (24.1) a
	Calving in Jan-Feb (%)	24.9 (20.6) a	19.5 (16.9) ab	16.3 (16.9) b
	Calving in Mar-Apr (%)[2]	18.6 (16.3) a	12.9 (12.8) b	13.5 (14.5) b
	Calving in May-Jun (%)	4.4 (6.35) a	3.76 (6.08) a	5.51 (8.44) a
	Calving in Jul-Aug (%)	5.34 (11) a	4.78 (9.7) a	10.8 (16.4) b
	Calving in Sep-Oct (%)	19.6 (25.9) a	25.9 (27.4) ab	28.6 (25.8) b
	Calving in Nov-Dec (%)	27.2 (24.6) a	33.1 (26.2) a	25.3 (23.5) a
Revenue, subsidies, sales	Beef revenue ratioed to total revenue (%)	56.3 (9.4) a	54.9 (12.7) a	54 (15.1) a
	Crop revenue ratioed to total revenue (%)[2]	4.44 (10.08) a	8.94 (14.8) b	14 (18.2) c
	Subsidies ratioed to total revenue (%)	36 (9.3) a	31.6 (9.9) b	27.4 (8.8) c
	Sales of calves (%)[2]	6.05 (14.05) a	7.98 (19.91) a	8.77 (20.32) a
	Sales of weanlings for fattening (%)[2]	35 (28.4) a	29.5 (25.6) ab	24.1 (26.5) b
	Sales of older weanlings for fattening (%)[2]	19.5 (25.2) a	13.7 (23.2) ab	8.33 (17.61) b
	Sales of heifers and young bulls for fattening (%)[2]	4.37 (13.14) a	1.11 (3.19) ab	1.09 (3.93) b
	Sales of animals for slaughter excl. Calves and cull cows (%)	9.42 (15.52) a	20 (24.9) b	28.8 (28.9) c
	Sales of cull cows (%)	18.4 (8.3) a	21.2 (8) b	23.1 (9) c
	Sales of breeder stock (%)[2]	6.33 (10.67) a	5.91 (10.58) a	5.15 (9.42) a
Farmer expertise	Work experience (years)[2]	24 (9.5) a	23 (10.3) ab	21.9 (10.4) b
	Feed costs (€/100 kg liveweight)[2]	54.1 (17.2) a	67.3 (21.4) b	78 (32.5) c
	Numerical productivity (%)[2]	91.2 (5.7) a	89.1 (6.2) b	86.1 (9.3) c
Farm characteristics	Utilised agricultural area (UAA) (ha)	144 (65) a	171 (85) b	171 (78) b
	Livestock units (LU)[2]	143 (56) a	163 (82) b	163 (77) b
	Annual work units (AWU)	1.77 (0.68) a	1.8 (0.71) a	1.87 (0.72) a
	LU per AWU	86.4 (31.9) a	95.5 (37.2) a	90.8 (33.8) a
	Stocking rate	1.19 (0.27) a	1.31 (0.44) a	1.6 (0.91) b
	Feed protein self-sufficiency (%)	91.9 (4.8) a	89.2 (5.4) b	83.9 (11) c
	Feed energy self-sufficiency (%)	94.3 (3.7) a	91.9 (5.1) b	88.8 (9.9) c

[1] Variables used in the structural equation model.
[2] Variables used in the logit models. a,b,c: values within a row with no common letter differ significantly (Wilcox-test: $p \leq 0.10$). Standard deviations in brackets.

The degree of specialisation of the farm is partly linked to LFA. Indeed, farms in the plain and in the simple disadvantaged areas often grow more crops and are thus less specialised in cattle production than farms in mountainous areas. Nevertheless, there is a non-negligible proportion of specialised cattle farms in the plain and in the simple disadvantaged areas (Appendix, Fig. A4).

The panel-data logit model and the standard logit model both had a sensitivity around 60% (60% for the panel-data model and 62% for the standard model), i.e. they correctly predicted more than half of the farms in the Multiperforming group. The specificity was 94%, meaning that only 6% of farms were falsely predicted to belong the Multiperforming group. Globally, the models correctly classified around 86% of the observations. The area under the ROC curve was above 90%, which indicates outstanding discriminatory ability (Mandrekar, 2010). The highest number of false positives was found in Group 3, which had high AW and ENV score, and low ECO scores, and in Group 5, which had high ECO and ENV scores and low AW scores (Table 7).

True positives (multiperformers correctly predicted by the model) had higher average scores in all three dimensions than false negatives (multiperformers not predicted as such by the model), whose average scores did not differ from farms that perform well on only one or two dimensions in the respective dimension (Appendix, Tables B2, B3, B4).

Regarding economic performance, we noted previously that the Multiperforming group had a lower gross operating surplus per AWU than the other ECO+ groups. However, this no longer holds true when we compare the false-negative group with the ECO+ groups. Regarding farm and cash income, the averages are higher for the false negatives but do not differ statistically from the true positives (Appendix, Table B4).

The false-negative group adopts practices that are intermediate between those of the true-positive group and those of the other groups, e.g. it is less grass-based than the true-positive group, but less crop-based than other groups, resulting in feed costs that are also intermediate.

Regarding farm characteristics, the false negatives counted bigger farms in terms of UAA and LU with less feed self-sufficiency than the true positives (Table 8). To wrap up, the false-negative group used similar practices to those used by the non-multiperforming groups, but their AW and ENV scores remained in the upper quantiles. The false negatives achieved good performance in all dimensions with higher incomes and higher percentages of sales of finished animals sold for slaughter than the true positives.

In addition, the true-positives group had a lower renewal rate than the other groups, although this variable was not significant in the logit models. Regarding calving season, the true positives had a higher percentage of calving in March–April, as well as in January–February. Further note that both the true-positives and the false-negatives groups had more subsidies ratioed to total revenues than the other groups (Table 8).

4. Discussion

This paper on French suckler cattle farms found that: 1) the SEM approach produces consistent variables describing animal welfare performance (AW), environmental performance (ENV) and economic performance (ECO), 2) there is a positive moderate-strength link between AW, ENV and ECO, and 3) the farms that perform well on all three dimensions (AW, ENV and ECO) are extensive cow–calf producer farms (i.e. with a low annual average number of LUs per hectare of fodder area, or stocking rate) that rely mainly on grass-based feed.

4.1. Construction of the variables for animal welfare, environmental and economic performances

The signs of the weights for the proxies in the latent variables for AW, ENV, and ECO calculated by the SEM approach remained stable over the 2016–2022 period, and were consistent with the literature.

Regarding the latent variable ECO, the model assigns a positive weight to the cost-effectiveness indicator 'gross operating surplus ratioed to total revenue'. By definition, the proxy chosen should be positively related to economic performance. The financial indicator 'debt-to-asset ratio' is negatively related to the latent variable ECO. The literature shows no consensus concerning the relationship between indebtedness and farm performance (Davidova and Latruffe, 2007; Minviel et al., 2023). The negative association found here could be related to the lack of additional credit sources (financial constraints) for highly indebted farmers. Financial constraints may slow the process of readjusting certain factors of production, and thus lead to lower farm performance (Minviel et al., 2023). Furthermore, the operational surplus generated makes it possible to self-finance a substantial share of required investments, and thus reduces the need to take out loans. The fact that the weight of the variable 'debt-to-asset ratio' in the model drops as we decrease the threshold of crop revenue in total revenue for the sample could mean that the debt-to-asset ratio varies less among specialised cattle farms than in a more diversified sample. French averages of the debt-to-asset ratio were 32% for cattle farms and 36% for farms producing cereals, oilseeds and protein crops in 2022 (Agreste, 2023).

Regarding the latent variable ENV, all input proxies have a negative weight. Pesticides, excessive nitrogen inputs and fossil-energy use are all environmentally-negative inputs, and the fact that they were negatively related to the latent variable ENV is in line with the low-input principle of agroecology, as explained in Rega et al. (2022).

Regarding the latent variable AW, 'calf mortality' and 'other-category mortality' have a negative weight in the model. High mortality of calves and other animals have been identified as important indicators for detecting herds with poor animal welfare (Krug et al., 2015; Nyman et al., 2011; Sandgren et al., 2009). Cow mortality is also one of the indicators of poor health used in the Welfare Quality protocol (Welfare Quality, 2009).

'Pregnancy rate' has a positive weight in AW. A high pregnancy rate is likely to result from a low occurrence of health issues, such as lameness (Collick et al., 1989), endometritis characterised by vulvar discharge (Gautam et al., 2010), mastitis characterised by somatic cell counts (Dahl et al., 2020), all of these health issues being used as poor welfare indicators in the Welfare Quality protocol (Welfare Quality, 2009).

'Mean building costs per LU' has a positive weight in AW. This result is in line with Adamie et al. (2022) who showed that building costs per LU are positively related to the housing principle in Welfare Quality (2009), which includes animal-based measures of good housing such as time needed to lie down or cleanliness of the animals. As already hypothesised during the section of the variable selection process, one possible explanation for this result is that more costly (expressed per LU) and newer buildings are more comfortable because they provide more space per animal and the lying area is better designed.

'Estimated amount of feed grazed out of total forage offered' has a positive weight in AW. Pasture is generally positively associated with animal welfare, and access to pasture improves Welfare Quality scores (Welfare Quality, 2009) for two criteria: ease of movement, and expression of other behaviours. Indeed, at pasture animals have more space for lying and moving, which leads to less injuries and more room to express their natural behaviours. However, the literature is inconclusive on some pasture-related health issues such as claw disorders, and pasture can be detrimental to animal welfare if animals are exposed to insufficient feed energy or parasitism, as summarized in Schulte et al. (2018). Here the positive effects of grazing on animal welfare appear to have outweighed the negative ones.

'Adjusted cow weight after calving' has a negative weight in AW. Body weight depends on parity, lactation stage, body-frame size, gestation, and breed (Roche et al., 2009). Our proxy is controlled for lactation stage and gestation because the weight is set after calving. Note too that we adjusted for the breed variability factor. Body-frame size may be partially controlled by the year adjustment, as a systematic selection for bigger frame size over the years is levelled out. Parity remains uncontrolled but cannot explain the negative weight of the variable in AW because the age structure of the herd should remain more or less stable across herds and years. The negative relationship between cow weight and AW found in our model thus appears to result from a causal relationship, suggesting that fatter cows after calving have worse welfare. This seems counterintuitive. Actually, any body-condition extremes—whether too high or too low—are harmful to animal welfare (Matthews et al., 2012; Petit and Agabriel, 1993; Roche et al., 2009). Over-condition (where cows are too fat) negatively impacts cow health, by altering lymphocytes, impairing liver function, inducing ketosis, or by driving metabolic disorders, greater risk of mastitis, and lameness (Roche et al., 2009). Note that our database contains largely 'best-in-class' farms, which means the sample has a higher chance of containing cows that are too fat after calving rather than cows that are too skinny. Some of the in-sample farmers may have had to contend with problems related to over-condition, which would explain the negative relationship between weight after calving and AW. Conversely, under-condition only affects calf development and cow functioning for dams that have undergone extreme weight loss (Petit and Agabriel, 1993), which is very unlikely for our sample. However, primiparous or young cows may be negatively affected at more moderate weight losses, as they are still growing (Petit and Agabriel, 1993; Roche et al., 2009). Here, the strategy pursued by the Multiperforming group includes the practice of first calving at older age, which reduces the risk.

Our model thus showed good coherency, which validates its use for further analysis.

4.2. Relationships between the variables for animal welfare, environmental and economic performances

This study based on the SEM approach found that the latent variables AW, ENV and ECO were positively moderately-strongly inter-related (coefficients of correlation around 0.3). In other words, on suckler cattle farms, there is no contradiction between having good results in each of the three dimensions.

Most of the studies published to date find a positive correlation between two dimensions but a negative correlation with the third dimension, e.g. a positive correlation between AW and ENV and a negative correlation with ECO (van Calker et al. (2006) in dairy cows) or a positive correlation between ENV and ECO and negative correlations with AW (Olsen et al. (2023) in pigs). Very few studies report positive correlations between all three dimensions (Brennan et al. (2021) in dairy cows and Vissers et al. (2021) in broilers). These divergent outcomes may be explained by the different indicators used; therefore larger-scale studies using the same indicators on different production systems are needed. The divergence may also stem from the fact that each study was conducted on production systems specific to a given animal type in a given country. This may imply that multiperformance may not be achievable on all production systems and/or that a precise farm-system design is a factor that dictates whether all three dimensions can vary consistently or not.

4.3. Relationship between the 'Winning strategy' and the three performance dimensions

In our study, some farms managed to perform better than the median of the studied population on all three dimensions (AW, ENV, ECO). The farms that had a better chance of performing well on all three dimensions were: specialised cow–calf producers (i.e. primarily selling animals to fattening farms) using mainly grass-based feed, calving at the end of winter/beginning of spring, with high farmer expertise, a small herd (−10% LU relative to the all-sample average) of a hardy breed such as Aubrac, and located in moderately mountainous areas. In this discussion we refer to this combination of practices as the 'Winning strategy'. On these farms, the variation in animals' nutritional needs is synchronised with the variations in grass availability (the highest nutritional needs are at a few weeks after the beginning of lactation and during calf growth, which should correspond to the period of highest grass growth). Calving at end of winter/beginning of spring was widespread practice in the past and is still used on small farms today (Dubrulle et al., 2023; Larue et al., 2012). Sector professionals praise the economic soundness of this practice (Lahémade, 2022).

Extensive-system farms with a low stocking rate (i.e. animal density per hectare of forage area), that are based predominantly on grazing and have high proportion of permanent grassland in their total UAA have both lower revenues and lower expenditures than intensive-system farms that have a high stocking rate. However, their decrease in expenditures being often stronger than their decrease in revenues, they achieve better net economic performance. Indeed, controlling feed costs is essential to good economic performance, as feed costs represent a high share of total costs in suckler cattle production systems. Grazing is the most economical feeding system. The strategy recommended by Petit and Agabriel (1993) to reduce feeding during winter, where grazing is not possible in the studied areas, is to set the calving period to one to two months before the pasture season starts and let the cows deplete their body reserves until they are turned out to pasture. Promoting grazing and end-of-winter calving therefore favours good ECO performances. However, taking advantage of cows' ability to deplete and restore their body reserves in order to adapt to the natural cycles of scarcity and abundance of feed resources should be kept within acceptable limits for body condition (Agabriel et al., 2014). Increased dry matter intake due to earlier depletion of body reserves increases grazing time at the expense of other essential activities such as lying time. Low body reserves also make it more difficult to withstand adverse climatic conditions, thus posing a risk to animal welfare (Matthews et al., 2012). The farms included in our study are likely to have limited the depletion of cows' body reserves during winter in an effort to avoid such risks.

The combination of grazing and spring calving also favours ENV performances. The comparison of spring versus autumn calving systems showed that there was little difference in output but that spring calving outperformed autumn calving on environmental indicators, such as air acidification, water eutrophication, and energy consumption (Larue et al., 2012). Our SEM model only uses energy consumption and polluting inputs to assess environmental impacts. Extensive low-input grass-based farming systems also have positive impacts on biodiversity, and permanent grasslands contribute to carbon storage (Doreau et al., 2018). Grazing unproductive plots helps to optimise land use by reducing feed–food and feed–fuel competition (Benoit and Mottet, 2023), and spending less time indoors also decreases GHG emissions (Doreau et al., 2018). Thus, the environmental benefits of the Winning strategy—largely based on grass feed—were probably underestimated here. However, it may also carry drawbacks, as substituting concentrates with grass feed increases enteric methane emissions (IPCC, 2006). Furthermore, selling off older animals for fattening, such as young bulls that can profit from two pasture seasons, offers attractive economic performances (Lahémade, 2022), but increased lifespan also increases GHG emissions (Doreau et al., 2018). Calving at a higher age, which was shown to be positive for the health of primiparous animals (see section 4.1), also increases GHG emissions and energy consumption (Doreau et al., 2018) due to increased unproductive time. However, this is counteracted by lower renewal rates, which also reduces the proportion of unproductive lifespan. Further study is needed to gain a deeper analysis of GHG emissions on farms adopting the Winning strategy.

Being a specialist cow-calf producer and having a hardy breed such as Aubrac increases the likelihood of being multiperforming. This may be explained by the fact that both young animals and hardy breeds are adapted to grass feeding. Farms in mountainous areas were more likely to be multiperforming than those in plain areas. There farms are better suited to grazing because: 1) the mountains are less affected by drought in summer than the plains, 2) as they cannot grow crops, they have to buy all the concentrate feed, so they tend to use less of the latter and make better use of the grass (Veysset et al., 2014). Higher subsidies related to LFA may also contribute to higher economic performance of farms located in non-plain areas. Our results also showed that farmers were less likely to multiperform in 2019, but more likely in 2022. We hypothesise that less favourable weather conditions led to lower economic performance. 2019 was indeed a drought year in France, but an even worse drought was recorded in 2022. The difference between 2019 and 2022 could be due to the fact that 2018 was already dry, while 2021 was very favourable for grass growth, allowing the formation of fodder stocks, which could have had a positive impact on 2022. Further, drought may not affect all French regions equally.

4.4. Other keys to multiperformance success

The Winning strategy may not be appropriate to all situations. Farm location, for instance, restricts the available grazing time over the year as the duration of the grazing season varies with climatic and soil conditions (de Vries et al., 2011). In some regions, the increase in frequency of drought years driven by climate change might jeopardize farms that are over-reliant on grazing.

External factors, such as market opportunities, might lead farmers to deliberately steer away from the Winning strategy. Farm practices affect product quality in ways that may or may not be desirable in terms of market opportunities and customers targeted. Examples of practices that change product quality include setting targets for cow BCS and choosing the proportion of grass in the diet – BCS impacts on milk composition (Roche et al., 2009) and grass feed impacts on meat quality (McCaughey and Cliplef, 1996; Normand and Gruffat, 2023).

There may however be alternative strategies that also enable multiperformance. Indeed, only 60% of the multiperforming farms were predicted as such by our logit models considering the Winning strategy (true positives). The false-negative group (multiperformers not predicted as such by the logit models) manages to achieve higher incomes and has higher percentage sales of animals for slaughter than the true-positive group. From an economic/financial perspective, it is likely that farmers are more interested in higher income than higher cost-effectiveness. False-negative farms adopt strategies that are in between the true-positive group and the non-multiperforming groups. The non-multiperforming groups together form a very heterogenous group, and looking at the averages of practices and conditions might be misleading. This might explain why the false-negative group was not statistically distinguishable from some of the non-multiperforming groups on certain indicators or practices and, thus, could not be characterised by specific practices. It is likely that the multiperforming farmers not adopting the Winning strategy manage to combine a similar set of practices to those used by the non-multiperforming groups in such a way that the indicators in all three dimensions are in the superior quantiles. This speaks in favour of systemic farm management approaches, and the search to use resources with optimal efficiency (Veysset et al., 2015).

4.5. Limitations

The SEM model that we built might overestimate the positive relationship between ECO and AW and between ECO and ENV, as we did not perform a complete lifecycle analysis of beef production, which would have implied adding the impacts of the fattening phase to the cow–calf systems. The fattening phase relying more on concentrate than on grass-based feeding would deteriorate ENV proxies on the complete lifecycle. A recent study in Spain showed no difference in environmental indicators between systems where the breeding and fattening phases were performed on the same farm and those where the two phases took place on two separate farms (Tinitana-Bayas et al., 2024), suggesting no benefit of separating the breeding and the fattening phases. In addition, transport and social mixing, associated with the movement of animals from the breeding to the fattening farm, are subject to welfare issues and losses in production (EFSA Panel on Animal Health and Welfare (AHAW) et al., 2022; Mounier et al., 2007), which can lower the AW benefits observed in suckler farms. To ensure multiperformance throughout the end-to-end process of producing beef animals, it will be important to identify winning practices that produce beef and not just unfinished animals, whose lifetime spent fattening (mostly outside France and therefore not captured in our database) could not be considered here.

The weights defined by the SEM approach give an indication of the explanatory part that each proxy plays in the variation of the latent variables representing AW, ENV and ECO performances. These weights should not be confused with the importance that experts lend to the different aspects that underpin a latent variable. Further research could verify that the latent variables give similar outcomes to the same concepts modelled with extensive protocols designed from expert consultation such as in Welfare Quality (2009) for animal welfare.

Some variables should also be handled with caution, as their potential nonlinear relationships with the latent variables is not considered in the SEM model. This is in particular the case with the adjusted cow weight used here, whose negative relationship with AW applies to the 'best-in-class' farms making up our dataset, but is not generalisable.

4.6. Business and policy implications

Grass feeding is a practice that has a positive impact on all three performance dimensions. The Charolais region used to be the destination for animals fattened on grass (Fayard, 2013). However, following the construction of stalls more suited to indoor feeding and the opening up of the Italian market in the early 1970s (Dubrulle et al., 2023), it is likely that the breeding selection process over the last decades has made breeds such as Charolais more adapted to concentrate feeding than to grass feeding. Thus, a business implication could be to promote again breeds that are more adapted to be fattened on grass. The beef sector has an active role to play, but so does research.

The business model of exporting live animals to corn-rich plains, such as those of northern Italy, raises serious animal welfare issues regarding the long-distance transport of live animals. At the same time, France imports beef for its domestic consumption. This discrepancy between production and consumption is likely to widen the gap between farmers and citizens as strict animal welfare and environmental regulations apply to domestic production, but not necessarily to imports. A rebalancing of domestic production towards domestic demand should therefore be envisaged.

The Multiperforming group had higher subsidies ratioed to total revenues than the other groups. This can be explained by the fact that many of the multiperforming farms most likely receive subsidies related to LFA (because they are in non-plain areas), as well as subsidies related to agri-environmental and climate measures (MAEC) (because they are mainly grass-based, have low stocking rates, use less concentrate feed, corn silage and pesticides). As LFA subsidies compensate for reduced economic revenues due to more difficult conditions and MAEC subsidies promote systems that are more virtuous in terms of the environment – and indirectly of animal welfare through more pasture –, these subsidies need to be maintained.

Finally, we also identified farmer expertise as a key factor to multi-perfomance. Adopting ecological practices is recognised to be more demanding with regard to farmer skills and cognitive capacities (Davidova et al., 2022). Access to training should thus be promoted, e.g. through the establishment of farmer networks, as underlined in Barnes et al. (2022).

5. Conclusion

This paper investigated how suckler cattle farms can concurrently achieve good performance on all three of its key dimensions, i.e. animal welfare, environmental, and economic performance. We analysed the relationships between these performances using a SEM approach based on economic indicators, as well as proxies for animal welfare and environmental performances that we obtained using a national technical-economic database. We then identified farming practices and conditions that lead to 'multiperformance'.

Our statistically-determined SEM model, which we used to identify multiperforming farms, gave results that are consistent with the literature. Our logit models identified a multiperforming strategy, which we called the Winning strategy, that is a combination of traditionally-used practices where animal nutritional needs are synchronised with the provision of natural resources. The natural resource is grass, and synchronisation is managed by exploiting certain key animal characteristics (depletion and restoral of body reserves), choosing the right calving season, and selling animals well adapted to grass-feeding, i.e. hardy breeds and animals that are sold before fattening.

However, it remains possible to 'multiperform' without choosing this Winning strategy, by foregoing some performances but nevertheless registering superior performance in all three dimensions. The multiperforming farms not adopting the Winning strategy produce finished animals and achieve higher incomes (but are less cost-effective) than the farms adopting the Winning strategy practices, and their strategy is not clearly distinguishable from that of the non-multiperforming farms. Further studies should dive deeper into the exact strategies that these farms adopt to achieve multiperformance. It might also be helpful to understand cases that lead to trade-offs between the three dimensions of performance, and use compromise-centred approaches to capture the decisional mechanics involved.

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CRediT authorship contribution statement

Larissa Mysko: Writing – review & editing, Writing – original draft, Visualization, Software, Project administration, Methodology, Formal analysis, Conceptualization. **Jean-Joseph Minviel:** Writing – review & editing, Writing – original draft, Supervision, Methodology, Funding acquisition, Conceptualization. **Patrick Veysset:** Writing – review & editing, Writing – original draft, Supervision, Conceptualization. **Isabelle Veissier:** Writing – review & editing, Writing – original draft, Supervision, Methodology, Funding acquisition, Conceptualization.

Declaration of competing interest

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

Data availability

The data that has been used is confidential.

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Appendix A

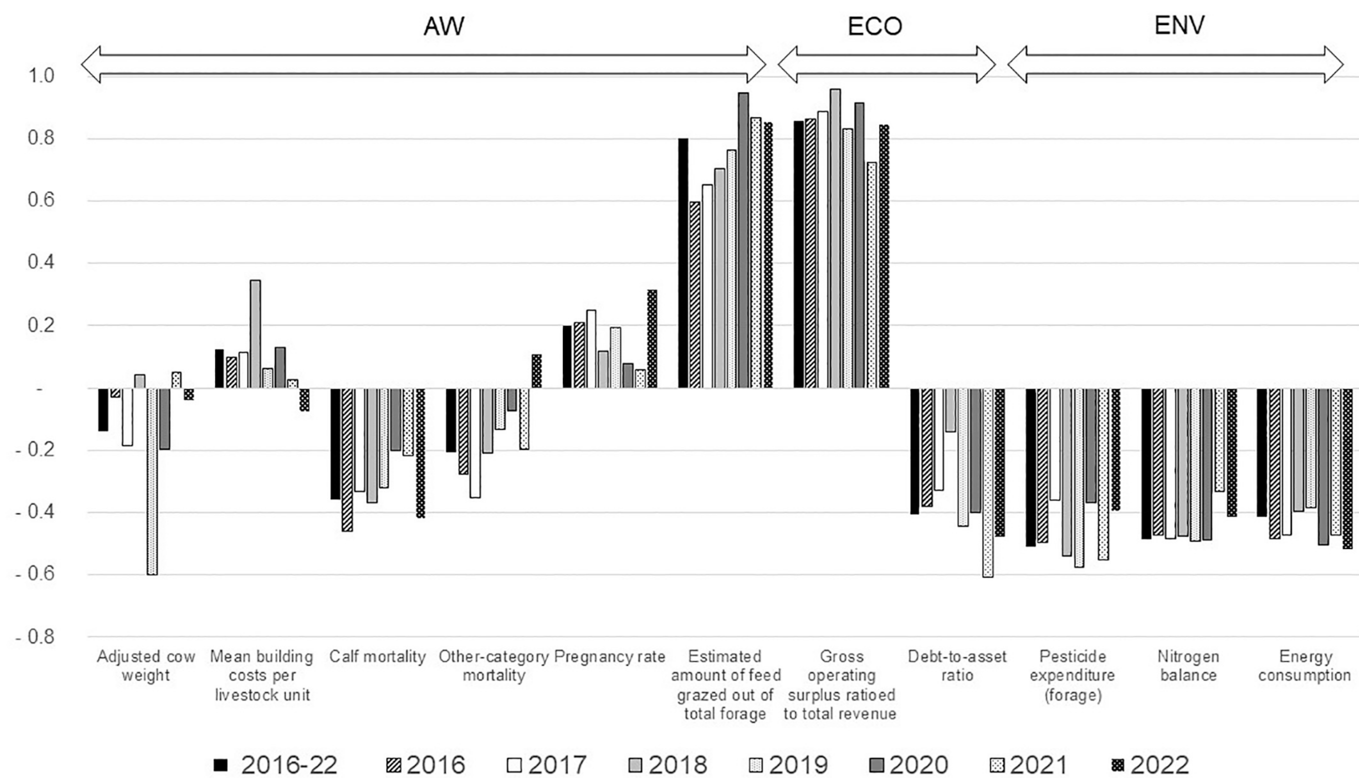

Fig. A1. Weights of each measured variable in its associated latent variable, i.e. animal welfare performance (AW), economic performance (ECO), or environmental performance (ENV), per year and across years between 2016 and 2022

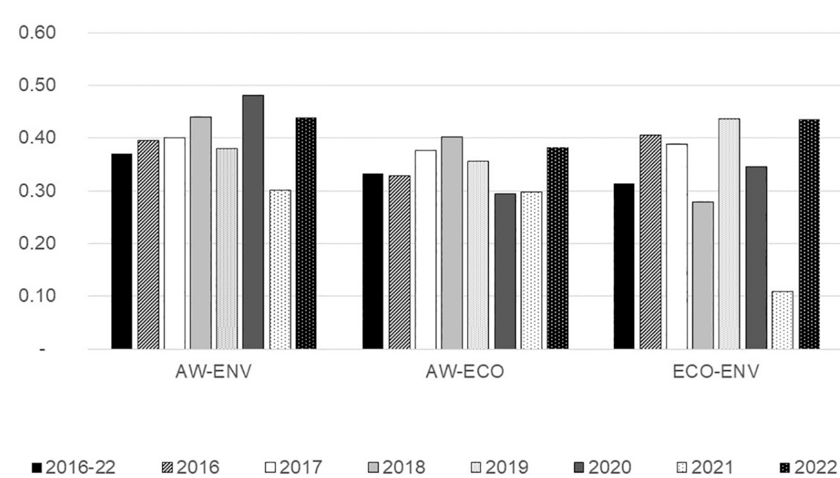

Fig. A2. Variations of the correlations between the three latent variables, i.e. animal welfare performance (AW), economic performance (ECO), or environmental performance (ENV), per year and across years between 2016 and 2022.

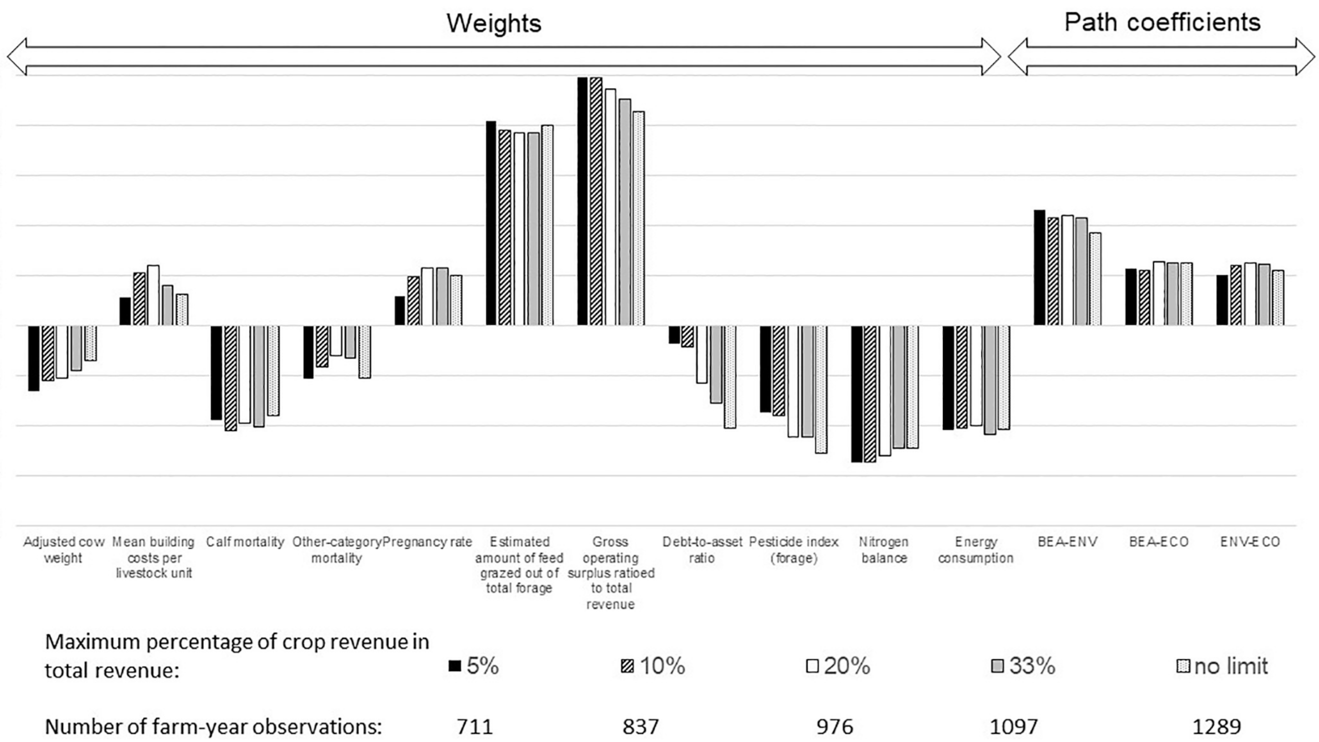

Fig. A3. Variations of the weights for the measured variables and path coefficients between the three latent variables, i.e. animal welfare performance (AW), economic performance (ECO), and environmental performance (ENV), in the structural equation model based on 2016–2022 data for samples with different maximum thresholds for crop revenue ratioed to total revenue.

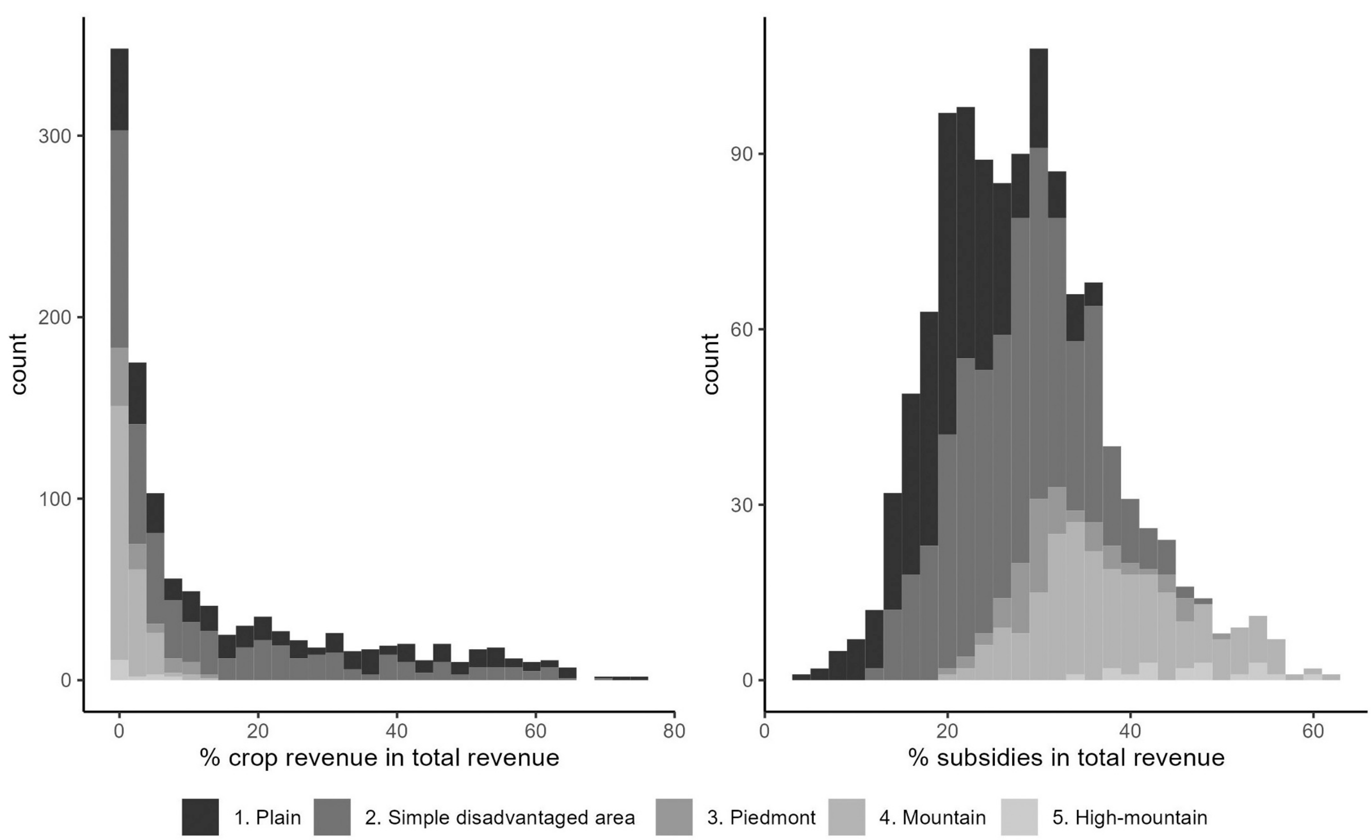

Fig. A4. Percentages of crop revenue (left) and subsidies (right) in total revenue versus farm topographic location based on the less-favoured area (LFA) nomenclature.

Table A1
Mean values of performance proxies for the eight groups defined according to their SEM model-based scores on animal welfare performance (AW), environmental performance (ENV) and economic performance (ECO).

		Group 1	Group 2	Group 3	Group 4	Group 5	Group 6	Group 7	Group 8
	Group definition	**AW > median** **ENV > median** **ECO > median**	**AW > median** ENV < median **ECO > median**	**AW > median** **ENV > median** ECO < median	**AW > median** ENV < median ECO < median	AW < median **ENV > median** **ECO > median**	AW < median ENV < median **ECO > median**	AW < median **ENV > median** ECO < median	AW < median ENV < median ECO < median
	Number of farms	287	93	133	131	118	146	106	275
Model scores	AW quantile	26.8 (13.7) a	34.5 (13.1) b	31.5 (13.8) ab	32.1 (14.8) ab	73.5 (13.2) c	79.7 (13.4) de	76.4 (14) cd	84.3 (13.7) e
	ENV quantile	27.4 (13.8) a	75.6 (13.9) b	31.8 (12.9) a	76.6 (14.4) b	31 (14.5) a	80.6 (13.7) bc	33.4 (15) a	82.7 (13.8) c
	ECO quantile	26.2 (14.2) a	32.5 (13.1) ab	75.3 (12.8) c	81.1 (14) d	29.9 (14.1) a	35.9 (12.4) b	78.9 (14.2) cd	82.1 (14.4) d
AW-Good feeding	Adjusted cow weight after calving (kg)[1]	740 (68) a	761 (71) a	757 (87) a	753 (80) a	743 (79) a	757 (76) a	738 (84) a	754 (70) a
	Gross liveweight production (kg per LU)	320 (51) a	330 (61) a	336 (52) a	333 (69) a	338 (62) a	346 (80) a	343 (86) a	348 (87) a
AW-Good housing	Mean building costs (€/LU)[1]	82.7 (62.4) a	63.1 (38) a	90.8 (95.6) a	81.6 (56.1) a	72.5 (44.7) a	62.8 (42.9) a	68.1 (43.8) a	70.2 (55.9) a
AW-Good health	Calf mortality (%)[1]	5.88 (3.21) a	6.22 (3.19) a	6.36 (3.2) a	5.72 (3.07) a	9.23 (4.08) b	8.87 (4.7) b	10.2 (5) b	10.2 (5.2) b
	Other-category mortality (%)[1]	0.483 (0.798) a	0.463 (0.868) ab	0.577 (0.915) abc	0.42 (0.734) a	1.15 (1.72) abc	1.08 (2.03) bc	1.33 (1.89) bc	1.38 (2.07) c
	Pregnancy rate (%)[1]	93.7 (5.4) ab	92.7 (5.5) abc	92.3 (6.5) abc	94 (5.6) a	89.9 (11) bc	91.4 (7.1) bc	90.6 (8.6) abc	89.8 (9) c
	Mean calving interval (days)	378 (14) a	379 (16) a	377 (13) a	381 (19) a	381 (18) a	380 (19) a	377 (41) a	384 (29) a
	Rate of 400-day-plus calving intervals (%)	18.9 (11.6) a	18.6 (12.7) a	18.6 (12.9) a	20.7 (13.8) a	19.3 (11.7) a	20.7 (16.7) a	19.9 (11.9) a	21.3 (14.1) a
	Dystocia rate (%)	4.06 (9.2) a	3.09 (3.97) a	4.25 (4.46) a	3.94 (4.58) a	2.99 (3.97) a	3.48 (4.98) a	3.73 (4.24) a	4.24 (5.68) a
	Abortion rate (%)	0.427 (0.946) a	0.655 (1.294) a	0.499 (1.058) a	0.379 (0.807) a	0.505 (1.227) a	0.555 (1.123) a	0.426 (1.22) a	0.346 (0.999) a
AW-Appropriate behaviour	Estimated amount of feed grazed out of total forage offered (%)[1,2]	63.5 (6.5) a	62 (6.5) a	62.6 (7) a	61.5 (8) a	51 (11.2) b	45.4 (12.6) cd	49.2 (12.1) bc	43.1 (14) d
ENV	Pesticide index per ha forage area[1]	0.023 (0.032) a	0.088 (0.064) b	0.026 (0.034) a	0.079 (0.091) b	0.029 (0.033) a	0.112 (0.118) b	0.023 (0.035) a	0.136 (0.148) b
	Fertiliser index per ha forage area	0.335 (0.244) a	0.639 (0.326) b	0.314 (0.237) a	0.817 (0.56) b	0.31 (0.225) a	0.694 (0.406) b	0.338 (0.327) a	0.736 (0.465) b
	Nitrogen balance (kg N/100 kg liveweight)[1]	7.87 (3.59) a	17.7 (10.2) b	8.76 (3.6) a	18.2 (7.9) b	7.88 (3.53) a	17.7 (8) b	8.57 (4.45) a	18 (7.6) b
	Energy consumption (MJ /100 kg liveweight)[1]	2060 (460) a	3250 (2140) b	2180 (430) a	3100 (850) b	2200 (600) ac	3340 (3180) b	2340 (480) c	3320 (1650) b
	Permanent grassland per UAA (%)	64.2 (25.2) a	49.6 (21.4) bc	61.6 (26.1) ab	44 (26.6) c	50.4 (26.2) bc	41.2 (23.3) cd	51 (25.5) c	36.7 (20.3) d
ECO	Gross operating surplus ratioed to total revenue (%)[1]	40.3 (6) a	37.8 (5.4) ab	27.7 (5.2) c	25.3 (6.3) de	38.5 (5.4) ab	37 (5.1) b	27.3 (6.2) cd	24.1 (7.1) e
	Gross operating surplus (€/AWU)	57,100 (21400) a	65,600 (28400) a	47,200 (16500) b	48,300 (19000) b	59,000 (22400) a	62,800 (24900) a	48,800 (20000) b	44,000 (18500) b
	Farm income (€/farmer)	27,800 (20500) a	38,100 (29500) a	15,300 (15600) b	14,000 (22000) b	30,400 (22100) a	35,200 (24900) a	18,600 (19300) b	13,500 (21100) b
	Cash income (€/farmer)	36,400 (22600) a	45,300 (27500) a	21,100 (16000) bc	19,400 (24300) bc	37,500 (24800) a	41,800 (24200) a	22,100 (18400) b	17,200 (24000) c
	Debt-to-asset ratio (%)[1]	27.4 (15.4) a	29.4 (12.8) a	41.3 (18.6) b	43.1 (18.5) b	28.4 (14.2) a	32.6 (14.3) a	48.9 (20.7) b	43.1 (22.9) b
	Capital intensity (€/AWU)	125,100 (48900) a	152,900 (61100) ab	134,200 (48200) ab	154,200 (48100) b	133,300 (49900) ab	148,500 (54600) ab	145,200 (52600) ab	145,700 (49600) ab

[1] Variables used in the structural equation model.
[2] Variables used in the logit models. a,b,c: values within a row with no common letter differ significantly (Wilcox-test: $p \leq 0.10$). Standard deviations in brackets.

Table A2

Mean values of practices, proxies for farmer expertise and farm characteristics for eight groups defined according to their score based on the SEM model.

		Group 1	Group 2	Group 3	Group 4	Group 5	Group 6	Group 7	Group 8
Feed	Estimated amount of feed grazed out of total forage offered (%)[1,2]	63.5 (6.5) a	62 (6.5) a	62.6 (7) a	61.5 (8) a	51 (11.2) b	45.4 (12.6) cd	49.2 (12.1) bc	43.1 (14) d
	Amount of corn feed out of total forage offered (%)[2]	2.87 (4.78) a	10.3 (7.2) bc	3.49 (4.91) a	7.14 (7.45) bd	5.06 (7.64) a	10.8 (9.2) b	5.45 (7.7) ad	14.9 (11.9) c
	Amount of silage feed out of total forage offered (%)[2]	3.59 (5.99) a	4.63 (5.97) a	5.1 (6.35) a	4.81 (6.07) a	5.43 (7.71) a	8.6 (9.42) a	4.97 (7.72) a	7.44 (8.83) a
	Amount of wrapped haylage out of total forage offered (%)	7.89 (6.68) a	6.42 (7.57) a	8.23 (7.45) a	6.68 (7.56) a	9.11 (8.34) a	9.53 (10.49) a	10 (10.2) a	7.46 (9.91) a
	Amount of hay feed out of total forage offered (%)	20.4 (9.2) abc	13.9 (7.7) d	18.2 (9.2) abd	16.1 (9.9) d	26.5 (13.8) c	21.1 (14.7) abc	24.1 (15) ac	19.5 (13.8) bd
	Amount of straw feed out of total forage offered (%)	1.11 (1.99) a	1.68 (3.83) a	1.38 (2.61) a	2.14 (3.84) a	1.49 (3.19) a	2.07 (5.3) a	2.49 (5.23) a	2.95 (5.88) a
	Amount of concentrate feed out of total ration (%)	8.38 (3.52) a	10.7 (3.4) bc	9.64 (3.64) ab	11.9 (4.9) c	9.55 (4.8) ab	12.8 (6) cd	10.8 (5) bc	13.9 (5.8) d
Herd management	Renewal rate (%)[2]	22.1 (5.9) a	23.7 (6.6) a	23.9 (5.7) a	23.7 (6.7) a	23.5 (6.8) a	24 (7.7) a	24 (6.7) a	24.4 (6.7) a
	Mean age at first calving (months)[2]	35.2 (1.6) a	35 (2.5) a	34.6 (2.1) a	34.6 (2.2) a	35 (2.4) a	34.8 (3.1) a	34.2 (2.9) a	34.7 (2.8) a
	Rate of calving before 30 months (%)	6.01 (15.9) a	3.8 (13.71) a	10.6 (22.5) a	11.1 (25.9) a	8.94 (20.94) a	13.7 (27.9) a	15.1 (26.6) a	10.6 (24.4) a
	Calving in Jan-Feb (%)	22.7 (19.3) a	18.2 (17.3) ab	20.8 (21.1) ab	15.6 (16.2) ab	15.3 (14.3) b	16.4 (17) ab	18.3 (20) ab	13.5 (13.6) b
	Calving in Mar-Apr (%)[2]	16.3 (15.2) a	12.3 (16) a	14.2 (13.5) a	11.5 (13.1) a	14.3 (15.1) a	12.4 (12.2) a	14.6 (16.5) a	14.4 (15.2) a
	Calving in May-Jun (%)	4.14 (6.24) a	4.2 (6.19) a	4.22 (9.3) a	5.66 (8.97) a	4.72 (6.52) a	6.08 (8.14) a	4.33 (7.26) a	7 (9.46) a
	Calving in Jul-Aug (%)	5.11 (10.48) a	9.52 (16.59) abc	8.15 (16.12) ab	7.49 (11.75) ab	8.83 (15.86) b	15.1 (17.4) d	8.6 (12.47) abcd	13.4 (18.4) cd
	Calving in Sep-Oct (%)	22.2 (26.7) a	27.3 (26.7) ab	22.3 (24.7) ab	27.4 (24.9) ab	28.2 (27.2) ab	30.3 (24.7) b	30.9 (28.4) ab	31.1 (24.9) b
	Calving in Nov-Dec (%)	29.6 (25.4) ab	28.4 (24.9) ab	30.4 (27.9) ab	32.3 (24.7) a	28.7 (24.7) ab	19.6 (20.7) b	23.3 (21.5) ab	20.6 (20) b
Revenue, subsidies, sales	Beef revenue ratioed to total revenue (%)	55.7 (10.8) a	54.9 (13.7) a	57.3 (10.3) a	48.7 (17.5) a	54.8 (13.8) a	54.9 (16.7) a	54.1 (13.5) a	53.7 (16.1) a
	Crop revenue ratioed to total revenue (%)[2]	6.26 (12.39) a	14.3 (17.7) bc	6.76 (11.13) ab	20.7 (21.8) c	10.2 (16.5) abc	14.6 (19.5) bc	12.2 (17.1) abc	16.3 (18.3) c
	Subsidies ratioed to total revenue (%)	34.2 (9.8) a	26.1 (8) bc	31.7 (7.9) a	25.9 (8.8) bc	31.2 (8.9) a	25.8 (8.9) bc	29.1 (9.2) ab	25.1 (8) c
	Sales of calves (%)[2]	6.83 (16.66) a	13 (27.1) a	3.58 (6.81) a	6.89 (17.81) a	8.42 (19.62) a	12.5 (25.6) a	7.4 (17.21) a	9.45 (20.88) a
	Sales of weanlings for fattening (%)[2]	32.8 (27.4) a	27 (26.8) ab	27.4 (26.8) a	32.5 (27.3) a	26.4 (26.9) ab	20.3 (26.2) ab	23.3 (25.3) ab	19 (25.2) b
	Sales of older weanlings for fattening (%)[2]	17.1 (24.6) a	6.82 (16.22) ab	15.4 (21.8) a	9.26 (18.34) ab	12.7 (22.7) a	5.04 (13.16) b	7.75 (15.98) ab	5.1 (14) b
	Sales of heifers and young bulls for fattening (%)[2]	3.05 (10.45) a	1.02 (3.57) a	1.77 (5.44) a	0.935 (3.415) a	1.79 (4.9) a	0.484 (2.269) a	1.32 (4.73) a	0.79 (3.176) a
	Sales of animals for slaughter excl. Calves and cull cows (%)	14.5 (20.5) a	25.1 (25.4) bc	23.5 (25.6) ab	22.1 (26.3) ab	22.9 (25.1) ab	32.6 (29.2) bc	30.6 (29.4) bc	37.9 (31.5) c
	Sales of cull cows (%)	19.6 (8.3) a	21.5 (7.3) ab	22.1 (8.9) ab	21.5 (9.1) ab	23.5 (8.4) ab	24 (9.1) ab	24 (8.5) b	23.9 (9.8) b
	Sales of breeder stock (%)[2]	6.16 (10.62) ab	5.63 (8.32) ab	6.34 (10.83) a	6.7 (10.96) ab	4.26 (7.97) ab	5.1 (9.66) ab	5.66 (9.24) ab	3.87 (8.62) b
Farmer expertise	Work experience (years)[2]	23.6 (9.8) a	21.1 (9.5) a	20.3 (9.4) a	19.2 (9.4) a	23.9 (10.4) a	23.3 (11.8) a	20.3 (9.7) a	23.2 (10.6) a
	Feed costs (€/100 kg liveweight)[2]	59.4 (20) a	79.1 (43.5) bc	63.9 (19.8) ab	85.1 (28.6) cd	58.8 (22.1) a	80.4 (26.6) cd	67.9 (24.6) ab	91.8 (36.2) d
	Numerical productivity (%)[2]	90.4 (6) a	89.8 (6.6) a	89.2 (7.3) a	90.9 (6.5) a	84.2 (10.5) b	85.1 (8.1) b	84.4 (10.3) b	83.1 (10) b
Farm characteristics	Utilised agricultural area (UAA) (ha)	155 (75) a	172 (77) a	183 (87) a	180 (75) a	168 (67) a	167 (76) a	172 (77) a	165 (80) a
	Livestock units (LU)[2]	151 (68) a	170 (76) a	168 (71) a	154 (67) a	151 (64) a	175 (93) a	161 (81) a	163 (79) a
	Annual work units (AWU)	1.78 (0.69) a	1.87 (0.69) a	1.82 (0.59) a	1.8 (0.65) a	1.85 (0.75) a	2.04 (0.73) a	1.77 (0.7) a	1.88 (0.79) a
	LU per AWU	90.1 (34.3) a	94.6 (34) a	95.9 (33.6) a	89.8 (33.5) a	87.6 (34.3) a	87.2 (33.9) a	93.7 (34.3) a	89.7 (33.4) a
	Stocking rate	1.24 (0.35) a	1.54 (0.41) bcd	1.21 (0.29) a	1.55 (0.52) bc	1.24 (0.34) a	1.69 (0.58) bd	1.48 (1.05) ac	1.97 (1.36) d
	Feed protein self-sufficiency (%)	90.8 (5.2) a	85.1 (7.5) bc	89.4 (5.2) a	83.9 (7.3) b	89.4 (7.1) a	82.3 (11) bd	86.2 (12.4) ac	78.6 (13.4) d
	Feed energy self-sufficiency (%)	93.4 (4.4) a	90.3 (6.6) bc	92.2 (4.4) ab	89.3 (6.5) bc	91.8 (7.4) a	87.9 (10.4) bc	89.3 (11.1) ab	85.3 (12.8) c

[1] Variables used in the structural equation model.

[2] Variables used in the logit models. a,b,c: values within a row with no common letter differ significantly (Wilcox-test: $p \leq 0.10$). Standard deviations in brackets.

Appendix B

Table B1
Correlation matrix between practices and other explanatory variables.

			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
Feed	Estimated amount of feed grazed out of total fodder offered (%) [12]	1																			
	Amount of corn silage feed out of total fodder offered (%) [2]	2	-0.32																		
	Amount of grass silage feed out of total fodder offered (%) [2]	3	-0.15	0.17																	
	Amount of wrapped haylage feed out of total fodder offered (%)	4	-0.17	-0.21	**-0.39**																
	Amount of hay feed out of total fodder offered (%)	5	-0.33	**-0.36**	-0.19	-0.10															
	Amount of straw feed out of total fodder offered (%)	6	-0.25	0.04	-0.14	0.08	-0.25														
	Amount of concentrate feed out of total ration (%)	7	**-0.36**	0.18	0.17	0.08	0.01	0.18													
Herd management	Renewal rate (%) [2]	8	-0.05	0.11	0.04	-0.06	-0.19	0.14	0.04												
	Mean age at first calving (months) [2]	9	0.04	-0.11	-0.11	0.02	0.10	0.05	-0.08	-0.19											
	Rate of calving before 30 months (%)	10	-0.07	0.11	0.08	-0.01	-0.05	-0.04	0.08	0.10	**-0.54**										
	Calving in Jan-Feb (%)	11	0.15	-0.10	-0.01	-0.10	0.02	0.02	-0.06	-0.13	0.08	-0.08									
	Calving in Mar-Apr (%) (2)	12	0.00	-0.06	-0.14	-0.10	0.15	0.08	-0.12	-0.17	0.12	-0.09	0.24								
	Calving in May-Jun (%)	13	-0.13	0.05	-0.10	-0.06	0.21	-0.06	0.02	-0.29	0.10	-0.01	-0.07	**0.40**							
	Calving in Jul-Aug (%)	14	-0.19	0.22	0.10	0.12	-0.04	-0.09	0.08	-0.05	-0.13	0.11	-0.27	-0.12	0.06						
	Calving in Sep-Oct (%)	15	-0.11	0.07	0.07	0.14	-0.11	-0.04	0.07	0.22	-0.13	0.11	**-0.57**	**-0.46**	-0.24	0.04					
	Calving in Nov-Dec (%)	16	0.18	-0.12	-0.02	-0.08	-0.04	0.06	-0.01	0.09	0.06	-0.08	-0.06	-0.35	-0.31	**-0.44**	-0.33				
Revenue, subsidies, sales	Crop revenue ratioed to total revenue (%) [2]	17	-0.14	0.08	-0.16	0.03	-0.11	**0.39**	0.07	0.20	0.00	0.02	-0.10	-0.07	-0.07	-0.20	0.05	0.21			
	Subsidies ratioed to total revenue (%)	18	0.19	**-0.42**	-0.12	0.03	**0.39**	-0.27	-0.30	-0.33	0.15	-0.13	0.17	0.17	0.08	-0.04	-0.13	-0.08	**-0.55**		
	Sales of calves (%) [2]	19	-0.12	-0.13	0.06	0.01	0.26	-0.13	0.09	-0.28	0.07	-0.07	-0.06	0.10	0.31	0.12	-0.04	-0.16	-0.12	0.08	
	Sales of weanlings for fattening (%) [2]	20	0.13	-0.24	-0.23	0.09	0.19	-0.01	-0.22	-0.09	0.06	-0.07	0.00	0.06	0.05	-0.13	-0.01	0.06	0.11	0.29	-0.20
	Sales of older weanlings for fattening (%) [2]	21	0.25	-0.12	-0.03	0.02	-0.02	-0.13	-0.13	-0.16	0.04	-0.07	0.11	0.04	-0.08	-0.06	-0.09	0.07	-0.14	0.17	-0.17
	Sales of heifers and young bulls for fattening (%) [2]	22	0.11	-0.03	-0.08	-0.05	0.07	-0.05	-0.07	-0.05	0.05	-0.04	0.03	0.19	0.02	-0.06	-0.09	0.00	-0.09	0.12	-0.07
	Sales of animals for slaughter excluding calves and cull cows (%)	23	-0.20	**0.48**	0.22	-0.09	-0.34	0.17	0.31	0.21	-0.11	0.14	-0.02	-0.15	-0.14	0.12	0.07	0.00	0.08	**-0.43**	-0.27
	Sales of breeder stock (%) [2]	24	0.02	-0.17	-0.05	0.07	0.08	-0.02	-0.09	0.01	-0.04	0.02	0.06	0.00	-0.06	-0.06	0.00	0.02	-0.07	0.12	-0.07
	Sales of cull cows (%)	25	-0.04	0.13	0.11	-0.04	-0.16	0.06	0.02	**0.50**	-0.12	0.10	-0.12	-0.15	-0.17	-0.01	0.17	0.06	0.17	-0.30	-0.23
Farmer expertise	Work experience (years) [2]	26	-0.02	0.02	-0.02	-0.01	0.07	-0.03	0.09	-0.02	0.03	0.02	0.00	-0.06	-0.02	0.04	-0.02	0.04	0.03	0.02	-0.10
	Feed costs (€ 100 kg liveweight) [2]	27	-0.29	0.08	-0.02	0.10	0.11	0.10	**0.45**	-0.12	0.05	-0.01	-0.09	0.01	0.24	0.13	0.03	-0.13	0.15	-0.13	0.27
	Numerical productivity (%) [2]	28	0.11	-0.09	0.06	0.07	-0.05	0.00	-0.06	-0.08	-0.07	0.02	0.06	-0.10	-0.14	0.02	0.01	0.05	-0.08	0.06	-0.02
Farm characteristics	Utilised agricultural area (UAA) (ha)	29	0.11	0.02	0.07	-0.04	-0.14	0.03	0.08	0.19	0.01	-0.03	0.07	-0.12	-0.15	-0.19	-0.03	0.22	0.32	-0.21	-0.26
	Livestock units (LU) [2]	30	0.09	0.27	0.22	-0.10	-0.29	-0.07	0.13	0.18	-0.05	0.04	0.11	-0.09	-0.12	0.05	-0.01	-0.01	-0.19	-0.20	-0.24
	Annual work units (AWU)	31	-0.03	0.10	0.11	-0.04	-0.10	0.02	0.13	0.13	-0.04	0.02	0.06	-0.10	-0.07	0.03	0.03	-0.01	0.05	-0.06	-0.03
	LU per AWU	32	0.16	0.20	0.14	-0.08	-0.24	-0.09	-0.01	0.11	-0.01	0.02	0.04	-0.01	-0.10	0.03	-0.04	0.04	-0.29	-0.17	-0.29
	Stocking rate	33	-0.29	**0.53**	0.04	-0.12	**-0.36**	**0.36**	0.22	0.16	-0.09	0.08	-0.06	-0.02	0.02	0.15	0.04	-0.10	0.25	**-0.47**	-0.09
	Feed proteic self-sufficiency (%)	34	**0.41**	-0.32	0.00	-0.04	0.19	**-0.40**	**-0.53**	-0.14	0.03	-0.04	0.05	0.06	-0.02	-0.10	-0.05	0.04	-0.22	**0.38**	0.08
	Feed energetic self-sufficiency (%)	35	**0.38**	-0.13	0.07	-0.08	0.13	**-0.45**	**-0.41**	-0.15	-0.02	-0.02	0.08	0.05	0.00	-0.05	-0.07	0.02	-0.24	0.29	0.07
	Breed [2]	36	0.00	-0.06	0.03	0.11	0.08	-0.10	-0.12	-0.22	-0.06	0.04	-0.16	-0.06	-0.06	0.20	0.15	-0.12	-0.16	0.20	0.11
	Organic farming	37	0.02	**-0.36**	-0.05	-0.03	0.23	-0.01	**-0.44**	0.19	0.07	-0.08	-0.02	0.13	0.06	-0.08	0.03	-0.09	-0.02	0.19	0.17
Control variables	Year [2]	38	0.00	-0.02	0.00	0.11	-0.05	-0.01	-0.05	0.01	-0.02	0.08	0.00	-0.02	0.00	0.03	-0.01	0.00	0.07	-0.11	0.01
	Less-favoured area (LFA) [2]	39	-0.17	0.26	-0.05	0.01	-0.19	0.31	-0.09	0.08	-0.15	0.18	-0.15	0.00	0.01	0.17	0.13	-0.14	0.14	-0.22	0.01

			20	21	22	23	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38
	Sales of weanlings for fattening (%) [2]	20																			
	Sales of older weanlings for fattening (%) [2]	21	-0.25																		
	Sales of heifers and young bulls for fattening (%) [2]	22	-0.04	0.07																	
	Sales of animals for slaughter excl. calves and cull cows (%)	23	**-0.60**	-0.26	-0.11																
	Sales of breeder stock (%) [2]	24	0.07	-0.11	-0.04	-0.20															
	Sales of cull cows (%)	25	-0.13	-0.10	-0.07	0.14	-0.27														
Farmer expertise	Work experience (years) [2]	26	0.06	0.08	0.05	-0.01	-0.04	-0.02													
	Feed costs (€ 100 kg liveweight) [2]	27	0.05	-0.09	-0.09	-0.08	-0.01	-0.05	0.04												
	Numerical productivity (%) [2]	28	0.09	0.05	-0.03	-0.08	0.15	-0.19	-0.03	-0.05											
Farm characteristics	Utilised agricultural area (UAA) (ha)	29	-0.07	0.10	-0.03	0.15	-0.10	0.20	0.06	-0.09	-0.05										
	Livestock units (LU) [2]	30	-0.25	0.08	0.01	**0.35**	-0.09	0.17	0.04	-0.10	-0.03	**0.66**									
	Annual work units (AWU)	31	-0.10	-0.08	-0.05	0.14	0.05	0.06	0.09	0.00	0.02	**0.55**	**0.59**								
	LU per AWU	32	-0.19	0.19	0.05	0.27	-0.14	0.15	-0.06	-0.15	-0.05	0.21	**0.54**	-0.30							
	Stocking rate	33	-0.22	-0.17	-0.05	**0.46**	-0.08	0.00	0.04	0.18	-0.12	-0.13	0.16	0.06	0.09						
	Feed proteic self-sufficiency (%)	34	0.13	0.17	0.06	**-0.36**	0.06	-0.05	-0.05	**-0.50**	0.12	0.01	-0.12	-0.08	-0.04	**-0.60**					
	Feed energetic self-sufficiency (%)	35	0.07	0.16	0.06	-0.26	0.03	-0.04	-0.05	**-0.44**	0.11	0.03	-0.04	-0.02	-0.02	**-0.52**	**0.93**				
	Breed [2]	36	-0.11	0.06	-0.02	0.04	0.10	-0.19	-0.02	-0.09	0.15	-0.16	-0.09	-0.04	-0.03	-0.07	0.17	0.15			
	Organic farming	37	0.04	-0.31	-0.20	-0.12	0.16	0.15	-0.31	**-0.50**	-0.08	-0.07	-0.27	-0.01	-0.29	**-0.40**	**0.56**	**0.45**	-0.05		
Control variables	Year [2]	38	-0.07	0.07	-0.04	-0.01	0.01	0.06	0.07	0.07	0.03	0.08	0.02	0.01	0.01	-0.07	0.01	0.00	0.01	0.00	
	Less-favoured area (LFA) [2]	39	0.03	-0.18	-0.15	0.11	0.04	0.00	-0.09	-0.01	0.01	-0.31	-0.17	-0.17	-0.04	**0.51**	-0.24	-0.25	-0.01	-0.02	-0.09

[1] Variables used in structural equation model, [2] Variables used in logit models

[1]Variables used in structural equation model, (2) Variables used in logit models.
[2]Variables used in logit models.

Table B2
Comparison of mean values for animal welfare performance (AW) proxies between the Multiperforming group (performing well on all dimensions), other groups performing well on AW (AW+ groups), and groups performing poorly on AW (AW- groups), based on the panel-data logit model.

		Panel-data logit model			
		Multiperforming Group		Other AW+ groups	AW- groups
		True positives	False negatives		
	Number of farms	171	116	357	645
	AW quantile	22 (12.4) a	34 (12.2) b	32.5 (14) b	80 (14.2) c
Good feeding	Adjusted cow weight after calving (kg)[1]	734 (71) a	748 (64) a	756 (80) a	750 (76) a
	Gross liveweight production (kg/LU)	313 (48) a	329 (55) ab	333 (61) b	345 (81) b
Good housing	Mean building costs (€/LU)[1]	85.3 (71.8) a	78.9 (45.3) a	80.2 (70.9) a	68.6 (49.3) a
Good health	Calf mortality (%)[1]	5.74 (3.41) a	6.08 (2.9) a	6.09 (3.15) a	9.71 (4.89) b
	Other-category mortality (%)[1]	0.447 (0.773) a	0.537 (0.833) a	0.49 (0.841) a	1.26 (1.97) b
	Pregnancy rate (%)[1]	94.3 (4.9) a	92.9 (6.1) ab	93 (6) a	90.3 (8.9) b
	Mean calving interval (days)	377 (13) a	379 (15) a	379 (16) a	382 (28) a
	Rate of 400-day-plus calving intervals (%)	18.9 (11.7) a	19 (11.5) a	19.4 (13.1) a	20.6 (13.9) a
	Dystocia rate (%)	3.78 (8.51) a	4.48 (10.16) a	3.83 (4.39) a	3.76 (5.03) a
	Abortion rate (%)	0.322 (0.809) a	0.582 (1.104) a	0.496 (1.047) a	0.436 (1.11) a
Appropriate behaviour	Estimated amount of feed grazed out of total forage offered (%)[1,2]	65.2 (6.5) a	61 (5.7) b	62.1 (7.2) b	46.1 (13.3) c

[1] Variables used in the structural equation model.
[2] Variables used in the logit models. a,b,c: values within a row with no common letter differ significantly (Wilcox-test: $p \leq 0.10$). Standard deviations in brackets.

Table B3
Comparison of mean values for environmental performance (ENV) proxies between the Multiperforming group (performing well on all dimensions), other groups performing well on ENV (ENV + groups), and groups performing poorly on ENV (ENV - groups), based on the panel-data logit model.

	Panel-data logit model			
	Multiperforming Group		Other ENV+ groups	ENV- groups
	True positives	False negatives		
Number of farms	171	116	357	645
ENV quantile	23.3 (13.1) a	33.5 (12.7) b	32 (14.1) b	80 (14.2) c
Pesticide index per ha forage area[1]	0.02 (0.029) a	0.027 (0.036) a	0.026 (0.034) a	0.112 (0.124) b
Fertiliser index per ha forage area	0.292 (0.21) a	0.398 (0.276) b	0.32 (0.263) ab	0.729 (0.459) c
Nitrogen balance (kg N/100 kg liveweight)[1]	7.09 (3.37) a	9.01 (3.6) b	8.41 (3.86) b	17.9 (8.1) c
Energy consumption (MJ/100 kg liveweight)[1]	1920 (400) a	2260 (480) b	2240 (510) b	3270 (2060) c
Permanent grassland per UAA (%)	66.8 (23.9) a	60.3 (26.6) b	54.8 (26.4) b	41.1 (23) c

[1] Variables used in the structural equation model. a,b,c: values within a row with no common letter differ significantly (Wilcox-test: $p \leq 0.10$). Standard deviations in brackets.

Table B4
Comparison of mean values for economic performance (ECO) indicators between the Multiperforming group (performing well on all dimensions), other groups performing well on ECO (ECO + groups), and groups performing poorly on ECO (ECO - groups), based on the panel-data logit model.

	Panel-data logit model			
	Multiperforming Group		Other ECO+ groups	ECO- groups
	True positives	False negatives		
Number of farms	171	116	357	645
ECO quantile	22.7 (13.2) a	31.2 (14.2) b	33 (13.4) b	80 (14.2) c
Gross operating surplus ratioed to total revenue (%)[1]	42 (6) a	37.9 (5.2) b	37.7 (5.3) b	25.6 (6.6) c
Gross operating surplus (€/AWU)	55,200 (19300) a	59,800 (24100) b	62,300 (25100) b	46,300 (18500) c
Farm income (€/farmer)	26,900 (17800) a	29,100 (24100) a	34,300 (25400) b	14,800 (20000) c
Cash income (€/farmer)	35,100 (17800) a	38,400 (28300) a	41,300 (25400) a	19,300 (21800) b
Debt-to-asset ratio (%)[1]	27.1 (16.3) a	27.9 (14) a	30.4 (14) a	43.7 (21) b
Capital intensity (€/AWU)	115,300 (42600) a	139,500 (54000) b	144,600 (55300) b	145,000 (49800) b

[1] Variables used in the structural equation model. a,b,c: values within a row with no common letter differ significantly (Wilcox-test: $p \leq 0.10$). Standard deviations in brackets.

Table B5
Contribution and significance of farm practices and other explanatory variables in two logit models assessing the probabilities of belonging to the Multiperforming group.

	Variable	Panel-data logit[1] Coefficient	Standard logit[2] Coefficient
Feed	Estimated amount of feed grazed out of total forage offered (%)	0.140*** (−0.018)	0.117*** (−0.0134)
	Amount of corn silage feed out of total forage offered (%)	−0.0796*** (−0.0277)	−0.0596*** (−0.0196)
	Amount of grass silage feed out of total forage offered (%)	−0.0146 (−0.0226)	−0.0231 (−0.0154)
Herd management	Renewal rate (%)	−0.00373 (−0.0239)	−0.00398 (−0.0175)
	Mean age at first calving (months)	0.1 (−0.0745)	0.105** (−0.0508)
	Calving in March–April (%)	0.0137 (−0.00965)	0.009 (−0.00668)
Revenue/sales	Crop revenue ratioed to total revenue (%)	−0.0221* (−0.0113)	−0.0192** (−0.00796)
	Sales of calves (%)	0.00684 (−0.00834)	0.00348 (−0.00625)
	Sales of animals for slaughter excluding calves and cull cows (%)	−0.0155** (−0.00707)	−0.0152*** (−0.00485)
	Sales of breeder stock (%)	−0.0221 (−0.015)	−0.0167 (−0.0103)
Farmer expertise	Work experience (years)	0.0358** (−0.0146)	0.0305*** (−0.00987)
	Numerical productivity (%)	0.131*** (−0.0204)	0.105*** (−0.014)
	Feed costs (€/100 kg liveweight)	−0.0543*** (−0.00781)	−0.0437*** (−0.00527)
Farm characteristics	Livestock units (LU)	−0.00296 (−0.00253)	−0.00136 (−0.00156)
	Breed = AUBRAC (base)		
	Breed = BLONDE D'AQUITAINE	−2.973** (−1.19)	−2.290*** (−0.838)
	Breed = CHAROLAIS	−2.043** (−0.99)	−1.608** (−0.647)
	Breed = GASCON	1.768 (−1.977)	1.259 (−1.156)
	Breed = LIMOUSIN	−1.766* (−0.956)	−1.325** (−0.617)
	Breed = PARTHENAISE	−0.14 (−1.835)	0.0468 (−1.195)
	Breed = SALERS	−1.223 (−1.037)	−0.954 (−0.666)
Control variables	Year = 2016 (base)		
	Year = 2017	0.472 (−0.364)	0.35 (−0.324)
	Year = 2018	−0.342 (−0.394)	−0.184 (−0.327)
	Year = 2019	−0.795** (−0.4)	−0.548 (−0.337)
	Year = 2020	−0.474 (−0.398)	−0.218 (−0.345)
	Year = 2021	−0.307 (−0.386)	−0.178 (−0.345)
	Year = 2022	0.333 (−0.41)	0.3 (−0.363)
	Less-favoured area (LFA) = Plain (base)		
	LFA = Simple disadvantaged area	1.704*** (−0.445)	1.274*** (−0.327)
	LFA = High-mountain	−1.817 (−1.751)	−1.478 (−1.053)
	LFA = Mountain	1.934*** (−0.588)	1.494*** (−0.396)
	LFA = Piedmont	1.634** (−0.682)	1.405*** (−0.434)
	Constant	−20.43*** (−3.916)	−17.52*** (−2.728)
	Observations	1289	1289
	Farms	254	

*** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$.
[1] Model accounting for the panel structure of the data and for unobserved heterogeneity.
[2] Model considering farm-year observations as independent.

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