Productivity gains, evolution of productive performances, and profitability of organic ruminant farms: farm size and feed self-sufficiency matter

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Metadata of the article that will be visualized in OnlineFirst

ArticleTitle	Productivity gains, evolution of productive performances, and profitability of organic ruminant farms: farm size and feed self-sufficiency matter	
Article Sub-Title		
Article CopyRight	The Author(s) (This will be the copyright line in the final PDF)	
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Schedule	Received	12 Jul 2022
	Revised	

	Accepted	10 Jan 2023

Abstract	We analyzed the productive and economic performances of a constant sample of 58 organic ruminant farms between 2014 and 2018, in a mountain grassland area (French Massif Central). Over this 5-year period, these farms expanded without increasing their labor productivity or animal density per hectare of forage area. While animal productivity has been maintained, we observed a decrease in feed self-sufficiency, and thus, an increase in feed purchases. Over the period, the volume of inputs used has increased more rapidly than agricultural production, resulting in a decline in the productivity surplus (PS) at a rate of −2.6%/year. As the prices of products and inputs were relatively stable, this decrease in PS was financed at 41% by an increase in public aid (drought aid, agri-environmental climate measures) and at 49% by a decrease in profitability for the farmer (the farm income per farmer fell by 40%). A binary choice estimation model, i.e., which variables determine the positive or negative sign of the PS, showed that farm size was a negative determinant of the PS, as was system specialization, while feed self-sufficiency was a positive determinant. More statistically robust references on price indices of organic farming (OF) products and inputs, as well as long-term follow-ups of OF farms, are needed to validate these original results, which were based on a small sample size and a short period of time.
Keywords (separated by '-')	Economics - Organic farming - Productivity Surplus - Ruminants - Technical efficiency
Footnote Information	The online version contains supplementary material available at https://doi.org/10.1007/s13165-023-00422-9.

Org. Agr.
https://doi.org/10.1007/s13165-023-00422-9

RESEARCH

Productivity gains, evolution of productive performances, and profitability of organic ruminant farms: farm size and feed self-sufficiency matter

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Received: 12 July 2022 / Accepted: 10 January 2023

Abstract We analyzed the productive and economic performances of a constant sample of 58 organic ruminant farms between 2014 and 2018, in a mountain grassland area (French Massif Central). Over this 5-year period, these farms expanded without increasing their labor productivity or animal density per hectare of forage area. While animal productivity has been maintained, we observed a decrease in feed self-sufficiency, and thus, an increase in feed purchases. Over the period, the volume of inputs used has increased more rapidly than agricultural production, resulting in a decline in the productivity surplus (PS) at a rate of −2.6%/year. As the prices of products and inputs were relatively stable, this decrease in PS was financed at 41% by an increase in public aid (drought aid, agri-environmental climate measures) and at 49% by a decrease in profitability for the farmer (the farm income per farmer fell by 40%). A binary choice estimation model, i.e., which variables determine the positive or negative sign of the PS, showed that farm size was a negative determinant of the PS, as was system specialization, while feed self-sufficiency was a positive determinant. More statistically robust references on price indices of organic farming (OF) products and inputs, as well as long-term follow-ups of OF farms, are needed to validate these original results, which were based on a small sample size and a short period of time. AQ1

Keywords Economics · Organic farming · Productivity Surplus · Ruminants · Technical efficiency

Introduction

In 2021, 2.78 million hectares of farmland and 58,400 farms were engaged in organic production in France, representing respectively 10% and 13% of the French farmland and farms. The productivity of organic farming (OF) systems has been questioned, mainly concerning crop yields per hectare of land (De Ponti et al., 2012) or animal productivity (Gaudaré et al., 2021) by comparing these yields to those obtained in conventional farming (Seufert et al., 2012). A number of studies have looked at the technical efficiency of organic production systems. They all used frontier analysis methods by constructing efficiency frontiers (benchmark or maximum possible production level from a given combination of inputs) from

Supplementary Information The online version contains supplementary material available at https://doi.org/10.1007/s13165-023-00422-9.

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national statistical databases of OF farms (Lakner & Breustedt, 2017). Most of these studies focused on a comparison of organic versus conventional farming; very few have investigated the main determinants of OF productivity per se (Guesmi et al., 2012; Karafillis & Papanagiotou, 2011; Paul et al., 2017). Moreover, these few studies concerned field crops or fruit crop production and, to our knowledge, the papers about the analysis of the organic livestock farming productivity are very scarce (Kostlivy & Fuksova, 2019; Lakner et al., 2011). The performance of organic livestock systems has been studied through various multi-performance indicators (Liang et al., 2018; Veysset et al., 2013), or through a specific indicator such as resilience (Perrin et al., 2020) or vulnerability (Bouttes et al., 2018). These studies revealed that some characteristics were determinant to maintain or improve these performances, mainly feed self-sufficiency (Escribano, 2018; Faux et al., 2022), crop-livestock integration (Liang et al., 2018), or diversification as multi-specie livestock farming (Martin et al., 2020). The evolution over time of the efficiency and profitability of OF systems is a rare topic in the scientific literature. Such studies require a relatively constant panel of farms over time, or statistically representative samples (Veysset et al., 2015). Lansink et al. (2002) conducted a diachronic study of the efficiency and productivity of Finnish OF livestock farms over 4 years (1994–1997) using data from the Farm Accountancy Data Network (FADN-Finland). Over the 4 years of the study, the number of farms in OF is not constant, as some farms converted during these years, and the average number of farms per year, 41, was relatively low; moreover, these farms were classified as livestock farms without further specification of the type of livestock: monogastric, small ruminants, cattle, milk, or meat production. All observations (farm years) were grouped into a single sample. Lansink et al. (2002) concluded that OF farms are more technology efficient than conventional farms. None of these studies analyzed possible productivity gains made by OF farms over time, nor price changes and thus shares of productivity gains (Veysset et al., 2019).

French Massif Central is one of France's largest livestock production areas, with 85% of its territory devoted to raising grazing livestock, including 38% of beef cattle, 20% of dairy cattle, and 16% of sheep/goat farms. The Massif Central concentrates 30% of French ruminant livestock certified in organic farming (OF). The objective of this work was threefold: (1) to carry out an overall medium-term (5-year) technical-economic analysis of OF ruminant farms in the Massif Central, (2) to evaluate the productivity gains of these farms over the period, their formation and distribution, and (3) to evaluate the determinants of productivity gains of these farms. After presenting the network of farms and the technico-economic database used, we explained the methodological choices adopted. We then presented the changes over the period in the main average characteristics of the farms, as well as the productivity surplus, its determinants, and the economic surplus account. Finally, we discussed the changes observed on these farms, before concluding on the conditions for maintaining the technical efficiency of organic livestock farms.

Materials and methods

The farm network and the database

The project's support farms are spread throughout the Massif Central (Fig. 1) and include the three ruminant species (cattle, sheep, and goats) and the two main productions (milk and meat) of this mid-mountain territory. The criteria for choosing farms respect the desire of local stakeholders to have data from specialized farms that meet regional challenges in order to produce references in OF (i) cow-calf-fattener suckler cattle systems, (ii) dairy cattle systems with at least 6000 L of milk per cow per year, (iii) dairy sheep systems with various production periods to meet the needs of the downstream market, (iv) meat sheep systems in search of feed self-sufficiency, in particular by using grass for lamb finishing, (v) finally, in dairy goat production, there are no references on the scale of the Massif Central on OF systems delivering milk and making cheese on the farm, these two systems are therefore present in the network set up. The farms in the network have all been certified organic for at least 5 years at the start of the project (50% have been certified for more than 10 years).

Annually, 70 farms were monitored according to the INOSYS-Réseaux d'Elevage methodology (Institut de l'Elevage and Chambres d'Agriculture, 2014) in order to analyze their functioning. Structural data

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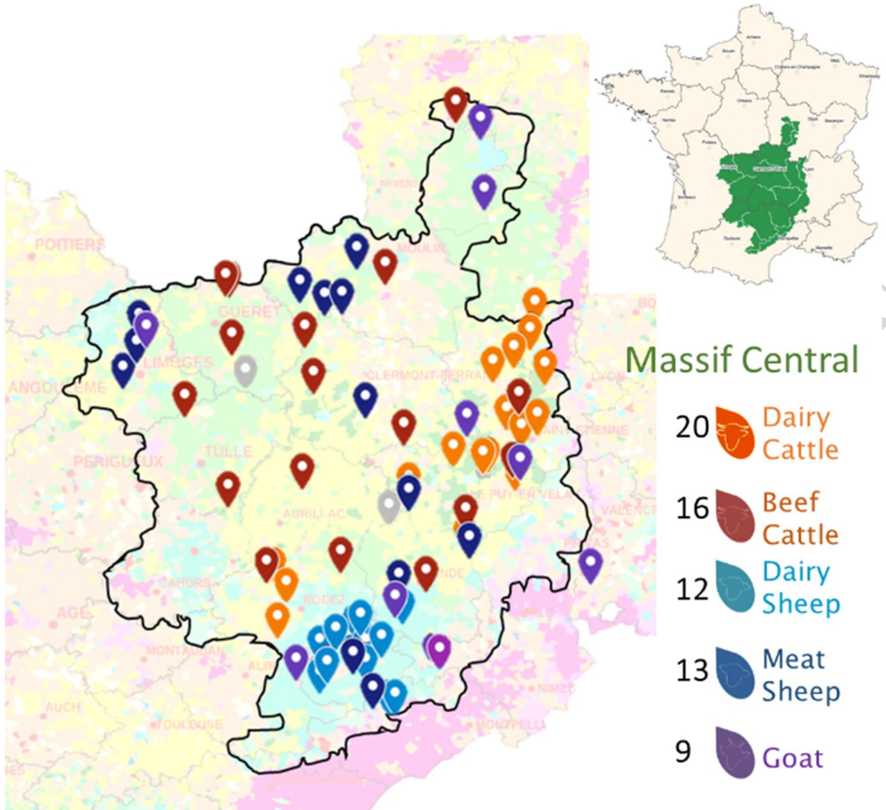

Fig. 1 Location of the 58 constant sample farms of the BioReference livestock farms network

(production means), technical data (global functioning of the herd and surfaces), zootechnical, and economic data were recorded in the Diapason database (Charroin et al. 2005) for each year from 2014 to 2018. Among these farms, we were able to build a constant sample over the period of 58 farms: 16 dairy cattle (DC), 13 beef cattle (BC), 11 dairy sheep (DS), 10 meat sheep (MS), and 8 goats (G). Our study focused on this constant sample.

Descriptive analysis and evolutions of farm characteristics

In order to characterize the sample, we performed an analysis of the means of the variables:

- Structural: number of workers expressed in annual work units (1 AWU = 1 full-time worker on the farm), size of the farm in hectares (ha) of usable agricultural area (UAA), annual crop area, grass area, and herd size in number of livestock units (LU).
- Technical: animal productivity, consumption of concentrates per LU, feed self-sufficiency. Some technical variables, such as animal productivity, depend on the type of production and are therefore not common to all farms (litres of milk per cow, ewe, or goat for dairy systems, kg of live-weight produced per LU or ewe for suckler systems). These variables were expressed for each farm in base 100 with respect to the year 2014.
- Economics: gross farm product (animal products, plant products, other products, and total aid), intermediate consumption, depreciation, financial costs, labor costs, gross farm surplus, value added, and farm income. All economic values were expressed in constant 2018 Euros (Consumer Price Index deflator, IPC given by the French National Institute of Statistics and Economic Studies, INSEE).

In 2014, the 58 farms in the study sample operated an average UAA of 89.9 ha (± 46.5) with a work collective of 2.08 AWU (± 1.16) of which 0.34 (±

0.84) AWU were salaried. The main forage area (MFA) occupied 87.8% of the UAA, with grassland (permanent and temporary meadows) constituting 99% of this MFA. Herds averaged 76.3 LU (± 39.9). The average annual stocking rate (number of LU per ha of MFA) was 1.01 (± 0.29). The 2014 animal productivity was 6400 (± 690) L of milk per dairy cow, 281 (± 42) kg live-weight per beef cattle LU, 246 (± 31) L of milk per dairy ewe, 116 (± 27) lamb per meat ewe, and 552 (± 142) L of milk per goat. The consumption of concentrates per LU was 744 (± 452) kg and the feed self-sufficiency of the herds (the proportion of the animals' energy needs covered by the resources of the farms) was 87.1% (± 9). The gross farm product (GFP) per ha UAA and per AWU was respectively €2406 (± 1071) and €97,940 (± 35,535), the total subsidies represented 28.5% (± 11.5) of this product. Total variable costs and fixed amounted to 26.6% (± 8.7) and 50.1% (± 10.7) of the GFP respectively. The value added (VA), the earnings before interest, taxes, depreciation and amortization (EBITDA), and the net farm income per ha UAA were respectively €813 (± 286), €967 (± 433), and €540 (± 332). The economic efficiency of the farms, assessed by the ratio EBITDA/GFP was 41.0% (± 9.3). Last, the net farm income per unit of family work was €27,462 (± 21,244).

Generation and distribution of productivity gains: productivity surplus and surplus account

Between 2 years, productivity gains measure changes in the volume of production, net of changes in the volumes of factors of production (intermediate consumption, capital, land, labor) and make it possible to analyze the relative competitiveness of firms (Ball et al., 2010). The productivity surplus (PS) produced between two fiscal years is estimated by the respective variations in the volumes of products and factors of production used between these two fiscal years. According to the hypothesis of product depletion in factor remuneration (the value of the various products of a firm completely covers the value of all the factors of production used), we can show that there is equality between the evolution of the PS of a firm and the evolution of the prices of the various products and inputs, called price advantages (PA). It is then possible to determine by the surplus account method (Boussemart et al., 2012) who are the economic agents that are direct partners of the farm (customers, suppliers, capital providers, workers, managers, the State) that benefit from these productivity gains. The PS will be positive when, between two periods, the volumes of products increase faster than those of inputs, conversely it will be negative. An increase in the price of an input is considered a price advantage for its supplier (its remuneration increases), and a decrease in the price of a product is considered a price advantage for the customer (the price of the product is lower). We can construct a balanced economic surplus account (Fig. 2) between the resource of this surplus (or origin) and its distribution (or use). This method requires decomposing the variation in the value of all the farm's products and expenses between 2 years into a variation in price and a variation in volume.

We calculated the PS and applied the surplus account method to individual data from the 58 farms in our farm network. Changes in volume, price, PS, and PA were calculated each year *t* +1 by difference with year *t* for each farm, making four results per farm between 2014 and 2018. An average of the annual PS and PA results was performed, and then we added these four averages to obtain the cumulative of productivity surplus and price advantages and thus achieve the balanced surplus account over the period considered (Veysset et al., 2019).

For all the farms, we had the volumes and real unit prices of the main products (cow, sheep, and goat milk; kg of sheep and beef meat) as well as the cereals or other crops sold. Concerning the factors of production, we also had the volumes and unit prices of a certain number of expenses of the farm: purchased feed, salaried and family labor, rented land, and financial expenses. For the other products and inputs for which we only had the economic value, the volume-price decomposition can be carried out using the price indices provided by INSEE: the IPPAP (indices of producer prices of agricultural products) and the IPPMAP (indices of purchase prices of the means of agricultural production). By deflating the annual values of these products and inputs by their respective indices, the changes in the value obtained between 2 years correspond to changes in volume, and the change in the price index of an item corresponds to its price change. These indices reflect the evolution of prices observed on a national scale, they concern the evolution of the price of products and inputs of conventional agriculture, but cannot be used as such for certain products or inputs of OF that are not on the same markets and

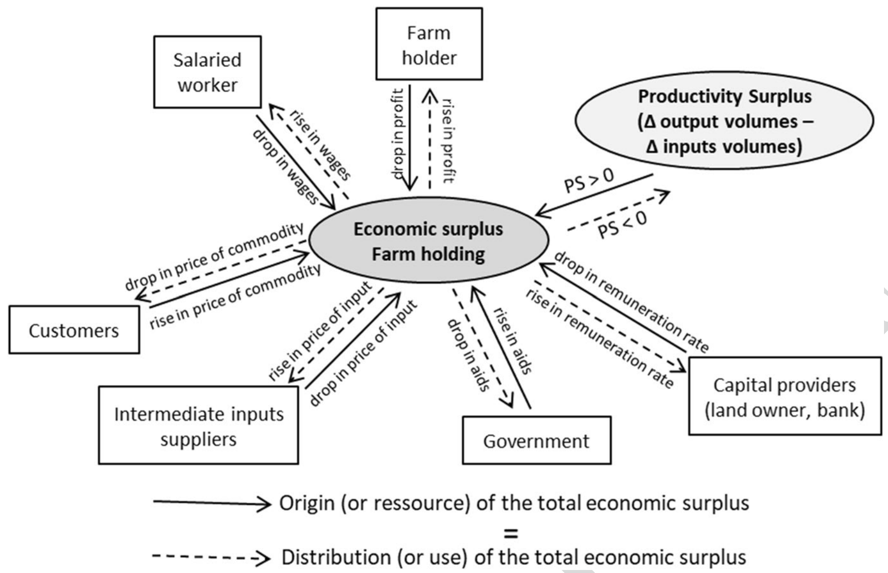

Fig. 2 Balanced economic surplus account. Distribution of the productivity gains and price advantages between the different economic agents that are direct partners of the farm

therefore do not follow the same evolution of their respective prices (for example, meat by-products of dairy farms, mineral feed additives, straw, soil improvers, seeds, and crop protection products). For these organic products and inputs, we had constructed our own indices based on the prices available in some of the network farms, by consulting the project's field experts and the reference systems produced within the framework of the BioReference project.

Since subsidies were an important contributor to the gross product of livestock farms, we had assumed that they did not have a (variation in) volume, so the variation in total value observed corresponded to the variation in the price of subsidies.

We thus made our calculations based on 14 products divided into 7 groups (including the subsidies) and 17 inputs grouped into 6 groups (including the manager) (Table 1). The sum of the aids and gross products for which we knew exactly the volumes and prices for each farm, represented between 90 and 95% of the gross operating product. The total expenses related to inputs for which we have volumes and prices represent 30 to 35% of the total costs of the 58 farms in our sample.

Estimating the determinants of the productivity surplus

We sought to explain the direction of change in the PS between two consecutive years (variable to be explained) by a set of variables (explanatory variables) that were not included in its calculation: variables of structure, practices, or operation of farms. To do so, we used a binary-choice econometric model in which the PS was transformed into a binary variable: value 0 when the PS was negative (loss of factor productivity), value 1 when it was positive (productivity gain). From a practical standpoint, the dichotomization of the PS allows us to examine factors related to the probability of obtaining positive productivity gains in order to find levers to promote organic farming[1].

The selected explanatory variables and their definitions are presented in Table 2. The size of the farms (economies of scale) was characterized by the utilized agricultural area (UAA) expressed in hectares (ha). We could have expressed the size of the farm by the size of the herd (number of total LU), but these farms being specialized in animal productions; the agricultural surface and the size of the herds are strongly correlated ($r^2 = 0.88$). Labor, in particular the use of hired labor or service providers, is a determinant of technical efficiency (Latruffe, 2010), which we characterized by the share of salaried labor in the total workforce. Feed self-sufficiency of farms plays an important role in

[1] Formal presentation of the econometrics model, including equations and additional motivations for the estimated model, were presented in the appendix of the manuscript Supplementary Information (SI A-Estimating the determinants of the productivity surplus: additional motivation for the estimated model).

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Table 1 Products, expenses, prices, or indices taken into account for the calculation of the productivity surplus and the balanced surplus account, divided into categories representing the various economic agents AQ3

Economic agents	Products, costs (annual economic value)	Prices or price indices
Downstream meat	Gross meat product of beef cattle	Individual prices
	Gross meat product of dairy cattle	Individual prices
	Gross meat product of meat sheep	Individual prices
	Gross meat product of dairy sheep and goat	Price indices BioRéférences
Downstream milk	Gross milk product of dairy cattle	Individual prices
	Gross milk product of dairy sheep	Individual prices
	Gross milk product of goat	Individual prices
Downstream other herbivores	Gross product of other herbivores unit	IPPAP[1] equine
Downstream other animals	Gross product of monogastrics	Price indices BioRéférences
Downstream cash crops	Gross product of cereals	Individual prices
	Gross product of protein-oil crops	Individual prices
	Sales of forages and straw	IPPAP forages
Downstream other products	Gross product other activities	IPPAP general indice
Government	Total subsidies	Individual subsidies
Suppliers of intermediate consumption	Fertilisers	IPPMAP[2] organic fertilisers
	Soil improvers	IPPMAP lime, calco-magnesian amendments
	Seeds and planting stock	Price indices BioRéférences
	Concentrates purchased	Individual prices
	Forages and straw purchased	IPPMAP hay, straw, other feeding stuff
	Veterinary and breeding	IPPMAP veterinary expenses
	Fuel and lubricants	IPPMAP fuel and lubricants
	Maintenance of machinery and buildings, other goods and services	IPPMAP small production tools, maintenance of equipment
	Third-party work	IPPMAP overhead expenses
	Water, electricity, other services	
	Insurances	
Capital providers	Depreciation—machinery	IPPMAP farm machinery
	Depreciation—buildings	IPPMAP farm buildings
	Depreciation—other	IPPMAP installations
	Financial expenses	Interest paid/debts, individual
Landowners	Land rent	Rent paid/ha UAA under tenancy, individual
Salaried workers	Employee-related expenses	Wages paid/salaried worker, individual
Social security	Farmers' social contributions	Social contribution paid/family worker, individual
Farmer, manager	Profit	($\sum$ output − $\sum$ input)/family worker, individual

[1]IPPAP: indices of producer prices of agricultural products

[2]IPPMAP: indices of purchase prices of the means of agricultural production

their economic efficiency (Lebacq et al., 2015; Lherm & Benoit, 2003) and was characterized by feed self-sufficiency (share of concentrates and conserved fodder produced on the farm out of the total concentrates and conserved fodder used). Straw self-sufficiency also reflects a certain degree of autonomy, but it also characterized a practice of connecting cereal and livestock production, a source of agronomic efficiency (Sekaran et al., 2021). Crop-livestock integration was also characterized by the share of forage and non-fodder (potentially saleable) crops in the total UAA, dedicated to animal feed. The productive diversity (or specialization) of farms was characterized by their degree of specialization (share of gross product excluding aid of

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Table 2 List, definition, and qualification of explanatory variables used in the semiparametric estimation model (SNP) of the sign of the productivity surplus (PS)

Variable name	Definitions	Qualification
UAA	Usable agriculture are, hectare (ha)	Size of the farm
S_AWUs	Share of the number of salaried workers (AWUs) on the number of total workers (AWUt)	Technical efficiency
Feed_self-suff	Feed self-sufficiency (%), T. feed produced on the farm / T. total feed consumption	Feed self-sufficiency
Straw_self-suff	Straw self-sufficiency (%), T. straw produced on the farm / T. total straw consumption	Crop-livestock integration
A_feed	Share of agricultural area used to produce animal feed (%)	
Spe	Level of specialisation, share of gross product excluding aids of the main unit on the total gross product excluding aids (%)	Farm and crop specialisation/diversification
Shannon	Crop diversity expressed by the Shannon index	
Aid	Total aid received per ha of UAA	Aids from government
Type of production	4 binary variables DC (1 if dairy cattle; 0 if no), BC (1 if beef cattle; 0 if no), DS (1 if dairy sheep; 0 if no), MS (1 if meat sheep; 0 if no)	Control variable

the main unit in the gross product excluding aid of the farm), the diversity of resources and plant production by the Shannon index characterizing the number and relative share of the different plant cover (permanent grasslands, temporary grasslands, forage corn, cereals, other crops) in the UAA. Public aids received by farmers can influence their production decisions (Minviel & Latruffe, 2017); aids were taken into account via their total amount received per hectare of UAA. Finally, in order to determine whether the type of production (cattle, sheep, goat, milk, or meat) influenced the sign of the PS, four binary control variables are introduced in the model (BC, DC, MS, DS), with goat production (G) as the reference. The correlation coefficients between these variables were relatively small, suggesting that multicollinearity issues can be safely ignored in our regressions (SI A, Table SI1).

Our database counted 290 farm years (58 farms * 5 years). This model was used with 232 farm years, 2014 being the base year for the PS calculation, the latter is therefore equal to 0 and its first sign of evolution appeared in 2015.

Results

Farm characteristics changes over 5 years (2014–2018)

Between 2014 and 2018, farms expanded by 8.7%, 8.5%, and 7.8% in UAA, workforce, and herd size, respectively (Fig. 3). Crop rotation (share of UAA, grass, and annual crops in UAA) remained stable overall, as did physical labor productivity (number of ha of UAA or LU per AWU), and stocking rate (number of LU per ha of MFA).

The average animal productivity (kg of milk produced per female dairy per year, or kg of liveweight produced per LU for meat herds) for the entire sample remained stable with a very slight downward trend (−1.28%). The stability of the stocking rate over the period showed that the forage area offered per animal remained stable, so any variation in forage supply was related to variations in the yield of this forage area. The years 2016 and 2018 were marked by a rainy spring (which disrupted the hay harvest) and a dry summer and fall, which limited grazing and fall grass regrowth, of varying severity depending on the geographical area. Forage purchases tended to increase (Fig. 4), with two peaks in 2016 and 2018 (respectively 420 and 430 kg of dry matter of forage purchased per livestock unit (LU) for a five-year average of 340 kg/ LU). The quantities of concentrates distributed per LU also tended to increase, from 775 kg/livestock unit in 2014 to 815 kg/livestock unit in 2018 (Fig. 4). Stagnant animal productivity over 5 years, along with an increase in the purchase of fodder and the consumption of concentrates per animal, has resulted in a decrease in the feed self-sufficiency of the herds (the proportion of the animals' energy needs covered by the resources of the farms).

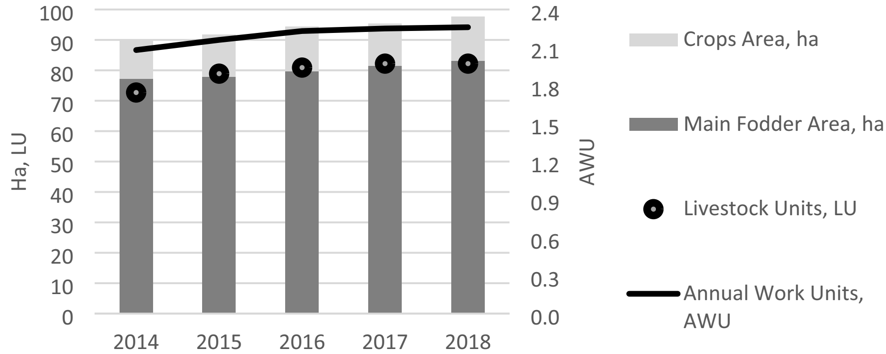

Fig. 3 Changes in the main average structural characteristics of the 58 BioReferences constant sample farms between 2014 and 2018

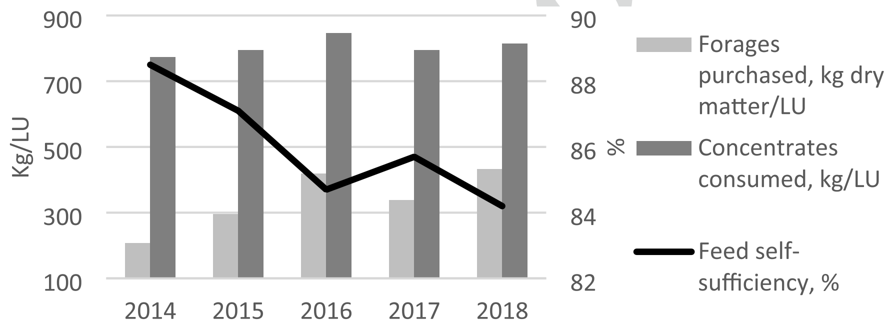

Fig. 4 Evolution of the average quantities of forages purchased per livestock unit (LU), concentrates consumed per LU, and feed self-sufficiency of the 58 BioReferences constant sample farms between 2014 and 2018

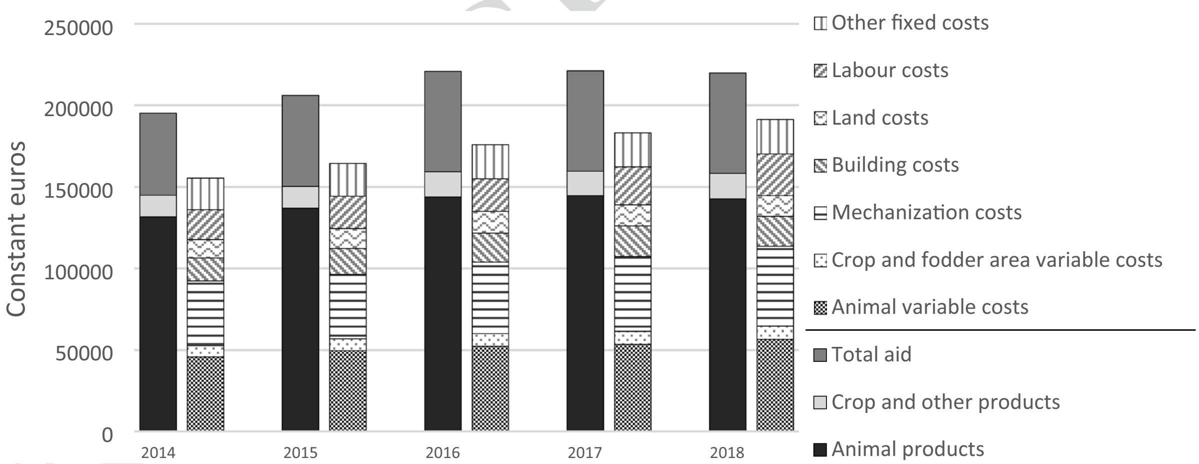

Fig. 5 Changes in product value and expenses, in constant euros, for the 58 farms in the BioReferences constant sample between 2014 and 2018. For each year, the left bar represents the product value's decomposition and the right bar the costs' decomposition

Over these 5 years, the average selling price of animals and animal products increased very slightly (+ 3.8%). Due to the increase in herd size and the maintenance of animal productivity, the quantities sold increased by 10.1%, resulting in an increase in the animal gross output value of 13.3% (Fig. 5). In addition to this increase in animal gross output value, there was a 22% increase in total aid due to the increase in the size of the farms as well as an increase in aid from the 2nd pillar (agri-environmental measures) of the Common Agricultural Policy (CAP) and the allocation of exceptional drought aid. The gross farm product increased by €24,626, i.e., +12.6% (Fig. 5).

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Total variable costs increased by €11,913, or +22.6% (Fig. 5). This increase is linked almost entirely to the increase in animal costs, +€10,786 due to the growth in purchases of fodder and concentrates. Total fixed costs increased by 23.2% between 2014 and 2018, or +€23,890 (Fig. 5). The item of fixed costs that increased the most in value is mechanization (+€9361), mechanization expenses represented 38% of fixed costs in 2014, they represent 40% in 2018.

Overall, over the 5 years, total expenses have increased more rapidly (+€35,803, +23%) than gross farm product. The value added (VA), the earnings before interest, taxes, depreciation and amortization (EBITDA), and the net farm income have decreased respectively by 11.1% (−€6,577), 5.6% (−€4,547€), and 25.3% (−€11,231). Per hectare of UAA, the gross farm product only increased by €110 (+4.6%) while total expenses increased by €229 (+13.2%), resulting in a decrease in VA/ha UAA, EBITDA/ha UAA and net farm income/ha UAA of 18.2% (−€120), 13.1% (−€118), and 31.3% (−€154) respectively. The value added (or wealth created) per total labor unit loses 21.5%. The net farm income per unit of family work unit falls from €27,462 in 2014 to €17,725 in 2018, or −39.8%.

Beyond these averages, there was considerable variability within the sample. However, this variability remained stable over the years and was much higher for structural and economic characteristics than for technical ones (Table 3). The coefficient of variation (CV) of structural characteristics and economic performance varied from 0.50 to 1.50 and more, while that of animal productivity was between 0.15 and 0.30. Feeding practices were relatively variable between farms, especially the use of purchased fodder (CV between 1.15 and 2.10); however, total feed self-sufficiency was not very variable between farms and years (CV close to 0.20). The detailed technical and economic results for each species and production and for each year were published in annual reports (Pôle Bio Massif Central, 2022).

Changes in productivity gains, productivity surplus

The cumulative productivity surplus (or cumulative change in factor productivity) between 2014 and 2018 is negative (−€21,640, Table 4), declining at a rate of 2.65% per year. For a cumulative increase in the volume of output equivalent to €10,061 between 2014 and 2018, the cumulative increase in the volume of intermediate consumption is equivalent to €17,155, with purchased feed being the item that has increased the most (+€5,558), followed by mechanization (fuel, equipment maintenance, and third-party work, +€4991). The increase in the need for mechanization and equipment resulted in a cumulative increase in the volume of fixed capital used equivalent to €7427. As the average number of total workers increased, this additional volume of labor corresponds to +€6150. Overall, the change in input volume between 2014 and 2018 was greater than the change in output volume. For €1 more input volume, the output volume only increased by €0.32, resulting in a decrease in the overall factor productivity of these 58 OF livestock farms over the 5-year period, 2014–2018.

Surplus account: origin and distribution of the cumulative economic surplus

Over the 5 years, the cumulative productivity surplus and the absolute value of negative price advantages represented, in constant euros and on average per farm, a total economic surplus of €28,636 (Table 5). This economic surplus came mainly from the decrease in the remuneration of the farmers or profitability of the farms (49%) and from the government (41%) due to the increase in subsidies (Table 5). The need to finance the decline in the productivity surplus (PS < 0) accounted for 75% of the economic surplus generated over the period, while the increase in farmers' social contributions accounted for 13% (Table 4). There was a slight increase in the prices of intermediate consumption, land rent, and salaried labor, which took 5%, 3%, and 4% respectively of the economic surplus. The prices paid to producers for milk and crops increased very slightly (respectively 3% and 6% of the economic surplus) while those for meat stagnated. The price advantage obtained for crops was beneficial for the farmers who sell them, and disadvantaged the purchase of concentrated feed, whose price increase was partly responsible for the price advantage of suppliers of intermediate consumption.

Table 3 Main structural, technical, and economic characteristics of the 58 BioReferences constant sample farms for each year from 2014 to 2018. Mean values and coefficient of variation (standard deviation / mean)

Variables	2014	2015	2016	2017	2018
Structural characteristics					
Total annual work units (AWUt)	2.08 (0.56)	2.16 (0.53)	2.23 (0.57)	2.25 (0.53)	2.26 (0.52)
Family workers (AWUf)	1.74 (0.45)	1.79 (0.42)	1.84 (0.43)	1.86 (0.43)	1.83 (0.43)
Salaried workers (AWUs)	0.34 (2.45)	0.36 (2.36)	0.39 (2.51)	0.39 (2.10)	0.43 (1.95)
Usable agricultural area (UAA), ha	89.9 (0.52)	91.7 (0.54)	94.4 (0.54)	95.3 (0.53)	97.7 (0.53)
Main fodder area (MFA), ha	77.2 (0.48)	77.8 (0.50)	79.7 (0.50)	81.4 (0.50)	83.2 (0.49)
Including grass area, ha	76.6 (0.85)	76.5 (0.88)	78.8 (0.91)	80.3 (0.90)	82.1 (0.88)
Including maize forage area, ha	0.62 (3.07)	0.8 (2.71)	0.9 (2.48)	1.0 (2.43)	1.1 (2.61)
Crop area, ha	12.7 (1.11)	13.9 (1.09)	14.7 (1.11)	13.9 (1.05)	14.5 (1.13)
Number of livestock units (LU)	76.3 (0.52)	78.9 (0.53)	80.9 (0.54)	82.2 (0.54)	82.2 (0.55)
Stocking rate, LU/ha MFA	1.01 (0.28)	1.05 (0.29)	1.05 (0.28)	1.05 (0.28)	1.02 (0.28)
Technical performances					
Dairy cow productivity, litre milk/cow	6406 (0.11)	6312 (0.15)	6166 (0.16)	6106 (0.15)	6022 (0.16)
Beef cattle productivity, kg live-weight/LU	281 (0.15)	287 (0.14)	265 (0.23)	278 (0.19)	283 (0.18)
Dairy ewe productivity, litre milk/ewe	246 (0.13)	257 (0.13)	271 (0.20)	271 (0.18)	267 (0.19)
Meat sheep productivity, lambs/ewe	1.16 (0.23)	1.06 (0.22)	1.13 (0.21)	0.98 (0.32)	1.00 (0.27)
Goat productivity, litre milk/goat	552 (0.26)	551 (0.28)	552 (0.28)	530 (0.24)	590 (0.28)
Concentrates, kg/LU	774 (0.58)	795 (0.58)	845 (0.60)	794 (0.60)	815 (0.58)
Purchased forage, kg dry matter/LU	207 (1.34)	295 (1.23)	419 (2.16)	338 (1.33)	432 (1.14)
Feed self-sufficiency, %	88 (0.10)	87 (0.13)	85 (0.17)	86 (0.14)	84 (0.16)
Economic performances					
Gross farm product (GFP), k€[1]	199.6 (0.65)	210.0 (0.65)	225.8 (0.66)	225.6 (0.69)	224.1 (0.67)
Animal gross output, k€	131.6 (0.81)	137.0 (0.79)	143.9 (0.80)	144.7 (0.85)	142.7 (0.82)
Crop and other gross output, k€	17.8 (1.21)	17.4 (1.20)	20.5 (1.15)	19.4 (1.16)	19.9 (1.12)
Total aids and subsidies, k€	50.2 (0.49)	55.7 (0.50)	61.5 (0.53)	61.5 (0.54)	61.5 (0.51)
Total aids and subsidies, % GFP	28.4 (0.41)	29.6 (0.38)	30.4 (0.40)	31.2 (0.45)	31.4 (0.42)
Variable costs, k€	52.7 (0.68)	57.1 (0.74)	60.2 (0.69)	61.4 (0.67)	64.6 (0.69)
Animal variable costs, €	45.8 (0.71)	49.7 (0.76)	52.3 (0.69)	53.6 (0.68)	56.6 (0.71)
Including purchased feed, €	26.8 (0.86)	28.6 (0.84)	29.7 (0.85)	30.2 (0.85)	31.5 (0.89)
Including veterinary, €	3.2 (0.66)	3.5 (0.68)	3.7 (0.69)	3.3 (0.71)	3.6 (0.69)
Crop and fodder area variable costs, €	6.8 (0.74)	7.2 (0.91)	7.8 (0.89)	7.8 (0.85)	8.0 (0.89)
Fixed costs, k€	102.8 (0.78)	107.6 (0.78)	115.9 (0.82)	121.9 (0.80)	126.7 (0.81)
Including mechanization costs, k€	39.6 (0.80)	39.4 (0.66)	43.7 (0.69)	45.9 (0.69)	49.0 (0.75)
Including building costs, k€	14.1 (0.91)	16.0 (1.26)	17.8 (1.28)	18.8 (1.26)	18.4 (1.22)
Including land costs, k€	11.3 (0.95)	12.2 (1.22)	13.4 (1.41)	12.9 (1.48)	12.8 (1.47)
Labor costs, k€	18.3 (1.40)	19.9 (1.37)	20.0 (1.45)	23.3 (1.20)	25.6 (1.18)
Including other overhead costs, k€	15.4 (0.58)	16.4 (0.59)	17.0 (0.56)	17.7 (0.59)	18.2 (0.57)
Value-added, k€	59.3 (1.17)	58.1 (1.13)	61.9 (1.12)	59.8 (1.32)	52.7 (1.28)
Value-added, €/ha UAA	813 (0.35)	645 (0.67)	673 (0.76)	627 (0.89)	561 (1.00)
Value-added, k€/AWUt	24.9 (0.60)	24.3 (0.61)	24.2 (0.71)	22.0 (0.92)	19.1 (0.96)
EBITDA[2], k€	81.0 (0.67)	82.6 (0.65)	91.0 (0.65)	85.7 (0.77)	76.5 (0.70)
EBITDA, €/ha UAA	966 (0.45)	973 (0.53)	1,057 (0.54)	962 (0.56)	862 (0.68)
EBITDA, k€/AWUf	50.2 (0.53)	50.0 (0.54)	52.6 (0.43)	47.4 (0.53)	42.4 (0.48)
Economic efficiency, EBITDA/GFP %	41.0 (0.23)	39.9 (0.30)	40.9 (0.24)	37.1 (0.31)	34.1 (0.32)
Net farm income, k€	44.3 (0.71)	45.6 (0.76)	45.9 (0.80)	42.5 (0.96)	33.1 (0.92)

Table 3 (continued)

Variables	2014	2015	2016	2017	2018
Net farm income, €/ha UAA	540 (0.61)	543 (0.86)	597 (0.80)	486 (0.86)	395 (1.20)
Net farm income, k€/AWUf	27.5 (0.77)	27.1 (0.87)	28.3 (0.62)	22.6 (0.79)	17.7 (0.95)

[1]Constant 2018 Euros (Consumer Price Index deflator)

[2]Earnings before interest, taxes, depreciation, and amortization

Table 4 Details of the productivity surplus (volume effect) accumulated over the period 2014–2018, in average constant euros per farm

Changes in output volumes	10,061	Changes in the volumes of production factors	31,701
Milk output	9023	Intermediate consumption	17,155
Live-weight (meat) output	869	Purchased feed and fodder	5558
Other output	169	Animal and area variable costs	3012
		Mechanisation (fuel, maintenance)	4991
		Other supplies and services	3593
		Capital	7427
		Land	969
		Family and salaried work	6150
Productivity surplus = −21,640 €			

Table 5 Cumulative economic surplus account, average per farm in constant euros, and as % of resources and uses

Distribution or use	Euros	%	Origin or resources	Euros	%
Downstream-meat	68	0	Downstream-milk	1861	6
Suppliers of intermediate inputs	1 373	5	Downstream-cash crops	833	3
Landowners	751	3	Downstream-other output	190	1
Farmer social contributions	3670	13	Bank	166	0
Waged labor	1134	4	Government	11,695	41
Productivity surplus	21,640	75	Farmers' profit	13,891	49
Total uses	28,636	100	Total resources	28,636	100

Determinants of the productivity surplus

Four explanatory variables among the eight selected had a significant effect on the sign (positive or negative) of the PS: farm size, feed self-sufficiency, productive specialization, and the subsidies they received (Table 6). The type of animal species raised and animal production, as well as the diversity of the crop rotation, straw self-sufficiency, the share of UAA dedicated to animal feed and the share of salaried workers in the work group did not have a significant impact on the sign of the PS. The variable with the greatest impact was feed self-sufficiency. Feed self-sufficiency was positively associated with the probability of having a positive PS. An increase of 1 percentage point in farm feed self-sufficiency was associated with the probability of having a positive PS by 0.66 percentage points. Increasing farm size had a negative effect: increasing UAA by 1 ha was associated with the probability of having a negative PS by 0.22 percentage points. Similarly, productive specialization (share of gross product excluding aid of the main production unit on the total gross farm product excluding aid) had a negative effect on the probability of increasing the productivity surplus (−0.32). The amount of aid received per ha of UAA had a positive effect, but it was very small and significant at the threshold of only 0.10.

Results from other type of models (standard panel model, probit panel model) were similar to ones of the main model estimated in terms of the direction of the effect of the explanatory variables (SI B, Table SI2).

Journal : Medium 13165 | Article No : 422 | Pages : 16 | MS Code : 422 | Dispatch : 17-1-2023

Table 6 Marginal effect of variables on the probability of having a positive or negative productivity surplus (PS), significance of effects, standard error

Variables	Marginal effect of the variable (percentage points)	*P*-value	Standard error
Usable agricultural area (UAA)	−0.2219	***	0.0669
Share of salaried workers (S_AWUs)	−0.0387	ns	0.0924
Feed self-sufficiency (feed_self-suff)	0.6648	***	0.1791
Straw self-sufficiency (straw_self-suff)	−0.0446	ns	0.0466
Agricultural area used to produce feed (A_feed)	0.0194	ns	0.0684
Productive specialisation (Spe)	−0.3246	**	0.1634
Crop diversity (Shannon)	5.4105	ns	7.8192
Total aid received per ha of UAA (Aid)	0.0162	*	0.0085
Dairy cattle (DC)	−5.2016	ns	7.6055
Beef cattle (BC)	8.0797	ns	8.5649
Dairy sheep (DS)	15.7365	ns	11.0944
Meat sheep (MS)	−2.7517	ns	7.8380

P-value: *** $p < 0.01$, **$p < 0.05$, *$p < 0.1$; ns, non significative

Discussion

Like all methods, the surplus accounts method was sensitive to the starting hypotheses, and the results obtained depended on the sample analyzed. The decomposition of changes in economic value into volume and price effects using the volumes and prices actually observed for each farm limited the bias associated with the use of average price indices for an entire sector over a vast geographical area (Méraud, 1979). Similarly, using individual farm data allowed us to more accurately trace changes in factor productivity established at a sectoral and/or regional level, rather than using aggregated data from regional or national statistics (Veysset et al., 2019). However qualitative the information we used (harmonized method of monitoring Inosys-Réseaux d'Elevages and the Diapason database), some intermediate consumption did not have volumes and was only known by its economic value, hence, the use of price indices. As INSEE did not publish specific indices for organic agriculture, we had to establish them based on the information available to us. The size of our sample was therefore a limitation, and our indices and results did not claim to be exhaustive, but they gave indications of trends observed in organic farming systems in the Massif Central. In order to study in detail the production and economic strategies of organic farmers in a given territory, as well as their evolution, variability and dispersion, it would be essential to have data from statistically representative long-term technical and economic networks.

Farms enlargement, volumes of input used, and financing of these inputs

These organic livestock farms followed an expansion trend, with the notable fact that labor productivity remained stable. Despite the constancy of labor productivity, the increase in the volume of variable factors of production used (excluding labor) has been faster than that of agricultural production, resulting in a drop in the productivity surplus. From a technical efficiency point of view, these OF farms in the Massif Central did not differ from the major trends observed in the whole European agriculture, of which OF is a part. Within the whole EU-28 agricultural sector, capital productivity showed a general downward trend, while there were no gains on intermediate consumption productivity; technical efficiency had not increased since the early 2000s (European Commission, 2016). The development of farm size on organic farms was observed by Langer et al. (2005) and was linked to the debate on the "conventionalization" of OF. The question of the conventionalization of OF is often observed via the evolution of structures, but the evolution of practices, the intensification of the use of intermediate consumption must also be considered (Darnhofer et al., 2010).

The prices of agricultural products and intermediate consumption remained relatively stable within the sample studied, and the volumes of intermediate consumption and capital acquired by OF livestock farmers in the Massif Central were financed by a drop in their remuneration as well as by an increase in the total aid received.

Mechanisation costs

Among the inputs, all of the costs of mechanization, i.e., fuels and lubricants, work by third parties, equipment maintenance (intermediate consumption) as well as the depreciation of owned equipment (capital), constituted the item that had increased the most over the 5 years studied. We did not observe any dilution of equipment use costs in the volume of products or in a larger UAA (Veysset et al., 2019). In addition, tax policy may induce farms with good economic performance to invest in equipment and over-equip, in order to limit taxable income, and thus reduce the amount of social contributions. The search for feed self-sufficiency can lead to a higher cost of mechanization of the forage harvesting and distribution chain than for our European competitors who more easily contract feed purchases (Chatellier et al., 2020). But, we observed that the mechanisation costs increased while the feed self-sufficiency decreased; part of this increase in mechanization costs can be explained by an increase in mechanized actions to try to cope with climatic hazards and preserve a certain degree of feed self-sufficiency: additional mown areas to build up stocks, reseeding of degraded grasslands, and distribution of fodder during the summer. This strategy was not necessarily a winning one in the event of severe drought and thus a sharp drop in forage yields, farm equipment can then be seen as a response by farmers to their risk aversion, and not as a source of improved productivity and economic performance (Sheng et al., 2016).

Feed self-sufficiency and specialization/diversification

Feed self-sufficiency on organic livestock farms was seen as a factor in reducing the vulnerability of these systems to climatic hazards (Bouttes et al., 2018). This autonomy also improved the economic efficiency of farms (Lebacq et al., 2015). The increase in feed purchases was indeed the primary cause of the decrease in surplus productivity, and income, of the OF farms in our sample over the 5 years of study. But the low availability of certified OF feeds on the market, and thus their high price, was a limitation to non-autonomous OF systems (Escribano, 2018). The search for feed self-sufficiency for livestock at the farm scale was therefore a productive, economic, and environmental necessity (Soteriades et al., 2016), feed self-sufficiency in pasture-based grazing systems also improved the resilience of organic dairy farms (Perrin et al., 2020). In the case of our sample of 58 farms, the adaptation strategy of farmers to climatic hazards (drought 2016 and 2018) was to buy fodder; in the face of these increasingly frequent (drought, rainy spring, late frosts) and localized hazards, farming practices will have to be adapted locally (date of grazing of animals, fodder stocks, fodder crops, etc.) in order to guarantee real feed self-sufficiency and to limit the need for purchases (Sidam, 2019). The feed self-sufficiency of livestock farms was reinforced by the diversification of forage resources cultivated on mixed crop-livestock farms (Bell et al., 2018; Havet et al., 2014) although crop diversification did not significantly affect productivity gains in our sample. This may be due to the fact that grasslands and their management (mowing, hay, silage, grazing) are considered as a single crop in the calculation of our Shannon index. Productive specialization decreased the probability of achieving productivity gains, so we can assume that the production of several agricultural goods on the same farm would improve the productivity of the system. Diversification on the farms in our sample mainly took the form of mixed crop-livestock farming, with the production of cereals or cereal/protein mixtures for animal feed in order to reinforce feed self-sufficiency. The integration of crops and livestock on mixed crop-livestock farms reduced the need to purchase inputs thanks to the recycling of nutrients within the system (Peyraud et al., 2014), and the productivity of these diversified production systems was thus improved (Sekaran et al., 2021). Some farms combined a second animal unit with their main animal unit (mainly cattle-sheep associations); the animal mix on pasture allowed to improve animal productivity thanks to the feeding complementarity and parasite dilution (D'Alexis et al., 2014). But feed self-sufficiency in organic livestock farming systems was not sufficient to achieve a good economic efficiency

(Faux et al., 2022), compromises must be made with the mechanization costs of producing, harvesting, and distributing feed produced on increasingly large areas of the farm.

Conclusion

Organic ruminant production systems, from a constant sample of 58 farms in the French Massif Central monitored for 5 years, seem to follow the same structural and technical trends as those observed in the agricultural sector as a whole. We observed an increase in the size of the utilized agricultural area, a decrease in feed self-sufficiency, and an increase in mechanization costs, hence, a decrease in technical efficiency. They were also characterized by relatively stable product prices (at least until 2018), the decline in farm profitability was therefore due to the decline in factor productivity (volume effect). More statistically robust references on price indices for organic products and inputs, as well as long-term monitoring of OF farms, are needed to validate these original results, which were based on a small sample size and a short period. The question of feed self-sufficiency is central to the productivity of these farms, but also to their resilience to climatic hazards. The resilience, vulnerability, and adaptability of farms to hazards and/or shocks require further work to study the trade-offs between increasing the agricultural area, diversifying resources, securing stocks, combining production factors and mechanization costs, and thus consuming non-renewable energy.

Acknowledgements The authors would like to thank the farmers who kindly provided data from their farms, as well as the engineers and technicians of the 20 research, development and teaching structures that were partners in the project.

Author contribution EK and PV contributed to the study conception and design. Material preparation, data collection, and analysis were performed by EK and PV. JJM proposed the econometric model and performed this analysis. The first draft of the manuscript was written by PV. As EK is no longer at Inrae since the end of 2020, only PV and JJM read and commented on previous versions of the manuscript.

Funding The project was financed under the Massif Central Convention by the French government (FNADT), the Languedoc Roussillon, Auvergne Rhône-Alpes and Nouvelle Aquitaine regions and the Aveyron and Corrèze departments.

Data availability Data used are individual economic data protected by statistical confidentiality. They were not deposited in an official repository. AQ4

Declarations

Conflict of interest The authors declare no competing interests.

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