RESEARCH ARTICLE

Interactions between animal enterprises and marketing strategies shape organic multispecies farming systems

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Abstract

One of the key ways to improve the sustainability of agricultural systems is through diversification, taking advantage of synergies between farm enterprises. Among diversified systems, multispecies livestock farms with at least two animal enterprises have rarely been studied. We explored 95 organic farms from six countries, accounting for the proportion of animal enterprises, sales management, workforce size, and work organization. The study reveals various types of interactions between animal enterprises. Complementarities were observed between ruminant and monogastric enterprises, particularly fertilizer transfer from monogastric manure to grasslands. Milk production was often associated with on-farm processing and short distribution channels, which enhanced farm viability and reduced its dependency on herd productivity. Eleven out of the 95 farms combined above-average production efficiency, on-farm processing, and the majority of sales in short distribution channels. Their labor productivity converged toward 22 livestock units per annual work unit, regardless of the number of workers. Combining farm structure; livestock production efficiency; social elements, such as the workforce; and sales management led us to distinguish four types of farms: (i) small and very autonomous grassland farms with on-farm processing and short distribution channels; (ii) dairy farms associated with a high-density pig or poultry enterprise, whose feed purchase contributes to high rates of cattle feeding self-sufficiency and stocking rate; (iii) large farms with an extensive, grassland beef enterprise associated with either sheep or monogastrics; and (iv) dairy sheep associated with goat or beef cattle on rangelands, with high added-value products enhancing salaries. This study highlights for the first time the diversity of organic multispecies livestock farms and how consistent patterns of interactions among farm structure, livestock management, sales management, and workforce management shape them. The results are a preliminary basis for designing policy interventions aiming to scale up organic farming and value social assets of diversified and small farms.

Keywords Organic farming · Mixed farming · Diversification · Farm typology · Short channel

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1 Introduction

The diversification of agricultural production systems is believed to enhance their sustainability and resilience, particularly by reducing inputs (Cardinale et al. 2007; Dumont et al. 2020b) and benefiting from synergies among farm components in agroecological (Kremen et al. 2012) or organic farming systems (Ponisio et al. 2015). Studies dedicated to the diversification of agricultural systems have historically dealt with cropping systems and crop-livestock farms (Gliessman 2006). Livestock farm diversification has been largely neglected thus far. However, the future of livestock farming is highly debated. This debate is highly polarized and often focuses on livestock production systems adversely impacting the environment. Policy-makers are increasingly aware of the need for change, but they lack knowledge about more sustainable and resilient alternatives such as multispecies livestock farms. Such knowledge could support policy interventions incentivizing the spread of such systems.

To study the benefits of livestock farm diversification, pluriannual system experiments (e.g., Prache et al. (2023)) make it possible to integrate knowledge of animal physiology, animal foraging behavior, and parasite dilution that assist in mixed grazing systems (Marley et al. 2006; Fraser et al. 2007; Fig. 1). System experiments allow testing of innovative and risky management options that could have led to unacceptable learning costs on commercial farms and provide useful references on system multiperformance (Dumont et al. 2020a). However, they are carried out under specific environmental and market conditions, which questions their reproducibility in commercial farms. In addition, they are cumbersome to set up, which leads to simplified experimental designs and often limits them to the comparison of animal batches of different species at the grazing season scale, for example (d'Alexis et al. 2014).

Fig. 1 Mixed dairy cattle and sheep grazing (picture Marc Benoit).

Modeling is a complementary approach (Liang et al. 2018; Mosnier et al. 2021) that allows generating large panel data about farms during successive years with contrasting market and climatic conditions. Once the model has been calibrated, it is possible to vary the variables, such as the respective size of each production enterprise, and to analyze these effects independently of any possible bias (Mosnier et al. 2021) (Cf Fox's paradox, Karagiannis (2012)). However, the lack of accurate and generalized data on biological mechanisms prevents modeling studies from properly accounting for the synergies occurring in multispecies livestock farms, such as the complementarity of feeding niches and parasite dilution (Joly et al. 2022). Indeed, the factors influencing variation are numerous and insufficiently recognized for their impact on potential synergies (e.g., between stocking density, species ratio, animal physiological stage, and pedoclimatic conditions). To our knowledge, even if some of these models simultaneously consider biological, economic, marketing, and social factors, none of them is able to simultaneously refine all of these factors with their interactions.

Surveys in commercial farms are a third option. Ulukan et al. (2022) conducted an analysis to identify positive deviants, i.e., those farms from the same European network that outperform others on three indicators: land productivity, independence on nitrogen inputs, and satisfaction regarding income. However, they did not consider the interplay between farm structure, farming practices, workforce and work organization, and sales management, including direct sales of products processed on-farm. Martin et al. (2020) suggested that these interactions determine the sustainability of multispecies livestock farming systems, as they reflect the farmers' strategies in pasture and herd management and for creating economic added value through sales management and marketing strategies.

Our objective is to explore the diversity of multispecies livestock farming systems in Europe and to build a typology of such systems according to the interactions among farm structure, operation of the farm, production efficiency of livestock enterprises, social elements including the work force, and sales management including diversification activities. Such a typology is a preliminary basis for any policy intervention aimed at supporting the spread of multispecies livestock farming.

The farm typology is based on 95 multispecies livestock farms from six European countries in various pedoclimatic and socioeconomic contexts. It focuses on organic farms, where farmers have a clear incentive to maximize synergies between farm enterprises to limit input use (Steinmetz et al. 2021) due to the ban on synthetic inputs and the high price of authorized inputs. To the best of our knowledge, no such study has been conducted on a transnational organic farm network.

2 Materials and methods

2.1 Farm selection

The 95 farms studied were located in six European countries (Austria, Belgium, France, Germany, Italy, and Sweden). They met the following three criteria: (i) they had at least two commercial animal production units, including at least one with ruminants; (ii) they were certified organic farms; and (iii) the work performed on the farm corresponded to at least half a full-time equivalent worker. We wanted at least one species of ruminant to be present because ruminants are dominant in multispecies livestock farms, at least in France (data not available in other European countries) where 75% of multispecies livestock farms were mixed-ruminant farms, 5.6% were mixed-monogastric farms, and 19% were ruminant–monogastric farms (year 2021; Benoit et al. 2023a). We limited the maximum share of monogastric animals to 85% of total livestock units (LUs) for the same reason. It should also be noted that the share of each species can be variable for each type of combination. Despite the large survey area, the recruitment of farms proved difficult in view of the above criteria for candidate farmers. Thus, all farms that met the criteria and were proposed by the partners were selected, regardless of the production mix they presented. In addition, approximately 1/3 of the proposed farms were ultimately discarded because the data were not complete or reliable enough. It is therefore clear that the sample is not a priori representative, but it presents a great diversity of situations (farm size, production combinations, etc.) well suited for such an exploratory study. Moreover, verifying representativeness would be impossible due to the lack of official statistics on such farms (Ulukan et al. 2021). Nevertheless, it can be noted that each country had a large range of farms in terms of the types of enterprise combinations, except Italy, which is overrepresented in dairy sheep production.

The surveyed data were from 2018 to 2019 and were obtained from semistructured interviews with a majority of questions calling for quantitative or binary answers and open-ended questions on production management. These data aim to characterize farm structure (area, workforce, herd size, and composition); the management of herds, grasslands, and crops; work organization; and sales channels. A data paper (Ulukan et al. 2021) presents the data from these surveys, how they were collected, and the verifications and corrections that were made before analyses. Some missing data were filled by using the NIPALS algorithm (Tenenhaus 1998). They mostly concern the evaluation of the workload, complexity, difficulty, and overall satisfaction of farmers or satisfaction regarding income. Of the 35 variables retained in the analysis, 11 have missing data, with an average of 1.4 missing items for the 25 farms with missing data out of 95.

For ruminants, two dairy and meat enterprises of the same species (cattle or sheep) were considered two distinct enterprises because they each have their own inputs, products, and management strategies. On the other hand, "poultry production," which groups broilers and laying hens, is considered a single entity, all of which represent 8% of the total LUs (from 0 to 82%) from the farm sample.

2.2 Analytical strategy

The analytical strategy proceeded through several steps. First, a multifactor analysis, principal component analysis (PCA), was conducted to allow us to relate the descriptive variables of the farms in structure, workforce, sales management, and productive performance (Section 3.1). This multifactorial analysis also allows us to highlight cross-relationships between variables, in particular the share of dairy cattle LUs, the share of monogastric LUs, processing and share of channel marketing, and the technical performance of the enterprises (production efficiency, based on feed use; Section 3.2). These first two sections inform the proposition of a farm typology and highlight the relationships between farm structure and farming practices with regard to animal species, sales management, and workforce (Section 3.3). A cross-sectional analysis of the sample was then conducted (Section 3.4) with the following aims: (i) highlighting the importance, beyond the types of species combinations, of the share of each enterprise in the construction of synergies expected in multispecies livestock farms and (ii) testing the hypothesis in terms of the importance of the workforce on technical performance and marketing strategy. Figure 2 summarizes the general approach used.

2.3 Variables used

According to the aim of the study, a set of variables was developed according to four themes (Table 1): (i) farm structure, (ii) productivity and production efficiency, (iii) social elements, and (iv) diversification activities and sales management.

2.3.1 Farm structure

These variables describe the share of farm areas, in particular the share of crops, permanent grassland, and rangelands, with the last considered outside the Utilized Agricultural Area. Animal production was specified using the notion of livestock unit to calculate the share of each enterprise and the stocking density on fodder area (herbivore LU per hectare of fodder area, including rangelands). A high variability was observed in animal phenotypes for each of the main productions, particularly for animal weight and production level (milk yield, for example). The notion of LU gives an

Fig. 2 Five-step approach implemented to explore the functioning and consistency of organic diversified livestock farms and build a typology of farms.
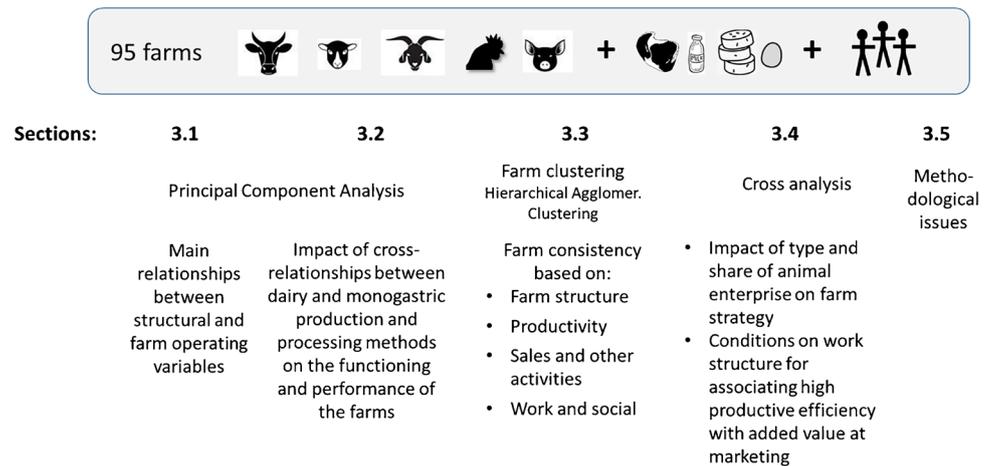

Table 1 Characteristics of the five clusters from the hierarchical automatic classification and for the global sample. Number of farms per cluster and average values of variables. *LU* livestock unit, *AWU* annual work unit, *CR_kg Prot. produced* variable kilogram of protein produced, standardized per enterprise to give a result at the farm level; (1–4) is the score from the survey, with 1 being the lowest level and 4 the highest. Farmer_1 off_roots (0/1) = the farm manager is not from a farming background (the value of this variable is 1 if this is the case). All these variables were used in the PCA, to which we added seven variables corresponding to the proportion of each animal species on the farm (see Table 2).

Cluster name	C1	C2	C3	C4	C5	Total
Number of farms	14	19	34	22	6	95
Farm structure						
Utilized agricultural area (ha)	36.4	54.5	110.0	110.3	20.4	82.5
Crop (% total land)	5.2	14.6	18.7	21.8	2.0	15.6
Permanent grassland (% total land)	73.9	38.8	36.9	29.4	0.0	38.7
Rangelands (% total land)	14.4	7.5	5.2	14.0	81.3	13.8
Ha temporary grassland/ha crop (%)	28.6	71.6	23.4	138.4	28.9	136.0
Stocking rate (LU ruminants/ha fodder area)	0.78	1.48	0.78	0.94	0.65	0.95
Total LU	27.5	136.3	68.3	115.0	79.0	87.4
Productivity and feed self-sufficiency						
LU/AWU	14.8	59.1	34.2	32.7	16.7	34.9
CR_kg Prot. produced/LU	-0.48	0.27	0.14	− 0.16	0.19	0.0
Farm fodder in rum. feeding (%)	78.6	81.2	88.3	81.2	46.1	81.1
Farm feed self-sufficiency (%)	82.9	53.0	91.4	74.3	54.9	76.2
Work and social aspects						
Farmers (AWU)	1.52	1.27	1.38	2.55	1.00	1.63
Paid workers (% AWU)	11.9	32.4	15.7	36.5	40.3	24.9
Unpaid workers (% AWU)	9.1	9.9	11.5	5.6	36.4	11.0
Experience in farming (1-4)	2.7	2.7	1.9	1.9	1.2	2.1
Training frequency (number/year)	3.4	4.3	2.7	1.6	0.3	2.7
Availab. external knowledge (1–4)	3.2	3.0	3.1	3.1	1.8	3.0
Satisfaction regard. income (1–4)	3.1	3.0	2.6	3.4	2.7	2.9
Workload (1–4)	3.0	3.2	3.1	2.9	3.0	3.0
Work difficulty (1–4)	1.7	2.2	2.1	2.7	2.0	2.2
Work complexity (1–4)	1.9	2.1	2.4	2.2	1.8	2.2
Overall satisfaction (1–4)	3.8	3.1	3.1	3.6	2.5	3.3
Farmer_1 starting year	1999	2003	2000	1998	2001	2000
Farmer_1 off_roots (0/1)	0.64	0.16	0.24	0.23	0.00	0.26
Year of farm conversion to organic	1995	2000	2002	1999	2013	2000
Marketing and other activities						
Processing at farm (% farms)	85.7	36.8	32.4	63.6	66.7	50.5
Sales on short channel (% € of sales)	72.3	35.1	53.1	48.5	80.0	53.0
Agritourism (% farms)	43.9	15.8	23.5	40.9	16.7	28.4

interesting proxy of the resources required to ensure the rearing of the animals, and their production is therefore crucial to calculate feed autonomy indicators at the farm level. For calculating ruminant LUs, we opted for the method proposed by Benoit and Veysset (2021), which is based on the references from the Intergovernmental Panel on Climate Change, i.e., on the net energy requirements of the animals for maintenance and production. However, these references do not provide an equation for monogastrics. Moreover, the usual LU values available for monogastrics (Cohen and Zahm 2008) concern intensive conventional systems, with short lifespans associated with high feed efficiencies. For pigs and poultry, we therefore proposed values adapted to organic farming based on the consumption of feed concentrate by monogastrics in organic farming systems and the energy content of the feed concentrate. For the energy content, we considered 1 LU = 3000 feed units, with one feed unit being the energy content of 1 kg of barley (INRA 2018). The determination of average concentrate consumption in organic farming was expert-based (Antoine Roinsard, ITAB, France, and Marie Moerman, CRA-W, Belgium, personal communication). We considered that an organic finishing pig consumes an average of 420 kg of concentrate (1 kg concentrate = 1 feed unit) regardless of the age at slaughter. Therefore, a coefficient of 0.14 LU (0.14 = 420/3000) was used for each pig sold. An organic sow consumes an average of 1500 kg of concentrate in 1 year and thus corresponds to 0.5 LU. Replacement sows were counted as 0.14 LU and piglets as 0.055 LU (Cohen and Zahm 2008). Organic laying hens consume an average of 44.5 kg of concentrate per year, corresponding to 0.014 LU, while organic broilers consume an average of 6.2 kg of concentrate regardless of the length of the rearing period, which corresponds to 0.002 LU for each broiler.

2.3.2 Productivity and feed self-sufficiency

To link farm structure to social dimensions, labor productivity was calculated through the number of LU per annual work units (AWUs). One annual work unit corresponds to the work performed by one person who is occupied on the farm on a full-time basis during the year.

In the absence of reliable and harmonized economic data for this group of farms, we focused on "production efficiency," which indicates the capacity of the farm to market animal products by mobilizing the minimum amount of concentrate, whether coming from the farm or purchased. This includes both the ability of the ruminants to use the farm's forage and the ability of the animals and, above all, the monogastrics, to transform the feed, i.e., their feeding efficiency. We can consider that this indicator "production efficiency" is connected with the feed-food competition concept (Wilkinson 2011). Indeed, a significant part

of the concentrate used by animals is usually human edible. Moreover, feed efficiency makes it possible, if the animal diet is based on a significant share of concentrate, to reduce the amount of human edible feed per kilo of marketed animal product.

To compare the technical performance of the farms, it is necessary to account for the specificity of each species and production. In our farm network, the average protein production was 8.4 kg N/LU for cattle and meat sheep; 19.3 and 20.3 kg N/LU for cattle and milk sheep, respectively; and 18.3 and 23.2 kg N/LU for pigs and poultry, respectively. To account for this variability and calculate productivity at the farm level, including the diversity of livestock enterprises, we opted to center and reduce this type of variable by farm enterprise. This allows for the calculation of a level of global productivity for each farm by weighting the reduced-centered productivity of each enterprise by its share on the farm, based on its LUs (Eq. 1).

$$LP\_CR_k = \sum_{i=1}^{n} Prod\_CR_{k,i} * \%LU_{k,i} \qquad (1)$$

where LP_CR_k is the livestock productivity (kg N/LU) of farm k, i is the livestock enterprise, and n is the number of livestock enterprises on farm k. CR means that the variable Prod (productivity, in kilogram N/LU) is centered and reduced. $\%LU_{k,i}$ is the percentage of LU of enterprise i on farm k.

Three variables were calculated in this way: kilogram nitrogen produced per LU (as meat, milk, or egg proteins), concentrate consumption as amount of concentrate in kilogram used per LU, and production efficiency as the ratio of kilogram of proteins produced to kilogram of concentrates used. The latter will be noted Eff_CR_{tot} when applied to all animal enterprises of the farm and Eff_CR_x with x representing one enterprise, e.g., Eff_CR_{bc} for beef cattle enterprise. Note that concentrates were considered the same whether they were produced on a farm or purchased.

The "Farm Fodder in ruminant feeding (%)" indicator allows us to characterize farms in terms of their capacity to use the forage available on the farm while limiting the use of concentrates. In other words, it represents the share of the farm's forage in terms of the animals' feeding needs. The calculation of monogastric livestock units uses the equivalent of 3000 feed units per year for one livestock unit, according to the following equation:

$$\text{Farm fodder in ruminant feeding (\%)} = \frac{(LUr_k * 3000) - \sum_i^n FC_{FU,i}}{(LUr_k * 3000)} * 100 \qquad (2)$$

where LUr_k is the total LU for ruminants on farm k, n is the number of ruminant livestock enterprises on farm k, and $FC_{FU,i}$ is the energy content (in feed unit; Ulukan et al. (2021)) of the concentrate produced on the farm and of all the feed purchased for enterprise i.

The indicator "Farm feed self-sufficiency (%)" is built on the same logic, but considering $FC_{FU,i}$ as only purchased feed (concentrates and forage).

For the analysis of the results, the variable "Sales product (€)" per enterprise (Ulukan et al. 2021) was used, which can be related to the number of LUs or the number of farm workers.

2.3.3 Workforce and farmer satisfaction with farming activity

Three categories of workers were considered in this study: owners and associates (farmers), paid workers and unpaid workers. Each of these categories is expressed in terms of full-time equivalent (average work unit (AWU)). Qualitative variables were used to describe farmer background (agricultural or not), level of training, and experience in organic farming based on the number of years of settlement as an organic farmer. The farmer's perception of his or her workload, work difficulty, work complexity, and satisfaction was evaluated along a gradient of 1 to 4 with their income and with farming activity.

2.3.4 Marketing and other activities

Agritourism is a frequent diversification option in this farm network, as organic farming certification is an asset as a tourist attraction and educational activity. The agritourism variable is binary (1 = yes, 0 = no). Assuming that the diversification of production has advantages for direct sales (enlarged basket of goods), two complementary variables were selected: whether processing of farm products occurred or not (binary variable) and the share, in monetary value, of farm products sold in short distribution channels.

2.4 Data analysis

The construction of a typology of farms is a major component of our analysis. It was based on hierarchical agglomerative clustering completed with principal component analysis. Both were conducted on the 95 farms based on 29 active variables (detailed in Table 1). Principal component analysis was implemented to identify the linear correlations between variables describing farm characteristics and activities. Because of the very different value ranges of many of the variables used, we standardized them before running the descriptive analysis. A Bartlett test was computed on the variables selected for the PCA to test whether the linear correlations between variables are significant and thus confirm that it made sense to implement a PCA. We also calculated the Kaiser−Meyer−Olkin criteria, which gives an indication of the potential of variables to be grouped according to different latent factors. A rotation of the factor matrix with

the varimax method was processed, aiming at improving the grouping of correlated variables on each of the main factors while maintaining orthogonality between factors. The production efficiency variable Eff_CR_{tot} is an additional (non-active) variable projected onto the PCA axes. This projection allows us to identify the links between farm production efficiency and the active variables, particularly the share of each farm enterprise and sales management. A hierarchical agglomerative clustering was then carried out on the same standardized variables as those used for PCA. The distance between variables used is the Euclidean distance, and the aggregation method is that proposed by Ward. The hierarchical agglomerative clustering highlights, for each of the five clusters proposed, the interactions between farm structure, farming practices, work organization, and sales management. These analyses (PCA and hierarchical agglomerative clustering) were conducted with XLSTAT software. The analyses concluded with a cross-sectional analysis focusing on the strategies implemented by the multispecies livestock farms. First, it aimed to specify which agronomic and marketing goals farmers seek to achieve according to the relative share of livestock enterprises on their farms. Second, it aimed to identify relationships between, on the one hand, the complexity of farm operations and their productive efficiency and, on the other hand, the workforce and work organization.

3 Results and discussion

3.1 Main factors of discrimination of farms and typology

Bartlett's test carried out on the variables selected for the PCA shows that there is a significant correlation between variables, which indicates that it is reasonable to run PCA, as practiced in most studies building typologies from quantitative data (e.g., Alvarez et al. 2018). Categorical or qualitative data would call for other methods (e.g., multiple factor analysis). The results of the Kaiser−Meyer−Olkin test give a relatively low result of 0.335. This is partly due to the presence of the seven fundamental variables describing the proportion of LUs in each livestock enterprise that include many zero values and lead to non-normal distributions of these variables. However, this is not an obstacle to running PCA contrary to including farms with outlier values as the analysis gives them disproportionate importance to the detriment of other farms. This led us to retrieve one farm with 87% of its LUs as monogastrics (and a very low UAA, 16.8 ha), by setting the maximum threshold at 85%. Finally, further Bartlett's and Kaiser−Meyer−Olkin tests confirm that our analysis (PCA) is valid. It should be noted that the rather low level of the Kaiser–Meyer–Olkin index is consistent

with the low variance explained on the first three axes of the PCA.

Figure 3 presents the main explanatory variables for the first three components (or axes) of the PCA after a varimax rotation. Axes 1, 2, and 3 represent 11.2%, 10.1%, and 9.9% of the total variance, respectively (vs only 6.8% for axis 4). Axis 1 (Fig. 3a) indicates dairy sheep production with a small farm size (utilized agricultural area) and a large use of rangelands, a high share of unpaid workers in the workforce, a low farm self-sufficiency for feed associated with a low share of farm fodder in feeding, and a low recourse to external knowledge. On axis 2 (Fig. 3b), the presence of beef cattle is characterized by a high share of pasture in the rotation and a recent conversion to organic farming (OF).

In contrast to beef cattle enterprises, dairy cattle activity is often associated with on-farm processing, a large workforce including a high share of paid workers, and satisfaction regarding income. Axis 3 (Fig. 3c) associates large farms (based on the number of LU) with high work productivity (LU/AWU), the presence of poultry enterprises, and a high stocking rate. These farms show a low level of marketing in the short channel.

The information provided by these three first axes confirms and highlights the specificity of the six dairy sheep farms in the sample. All are located in Italy and in a comparable pedoclimatic and socioeconomic context, and they share fairly similar strategies, which makes them stand out as a priority in the analysis (axis 1). We could have subtracted

Fig. 3 Contribution of the main variables to principal component analysis after a varimax rotation: axis 1 (**a**), axis 2 (**b**), and axis 3 (**c**). The percentage represents the explanation rate of the variable to the axis studied. The positive or negative sign indicates the position of the variable on the axis studied and the positive or negative correlation between variables. AWU average work unit.

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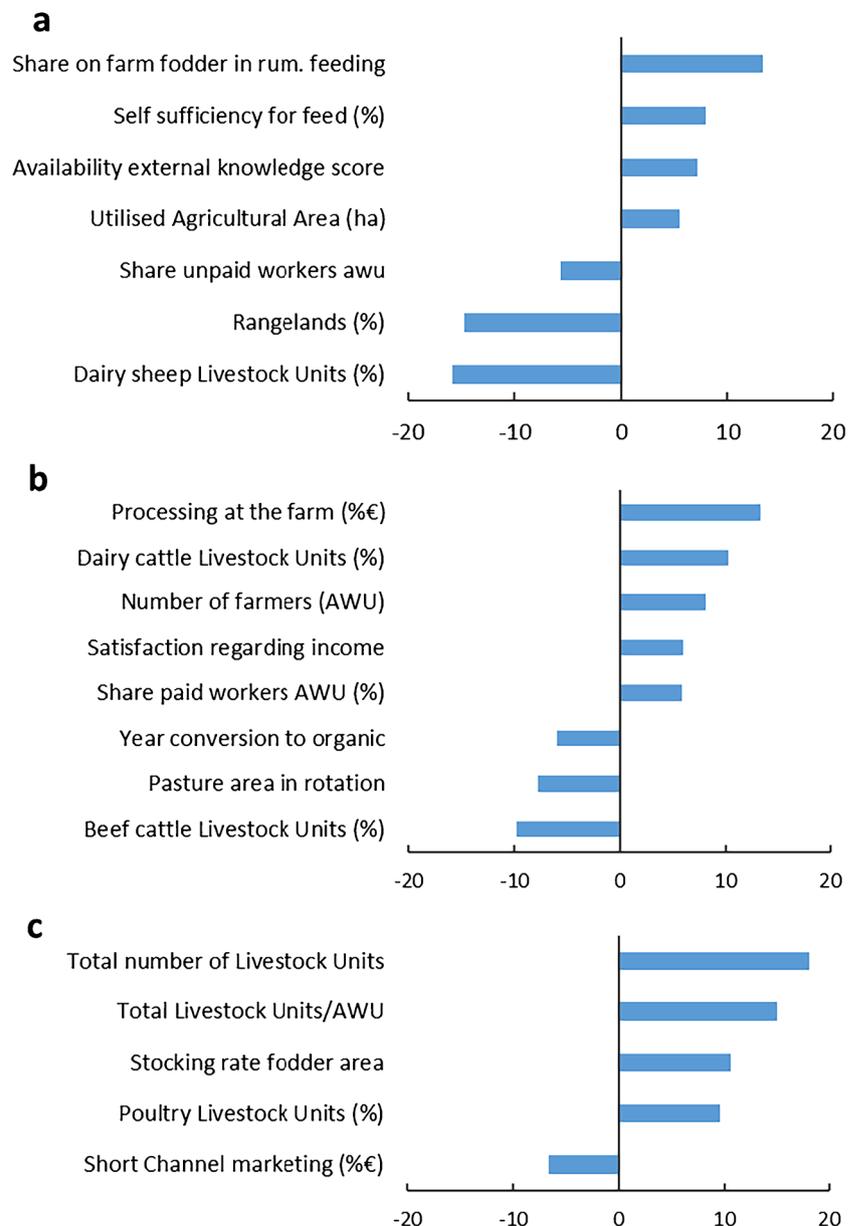
them from the analysis to better highlight the logic of the other enterprise combinations. However, the presence of these six farms highlights an original strategy (see the cluster presented next) and enriches the global analysis of multispecies livestock farms. The other farms, combining other types of enterprises, are well distributed in the other countries, which reveals that farm strategies are independent of local conditions.

3.2 Complex interactions between the share of dairy production, the marketing strategy, and the presence of monogastric animals

Figure 4 shows the 13 variables explaining at least 4% of the variability in axes 1 and 2. The variable Eff_CR$_{tot}$, livestock production efficiency at the farm scale, is positively correlated with the share of fodder in the diet (fodder_Rum_feed_%) and with farm feed autonomy (feed_Rum_Suff_%), which is quite consistent with the calculation method used. On the other hand, it is opposed to the share of sales in short distribution channels (%S.Channel_€) and on-farm processing (process). Figure 4 shows that these last two variables are correlated with dairy production (cow, sheep, and goat). This leads to several interpretations:

– Dairy farms have the possibility of processing their milk on-farm (which is more difficult and expensive with meat, particularly with cattle) and to market a significant part of their production in short distribution channels. These activities most likely contribute to farm economic output and profitability through the creation of added value. Notably, Swedish farms were different: for farms with more than 50% dairy LU, no on-farm processing occurred, and only 5% of products were sold in short distribution channels. In the other countries, in farms with at least 50% dairy LU, on-farm processing occurred in 60 to 80% of farms (average of 69%), and short distribution channels represented 34 to 88% of sales (64% on average).
– Technical performance was not a priority on the farms where dairy cows are the main production, with high on-farm processing and direct sales. This is revealed by the negative correlation between on-farm processing or direct sales and livestock production efficiency (Eff_CR$_{tot}$). Concentrate feeding was, however, well valorized from an economic perspective through the marketing of dairy products sold with a much higher economic value than selling milk on long distribution channel. Conversely, as the farm profitability of beef cattle farms largely depends on feed self-sufficiency (Veysset et al. 2009), we can consider that the farm profitability of multispecies farms with a large beef cattle enterprise was highly dependent on a high share of fodder resources and feed that were produced on-farm in animal diet.
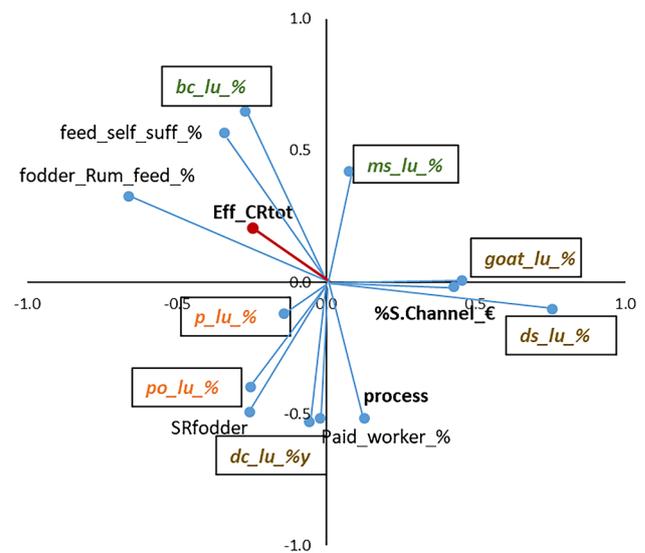

Fig. 4 Projection (blue lines) of 13 active variables of the principal component analysis and one additional variable (Eff_CRtot, red line) onto the first two axes of the principal component analysis. Eff_CRtot is the farm production efficiency calculated as the ratio of kilogram of proteins produced to kilogram of concentrates used, centered and reduced per species. The framed variables correspond to the livestock unit (LU) proportions of each animal enterprise. Green = meat-ruminant-production enterprises (bc beef cattle, ms meat sheep), brown = dairy enterprises (ds dairy sheep, goat, dc dairy cattle), orange = monogastrics (p pigs, po poultry). bc_lu_% represents the share of beef cattle livestock units in the total farm livestock units and the same meaning for other species. The average values of the variables are given in Table 1, with fodder_Rum_feed_%, farm fodder in ruminant feeding (%); feed_self_suff_%, farm feed self-sufficiency (%); SRfodder, stocking rate on fodder area; Paid_worker_%, paid workers/average work unit (%); process, processing at farm (0 or 1); %S.Channel, sales on short channel (% €).

– Pigs and poultry were frequently associated with dairy cows. The transfer of fertility they provide (large purchases of concentrate for large monogastric enterprises and manure spread on the fodder area) allowed some farmers to increase stocking density and milk production. In Fig. 4, the stocking rate variable (SRfodder) is therefore associated with variables showing high shares of dairy cattle and monogastric enterprises.
– Workforce composition is influenced by the types of livestock enterprises and marketing. There were more paid workers in dairy farms with on-farm processing (see variable Paid_Workers_%).

Overall, there are new elements, compared to those noted by Martin et al. (2020). We pointed out that some types of products associated with dairy production in particular have a specific role in the strategy and performance of multispecies farms. The opportunity to process milk and sell the products in short distribution channels seems to coincide with a strong economic added value that can modify

productivity efficiency and the type of labor (possibility of hiring employees). In these situations, the existence of other enterprises reinforces the economies of scope linked to the marketing of milk products and can provide synergies from a biotechnical point of view (flow of materials between enterprises); that means that producing a variety of products is more cost-effective than producing each product independently, while an economy of scale would be based on larger quantity produced. Thus, it seems interesting to highlight asymmetry among different types of livestock enterprises in multispecies farms, in particular (i) from the point of view of their contribution to the profitability of the farm (via the products and types of transformation), (ii) the type of biotechnical interactions, and (iii) the type and volume of work devoted to each enterprise.

3.3 Farm clustering

The hierarchical agglomerative clustering that was carried out on the same centered and reduced variables as those used for the PCA allows us to highlight five groups of farms (19.2% of the global variance explained), whose main characteristics are given in Table 1. The share of each livestock enterprise per farm (% of LU) is given in Fig. 5. Table 2 gives the average share of each livestock enterprise per cluster.

A synthetic representation of farms in each cluster is shown in Fig. 6, with Clusters 2 and 4 merged. The purpose of these diagrams in Fig. 6 is to highlight the consistency between the presence and share of the different livestock enterprises (in particular ruminants vs monogastrics), sales

Table 2 Average share of each animal enterprise in the five clusters (C1 to C5) (share of the total farm livestock units).

	C1	C2	C3	C4	C5
Beef cattle (bc)	20%	19%	79%	19%	19%
Meat sheep (ms)	17%	1%	14%	3%	0%
Dairy cattle (dc)	43%	37%	0%	45%	0%
Dairy sheep (ds)	1%	0%	0%	0%	70%
Goat (g)	13%	0%	0%	0%	11%
Pig (p)	5%	1%	5%	25%	0%
Poultry (po)	1%	43%	2%	8%	0%
Total	100%	100%	100%	100%	100%

distribution (and the creation of added value generated by on-farm processing and direct sales), and workforce type.

Cluster C1 is composed of farms with a large diversity of livestock enterprises, but dairy cows were on average the most common (43% of LU, Table 2). These farms are small (36 ha and 27.5 LU), with a low number of LU per worker (14.8 LU/AWU). They are grassland-based farms (74% of permanent grasslands in the utilized agricultural area), with a low stocking density (0.78 LU/ha) and a high level of farm feed self-sufficiency (82.9%). Animal productivity was the lowest among the five clusters (CR_kg Prot. produced/LU = − 0.48), revealing the low overall intensification. However, Eff_CR$_{tot}$ is close to the farm network average (0.049) due to (i) a consumption of concentrate feeding that is lower than the farm average (variable CR_kg Conc./LU = − 0.13) and (ii) interactions among farm enterprises (pigs using whey, for example), leading to economies of scope. These farmers aim
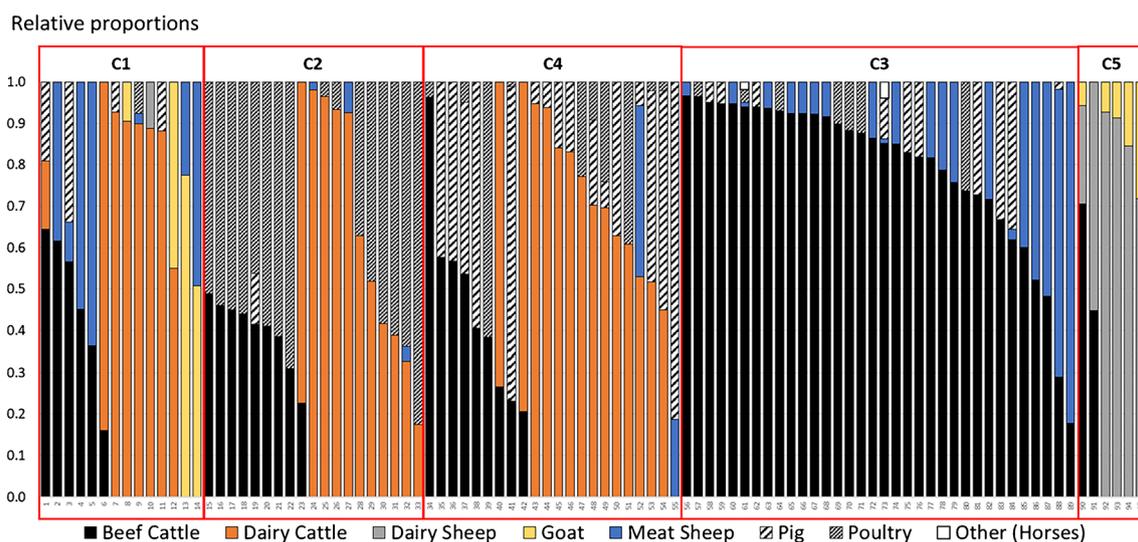

Fig. 5 Share of the livestock units of each enterprise in each of the 95 farms grouped into five clusters (C1 to C5). Farms are sorted by (i) cluster, (ii) percent beef cattle, (iii) percent dairy cattle.
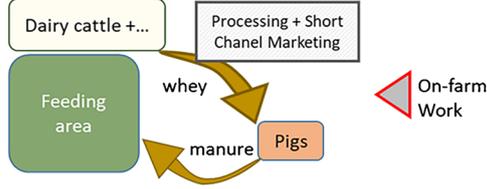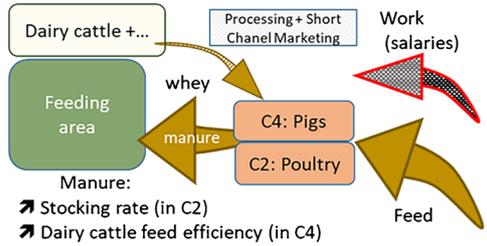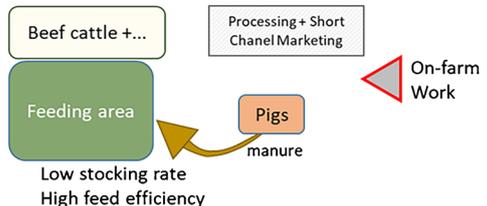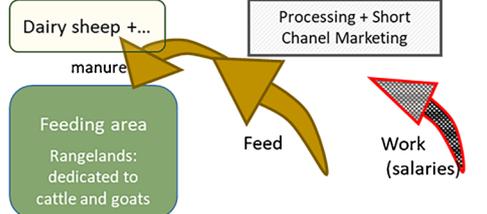
Functioning pattern of the 4 types of farms	Farm self-sufficiency	Key principles
C1 — Dairy cattle +… / Processing + Short Chanel Marketing / Feeding area / whey / manure / Pigs / On-farm Work	**+** Inputs (feeding) Capital (animals, equipment) Work Marketing (short channel)	***Small (family) farms*** Autonomy (high complementarity between farm enterprises) and high added value (processing, short chanel marketing, agrotourism)
C2 & C4 — Dairy cattle +… / Processing + Short Chanel Marketing / Work (salaries) / Feeding area / whey / manure / C4: Pigs / C2: Poultry / Feed / Manure: ↗ Stocking rate (in C2) ↗ Dairy cattle feed efficiency (in C4)	**+** C4: Marketing (short channel) **−** Inputs Capital (animals, equipment) Work (salaries)	***High monogastric share*** **C2:** Intensive system; high stocking rate and sales turnover. Work devoted to production **C4:** Hight work (3.5 workers), seek for ruminant feeding autonomy and added value with short channel marketting
C3 — Beef cattle +… / Processing + Short Chanel Marketing / Feeding area / Pigs / manure / On-farm Work / Low stocking rate High feed efficiency	**+** Inputs (feeding) Work	***Family farm; ruminant meat production*** requiring low inputs (low price premium on organic farming), high feeding efficiency (sheep complementarity), direct selling with small monogastric production (economy of scope)
C5 — Dairy sheep +… / Processing + Short Chanel Marketing / manure / Feeding area / Rangelands: dedicated to cattle and goats / Feed / Work (salaries)	**+** Capital per worker (animals, equipment) Marketing (short channel) **−** Inputs Work (salaries and no paid)	***Entrepreneurial farm*** (1 farmer) focusing on a high valorization of milk (small ruminants, processing + short channel) allowing remuneration of salaries and large purchase of feed. Sheep + goats or cattle

Fig. 6 Four types of multispecies livestock farms, based on the five hierarchical agglomerative clustering clusters (C1 to C5), after merging C2 and C4. Clustering highlights farmer consistency based on three main factors: the share of monogastric and dairy enterprises, the share of on-farm processing and short-distribution channels, and the size and characteristics of the workforce. Gray−red bordered arrows = main type of workers with hatched gray if paid workers represent more than one-third of the workforce. Brown arrows = specific raw material flow. The main items pointed out the notion of autonomy (high or low) for inputs, work and farm capital, and the key principles of farmer strategy and farm operation. "Feeding efficiency" (for C3 key principal) refers to the indicator Eff_CR_{tot} (ratio of kilogram of proteins produced to kilogram of concentrates used).

at a good valorization of farm products, with a very important share of on-farm processing, short distribution channels, and agritourism (in 43% of the farms). These farmers have a high level of training and experience and are among the most satisfied with farming activity. The importance of short circuits strengthens the link with the local community. Notably, 64% of farmers are off-root, i.e., coming from other places and/or activities. Despite the great diversity of production and activities, the work is neither considered complex nor difficult compared to the other clusters. Autonomy is a core principle of these small-scale farms, concerning work (few employees), capital (small size), inputs (including animal feed), and marketing. This type of farm is now identified in research studies that confirm the characteristics observed here, including the high added value for the products, sales in short distribution channels and a high level of training among the farmers (Lecole 2021).

Clusters C2 and C4 have some common features, in particular a high share of monogastrics (38% of LUs vs less than 7% in the three other clusters) and dairy cows (37% and 45% of LU), crops in the utilized agricultural area (18%), and large herds (125 LUs on average vs 58 LUs on average in the three other clusters). They were therefore merged. Monogastrics are either mainly poultry in C2 or pigs in C4 (Fig. 5 and Table 2). The stocking density is very high in C2 (1.48 LU/ha vs 0.94 for C4) thanks to a large amount of feed purchased and to the spread of poultry manure to grasslands and cropping areas. Consequently, the level of farm feed self-sufficiency is only 53% for C2 vs 74.3% for C4. Despite the high stocking density, the farm fodder in

ruminant feeding of C2 reached 81.2%, and the animal productivity was the highest (CR_kg Prot. produced/LU = 0.27 for all the C2 enterprises, with 0.63 and 0.20 for dairy cattle and monogastrics, respectively). These farms are the most recent in all clusters (starting year = 2003), and the share of products sold in short distribution channels is the lowest (35%). Cluster C4 differs from C2 by a higher share of sales in short distribution channels (49%), more agritourism (41% of the farms vs 16% for C2), and a larger workforce, with 3.5 AWU vs 2.3 AWU for C2. The number of associated farmers is also the highest of all clusters (2.5 farmers vs 1.3 on average). Farms from Clusters C2 and C4 are intensive with a large number of animals and large housing facilities, which require high investments. Monogastrics are partly fed with off-farm concentrate. The share of paid workers in the workforce is also high (32.4% and 36.5% for C2 and C4, respectively). Overall, C4 farms appear to be slightly less capital intensive than C2 farms, with almost half as many livestock units per AWU and a stronger link to the consumer. Although work difficulty is considered to be high in C4 farms, satisfaction with farming activity is also high.

Cluster C3 is the largest, with 34 farms out of the 95. It is characterized by (i) a very high share of beef cattle (79.4% of LU), associated with either meat sheep or monogastrics (Fig. 5), and (ii) a large utilized agricultural area (110 ha vs 82.5 on average). The stocking density is low (0.78 LU/ha), which results in a very high level of farm fodder in the ruminant diet (88.3%) and a low use of concentrate feeding. This strategy is a condition for profitability in that type of livestock farming system (meat production from ruminants; Experton et al. 2017 ; Veysset et al. 2009). On-farm processing of products is the lowest among all clusters. Farm economic profitability is limited, as revealed by the low satisfaction of farmers with their income (lowest score, at 2.6 out of 4) and the low share of paid workers in the workforce. These farms appear to be very autonomous, particularly for animal feeding and labor. Many references show that the association of sheep and cattle, with contrasting grazing ability and foraging behavior, can enhance resource use efficiency (Martin et al. 2020). Recent studies have assessed the relative strength of the underlying biological processes (Jerrentrup et al. 2020; Joly et al. 2022) involved in mixed grazing systems of sheep and cattle and how they increase sheep productivity and overall system productivity (Benoit et al. 2023b, Prache et al. 2023).

Farms from Cluster C5 are all located in Italy and are based on large dairy sheep flocks that are associated with either cattle (cows can graze on rangelands, even if fattening requires better pasture and concentrate feeding) or goats that efficiently browse harsh rangeland resources. Rangelands cover an average of 81% of the farm area. The workforce is very important (4.7 AWU), with 40% paid workers, 36% volunteers, and only one farmer per farm. The share of on-farm processing and of products sold in short distribution channels is very high, with good valorization (processed ewe's and goat's milk), which makes it possible to hire employees and to purchase a high amount of feed. This results in low levels of farm fodder in ruminant diets (46% on average) and in low feed self-sufficiency (only 55% on average). As for C2, these feed purchases can increase soil fertility and forage production due to manure spreading. Overall, farmer satisfaction is the lowest of all clusters, which could be explained by low levels of income. Work complexity and difficulty are considered low. All of these farmers have agricultural backgrounds, and conversion to organic farming is recent compared to the other clusters. These farms highly depend on off-farm work and purchased feed. The high added value provided by milk processing limits the number of animals (LUs per AWU) and capital required per worker.

3.4 Cross-analysis of the whole farm sample

Figure 6 summarizes cluster characteristics and highlights the consistency between farm structure, farming practices, workforce, and sales management in each cluster.

The type and share of livestock production, particularly dairy and monogastric, on the one hand, and the share of products processed on-farm and sold in short distribution channels, on the other hand, shape both farm operations and farm structure (e.g., number of LUs per worker). They also have a strong impact on farm autonomy, which is assessed through the inputs used (in particular feed input), the capital used, and the workforce. A holistic vision of farm autonomy can be a core principle in some farmers' strategies (de Roest et al. 2018). Some farms, especially those in Clusters 1 and 3, are very autonomous from various perspectives (inputs, capital, and labor with a central role in product distribution channels), which could strengthen their resilience to various types of hazards (Dumont et al. 2020b, Bell et al. 2021; Mosnier et al. 2021). However, managing a highly diverse, autonomous, and efficient farm requires time for monitoring pastures, crops, and herds and a significant amount of knowledge to benefit from synergies between system components (Dumont et al. 2020b). This was particularly successful for farms in Cluster C1 that are managed by farmers who do not have an agricultural background. However, they have a long experience in farming (highest score, with C2, at 2.7) and the oldest conversion to OF, in 1995. In addition, they largely rely on external academic knowledge.

Beyond the type of association, the consistency of farm operations and their performances are built on the basis of the relative size of each enterprise. This can be illustrated by monogastric enterprises that play contrasting roles in farm operations according to their size. When small monogastric herds are associated with dairy ruminants and on-farm processing of milk, they allow for the recycling of part of

the coproduct (whey) of cheese processing (Cluster C1, for example). This contributes to improving production efficiency at the farm level due to a partial substitution of concentrate feeding (Reyes-Palomo et al. 2020). A small pig fattening enterprise is also quite compatible with agritourism and generates less olfactory nuisance to the neighborhood than a large fattening unit. Associating a small monogastric enterprise with cattle makes it possible to have a more regular income during the year (Dumont et al. 2020b) and provides an opportunity to sell diversified "food baskets" on farms. Vollet and Said (2018) showed that these were popular with local consumers in central France. Among the 17 multispecies organic livestock farms characterized by Steinmetz et al. (2021) by ecological network analysis, the two most economically efficient farms combined beef cattle and monogastric animals and had on-farm processing. Conversely, a large monogastric enterprise will mainly use long distribution channels, and other types of synergy appear, as in Clusters C2 and C4. The high amount of monogastric feed purchased from outside the farm generates a transfer of fertilizer (manure) to meadows and fodder crops, thus increasing fodder feed autonomy and farm stocking density (Fig. 4). This strongly shapes nitrogen flows within the production system (Steinmetz et al. 2021). This high dependency on external inputs can penalize economic efficiency. Nitrogen flows must be carefully managed to avoid nitrate leaching, depending on the pedoclimatic context, on the share of land where manure can be spread, and on the outdoor area dedicated to monogastric livestock and its management.

The pedoclimatic context can also determine the livestock combinations, as illustrated by Cluster C5, where all farms are in Mediterranean areas. Rangelands cover, on average, 81% of the farm area and were the only resources available in three out of these six farms. Five out of the six farms in this cluster have goats, and two have beef cattle (Fig. 5). These herds are better adapted to forage on rangelands than the dairy sheep that are managed intensively. More globally, associating production with high feed requirements (milk in particular) with more extensive production (ruminants for meat) allows better use of heterogeneous resources in space and time (Rouel et al. 1995; Aigrain et al. 2016). Meat sheep have the ability to use resources poorly utilized by cattle and, in particular, can graze throughout the year, including winter (Dedieu et al. 1990). Diversifying farm activity with two or more ruminant enterprises brings flexibility and thus reduces sensitivity to hazards (Cournut et al. 2012; Mugnier et al. 2020). As shown by Pierson et al. (1982), mixing meat sheep and beef cattle can lead to increased livestock density, up to 34% in their study, compared to specialized beef. This meat sheep-beef cattle association results in a better use of fodder resources and better management of sanitation issues, leading to higher meat production per hectare (d'Alexis et al. 2014). In Cluster C3, the association between

sheep and cattle is correlated to a high share of fodder in animal feeding.

Having several small enterprises on a small farm is part of an economy of scope strategy aimed at the following: (i) benefiting from between-enterprise interactions and (ii) developing short distribution channels by selling consumers a wide range of products (Vollet and Said 2018). Farm profitability is built on the creation of high added value in all production, as well as from agritourism (de Roest et al. 2018). Cluster C1 is representative of this strategy; the average of the three indicators "Sales in short distribution channel," "On-farm processing," and "Agritourism" reaches 0.67 vs 0.40, 0.36, and 0.54 for C2 + C4, C3, and C5, respectively. Added value seems to be a core principle with the small size of enterprises. The average size of the largest enterprise in C1 is 12 LU only, vs 55, 52, and 55 LU for C2 + C4, C3, and C5, respectively.

A final question is thus whether there is a common structure of the workforce in these multispecies organic farms. The PCA suggests that there is negative correlation between the good technical performance of the animal enterprises (based on the variable Eff_CRtot) and high added value achieved with strong labor investment in processing and selling in short channels (Fig. 4). We hypothesize that only farms with a large workforce can assign specialized workers to on-farm processing and direct sales or to a given livestock enterprise, resulting in high overall technical performance. To explore this hypothesis, those farms with (i) Eff_CR_{tot} above average for each livestock enterprise, (ii) on-farm processing of at least one product, and (iii) selling more than 50% of their products in short distribution channels were extracted from the database in a "positive deviant" perspective (Ulukan et al. 2022). We then split these farms into two groups according to workforce: "G<3_AWU" for farms with less than three AWU and "G>3_AWU" for farms with more than three AWU. Among the 95 farms, 11 farms met these criteria, with seven in the G<3_AWU group and four in the G>3_AWU group. Herd size in farms with a high workforce was twice that in farms with a limited workforce (98 vs 47 LU on average), leading to very similar labor productivity (21.7 and 22.7 LU/AWU for G<3_AWU and G>3_AWU, respectively). The number of LU per worker was on average 64% higher in the other farms of the network (36.5 LU/AWU). The farms in G<3_AWU show a high level of feed autonomy and a production per LU above average (CR_kg Prot. produced/LU = 0.23). Despite much lower work productivity (LU/AWU), their gross product per AWU is 43% higher than the farm network average, reflecting good control of both production and marketing. In addition, these farmers show the highest overall satisfaction (score of 3.71 out of 4 vs 3.29 on average). This study thus shows for the first time that combining good

technical performance and high added value is therefore not only possible on farms with a very high labor force but shows also that this combination allows the viability of small farms in terms of surface and investments per worker.

3.5 Methodological issues when studying diversified farming systems

Studying this type of diversified farm is challenging from a methodological point of view. The four dimensions considered—farm structure, workforce, sales management, and share of each animal enterprise—and many possible types of enterprise combinations provide a high potential diversity of farm profiles. Given this diversity, obtaining more statistically significant results and a better representation of the various types of farms studied (multispecies livestock farms with various types of enterprise combinations with various shares of each animal enterprise) would require a very large farm sample that could not even exist. Such farms are scarce, and not all farmers are willing to spend time on research and development projects. In addition, these surveys are cumbersome to carry out due to the amount of data needed to develop a holistic view of each farm, as is the checking of the large panel data. We propose several solutions to be combined to refine the study of multispecies livestock farms: (i) limit the panel of farms to one type of combination of animal enterprises to improve the significance of the statistical analyses while maintaining a large gradient for the share of each species; (ii) broaden the context to nonorganic farms, which will greatly expand the sampling possibilities; (iii) elaborate expert-based typologies that can account for the perception of different types of stakeholders; and (iv) use bioeconomic farm models to simulate multispecies farms with contrasting structures, shares of animal enterprises, workforce, etc. (Mosnier et al. 2021) and assess their resilience (Dumont et al. 2022).

4 Conclusion

We explored the diversity of European multispecies livestock farms and empirically describe for the first time what underlies the consistency of farmers' strategies in this context. In a systematic approach, we simultaneously accounted for farm structure, share of animal enterprises, diversification of sales management, and workforce size. We explicitly describe farmers' strategies and farm organization through five farm types. This typology aims primarily at highlighting not only the interactions between the previous five main factors but also the livestock production efficiency. We do not claim to give a representative vision of all diversified farms at the European scale through the profiles proposed. We are aware that it would be interesting to confirm these results on a larger number of farms and possibly refine the proposed farm typology. Another way to strengthen the results from a statistical point of view would be to tighten the range of livestock enterprise combinations studied. The farm strategies highlighted go beyond the framework of organic farming and more generally enable the analysis of the sustainability of agroecological livestock farms. Livestock activities are currently being questioned, and alternatives to livestock farming systems implemented for several decades are expected. This study provides proposals based on still rather uncommon farming systems combining several animal enterprises. Beyond the interest in potentially improving the efficiency, sustainability, and resilience of livestock production, the combination of animal enterprises creates opportunities for short distribution channels, on-farm employment, and stronger trust between producers and consumers. In this study, we showed that small farms can be viable when based on short distribution channels and on-farm transformation. Small farms are also easy for newcomers to set up with reduced capital and land. Finally, the description of contrasting organizations and strategies in organic multispecies farms provides references for the implementation of public policies aiming to promote farming systems that generate positive externalities for society.

Declarations

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