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Orchard Grazing in France: Multiple Forms of Fruit Tree–Livestock Integration in Line with Farmers' Objectives and Constraints

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Abstract: Although the grazing of extensive standard orchards has long been a common practice in Europe and continues to take place on a considerable portion of existing traditional orchards, it is more unusual for current specialized and intensive orchards (with bush trees) to be grazed. The way in which animals are integrated into these modern forms of orchards differs according to the animal and tree species as well as to the place relegated to livestock as well as the expected and provided ecological services of that place. However, little literature is available on these modern forms of sylvopastoralism. The objective of this paper is therefore to provide the first overview of the advantages and limitations of these systems as perceived by the actors involved. Based on several research programs, we first tracked on-farm innovations to describe a diversity of systems. We then conducted a multifactorial analysis to characterize these systems according to: (i) structural farm variables; (ii) farmer motivations to integrate livestock; (iii) technical adaptations generated by sylvopastoralism; and finally, (iv) observed services and disservices provided by livestock in orchards. A total of 34 farms and 21 variables were used to differentiate three types of systems that differed according to animal species, grazing patterns, the degree of system redesign, and compliance between initial farmer motivations and the observed services. The results showed that while the practice of livestock grazing in orchards can be agronomically effective and economically viable, its success depends on the ability of growers to integrate all of the dimensions of livestock farming into their orchard system for a win-win association. There are a large number of variables that are involved in successful orchard grazing that result in both challenges and opportunities, but success is closely linked to the grower's ability to adapt the production system to suit the intended role of livestock and to acquire new skills. This typology paves the way for numerous combinations between orchards and livestock. The analysis of the determinants, obstacles, and benefits provided by orchard grazing provides some preliminary elements that are necessary to adapt agricultural support to a diversity of integration patterns in integrated tree and livestock systems.

Keywords: grazed orchards; sylvopastoralism; agroforestry; agroecology

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1. Introduction

Combining livestock and trees in different forms of silvopastures has long been a traditional practice in Europe, but one that is now outdated given the current highly specialized production systems that exist at the present time [1,2]. Today, in the context of a shift towards agroecological and more sustainable agricultural systems, some fruit growers are diversifying and have chosen to reintroduce livestock into their specialized "bush" (or low-stem) orchards [3,4]. In general, integrated crop–livestock systems are considered to be an efficient design for sustainable, ecologically based farming systems since they rely on the complementarities between crops and livestock and the connectedness of livestock to the land [5]. The complementarities first correspond to the ability of animals to enhance natural and cultivated vegetal resources, especially non-food biomass.

Abundant literature on crop–livestock combinations exist, with many studies suggesting typologies and discriminating factors to describe the diversity of crop–livestock systems according to the level of coupling [6,7], achieved autonomy [8], or ecological functioning [5], either at the farm [9] or territory [10,11] scale. There is also abundant literature concerning forms of silvopastures that may, in particular, provide insight into animal feeding and foraging behavior [12]. However, these forms of crop–livestock integration are relatively different from those considered in the present study, where animals are fully combined (in reference to Hilimire's typology [2]) with high-value trees (in reference to Den Herder's stratification; [13]), i.e., intensive, perennial and productive orchards with low-stem trees.

The integration of livestock into specialized and intensive fruit orchards may not be particularly well-suited to sylvopastoralism, but additional benefits for grass, pest, and disease management may be expected and may motivate this practice. These innovative systems may have specific characteristics that consider the benefits that they can offer and the drawbacks that they need to overcome. As for traditional meadow orchards with scattered trees, grazing orchards could facilitate grass management [14,15] and thus decrease herbicide use and tillage, which have drawbacks in terms of labor, machinery, and the environment. Many sheep breeders graze their animals in vineyards during the winter to avoid forage expenses—an ancestral practice that is regaining interest [16]. Another additional benefit that may motivate fruit growers is the regulation of aerial pests (plum curculio—*Conotrachelus nenuphar*; Japanese beetle—*Popillia japonica*), or pests that live all year long (vole—*Microtus duodecimcostatus*) or part of the year (codling moth—*Cydia pomonella*) in the soil, contributing to the sanitation of the orchard through the consumption of fallen leaves and leftover fruits [3,17,18]. With regard to animals, grazing may offer benefits in terms of animal health and welfare [19]. Depending on how it is implemented, it may even represent some form of additional income and a reduced environmental footprint for the agriculture sector [20]. Nevertheless, the reintegration of animals into bush orchards may also provide disservices such as soil compaction (the overgrazing of ground vegetation can lead to soil and feeder root problems), phytosanitary issues (the impacts of the pesticides used in orchards on animals are still unknown), and socio-economic considerations (labor availability and investment costs are critical to profitability) [21,22].

Overall, the benefits may counterbalance the technical and structural constraints and may explain farmer motivations to explore such an innovative practice. This practice has not yet been the subject of much experimentation, and very few technical references are available regarding the services or disservices that are provided by this practice. Moreover, the little literature that does exist encompasses various combinations according to the plantation density of the trees in different types of orchards (from orchard meadows to low-stem fruit trees) and the species that should be considered: tree species (various species or fruit trees) and animal species (chickens, geese, pigs, sheep). Likewise, a diversity of grazing forms in orchards and modes animal integration into those orchards can coexist. Some growers may own the flock while others will cooperate with breeders; grazing may be permanent or seasonal; and livestock integration may result in no or a significant adaptation of a system, resulting in a diversity of forms that will undeniably condition the benefits and challenges of animal reintegration [23].

Meanwhile, over the past 10 years, there has been a growing interest among farmers and even neo-farmers in the grazing of commercial orchards. This interest has given rise to a dynamic among various research and development actors to characterize and evaluate these emerging forms of livestock integration. Through our involvement in these research and development projects, we have initiated several studies to characterize the systems and level of animal integration as well as farmer motivations and trajectories. We compiled data from surveys, and in this article, we propose the first typology of this practice according to the type of systems, motivations, and services expected by farmers. Such an overview aims to provide insight to help adapt systems to the diversity of contexts that farmers work in and proposes criteria that are essential for producers that could be considered for the further evaluation of these systems.

2. Materials and Methods

2.1. Identifying and Characterizing a Diversity of Orchard and Livestock Integration

We focused our analysis on the integration of livestock in commercial low-stem orchards. Our aim was thus to explore and describe why and how livestock could be integrated into the system. A sample was built to encompass a large diversity of systems and integration patterns. Individuals were therefore chosen for their diversity rather than for their representativeness. Considering the marginal nature of low-stem grazed orchards, farms were identified following a snowball process [24] starting with research and development projects that aimed at characterizing innovative orchard systems:

- The focus group "Vergers + Durables" (V + D), 2008–2013 [25,26], which brought together researchers, extensionists, and fruit growers from France, Belgium, Switzerland and Spain; Objective: to analyze different forms of sustainable orchard prototypes and to share experiences; Method: semi-directive interviews; System: sheep grazing in orchards (n = 2 farms).
- The research project "ARDU", 2014–2016 [27,28]; Objective: to study motivations, determinants and trajectories of producers who implement diversified orchard systems, including grazed orchards [27]; Method: semi-directive interviews and workshops with practitioners and advisors; System: sheep or poultry grazing in orchards (n = 5 farms).
- The agricultural development project, "IRAEE", 2016 [29,30], which was composed of development actors engaged in farm energy savings; Objective: to study grazed orchard farming system models by substituting some mechanized work with livestock; Method: semi-directive interviews; System: sheep or poultry grazing in orchards (n = 9 farms).
- The action research project "PEI", 2018–2022 [31], which was composed of agricultural research and development actors; Objective: regional development of pastoralism in perennial crops; Method: semi-directive interviews; System: sheep or poultry grazing in orchards and olive groves (n = 14 farms).
- Diversified orchards surveyed independently of any research and development program (HD); Objective: exploration of different forms of grazed orchard systems; Method: semi-directive interviews; System: sheep or poultry grazing in orchards and olive groves (n = 4 farms).

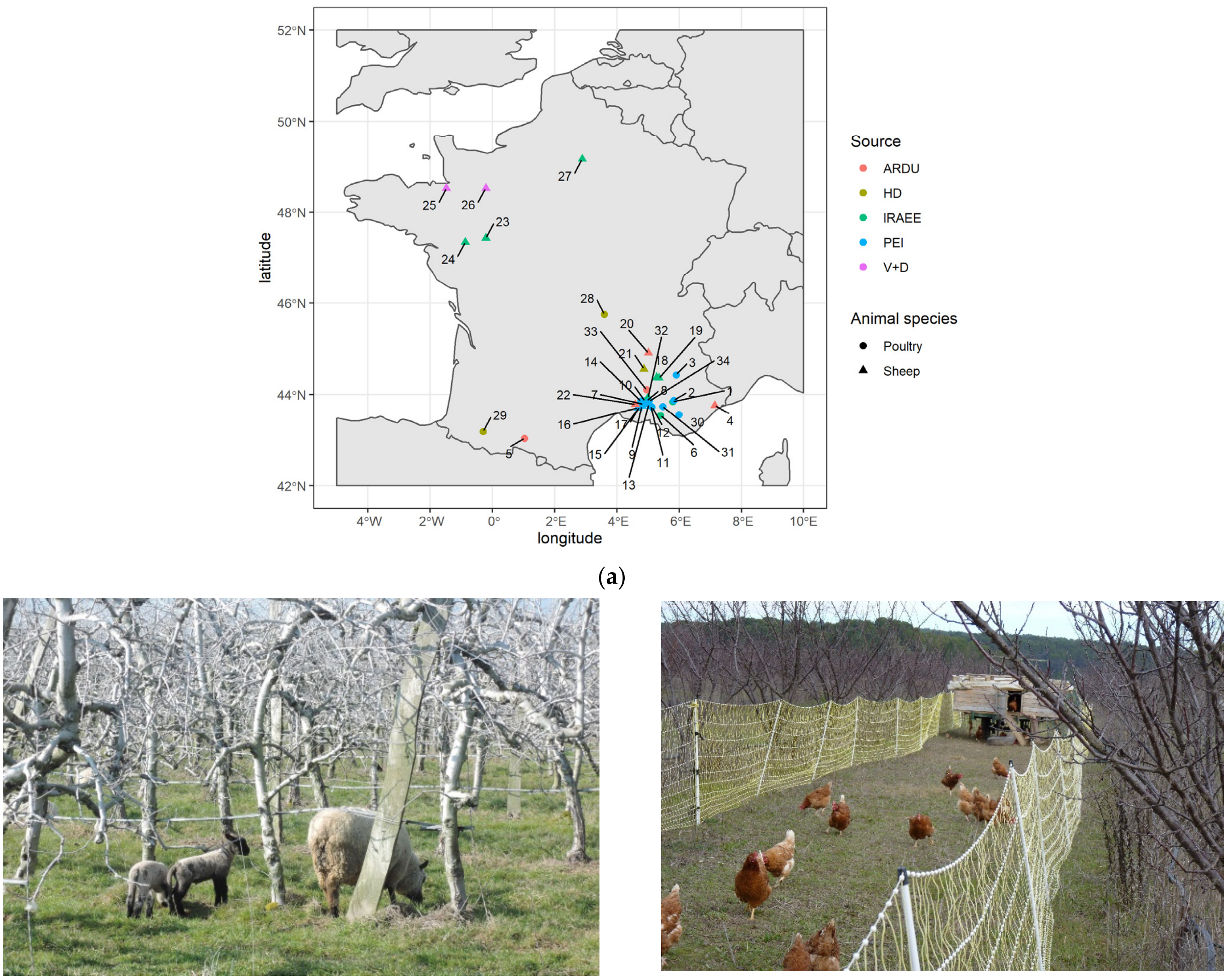
The data were collected through semi-directive interviews that had been conducted within the framework of the different projects, resulting in a heterogeneous dataset. The 34 farms that were finally selected (Figure 1) are those for which we had sufficient, homogeneous, and quality data for all of the selected variables and are presented in Table 1.

Table 1. Summary of variables and respective categories organized into groups.

Group Description	Variables	Code	Modalities
Farm structural descriptors	Tree component	initial_prod	Orchard, Olive grove
	Livestock component	animal_species	Poultry, Sheep
	Utilized Agricultural Area (UAA) used for tree-livestock integration (ha)	UAA	Small (<5 ha); medium (5–20 ha), large (>20 ha)
	Land structure	Land_structure	Merged, Fragmented
	Time since tree–livestock integration (years)	Div_date	<2005, 2005–2015, >2015
	Ownership of livestock	Div_property	Yes, No, Both
Farmers' motivations	Economic motivation	Motiv_eco	Yes, No
	Grass management motivation	Motiv_grass	Yes, No
	Biological control motivation	Motiv_biocontrol	Yes, No
	Improving nutrient recycling motivation	Motiv_nutrients	Yes, No

Table 1. *Cont.*

Group Description	Variables	Code	Modalities
Technical adaptations	Adaptation of tree management practices (training, pruning, shaping)	Adapt_trees	Yes, No
	Adaptation of fertilization practices (modification or reduction of doses)	Adapt_ferti	Yes, No
	Adaptation of phytosanitary practices (postponement of treatment, reduction, or substitution of products)	Adapt_phyto	Yes, No
	Adaptation of farm buildings (irrigation, trellising)	Adapt_buildings	Yes, No
	Temporality of tree-livestock integration	Div_duration	Permanent, Temporary
	Proportion of land diversified within the farm	Land_proportion	All, Part
Benefits and disadvantages	Biological control	Positiv_biocontrol	Yes, No
	Grass management	Positiv_grass	Yes, No
	Soil fertility improvement	Positiv_soil	Yes, No
	Time constraint	Limit_time	Yes, No
	Financial investment constraint	Limit_money	Yes, No



(**a**)

(**b**) (**c**)

Figure 1. (**a**) Map of the 34 surveyed farms, France; (**b**) sheep (Shropshire breed) and commercial apple, Farm no. 24 (*Malus Domestica*); (**c**) laying hens and commercial apricot (*Prunus Armeniaca*), Farm no. 6 (photo credits: M. Compagnone).

2.2. Data Processing and Statistical Analysis

As highlighted by several authors [6,7,32], farm typologies and performance evaluations differ considerably based on the criteria that is used. These criteria might be defined according to the objectives of the analysis. Since the aim of the present study was to analyze the redesign of systems that integrate livestock and orchards, in the absence of stabilized references on this type of system, we based our analysis on farmer perceptions of the advantages and limitations, constraints, and levers for implementing this practice.

To combine information for a great diversity of farms, the variables were coded and divided into four groups: (i) structural farm descriptors; (ii) farmer motivations to diversify into grazed orchards; (iii) technical adaptations resulting from the integration of trees and livestock; and (iv) observed benefits and disadvantages of the practice (Table 1). Benefit and disadvantage assessments were constructed based on the farmers' own assessments and were based on their own expertise or on previous experiences. We then conducted a multiple correspondence analysis (MCA) followed by a hierarchical cluster analysis on principal components (HCPC) on the sample of 34 farms. MCA is a multivariate exploratory analysis that makes it possible to analyze the pattern of relationships between several categorical dependent variables [33]. MCA is an extension of simple correspondence analysis in that it is applicable to a large set of categorical variables [34]. Its graphical output provides a structural visualization for variables in a multi-dimensional space, which is useful for identifying patterns and associations between the investigated variables in a dataset. In the present study, the analysis was conducted on the categorical variables presented in Table 1. To identify the variables that explain each cluster, we tested each group of farmers with regard to the whole sample. A significant difference implies that the tested variable discriminated the cluster of individuals (Vtest with p value ≤ 0.05) and contributed to characterizing the cluster. All statistical analyses were conducted using R software [35] with the FactoMineR package [36].

2.3. Farm Sample Description

Among the 34 farms that were surveyed, nearly half raised sheep (n = 18), and the other half raised poultry (n = 14). Tree species found on these farms were fruit trees (genus *Malus*, *Prunus* and *Pyrus*; n = 28) and olive trees (*Olea europaea L.* n = 6). The integration of animals into the orchard can occur at different stages of the farm's trajectory (Figure 2). In our sample, it not only occurred at the set-up and at orchard replanting, but it also occurred during the growth or production phases of an orchard as well. The farms that integrated sheep are relatively older (average set-up date: 1995) than the farms that integrated poultry (average set-up date: 2002). However, the integration of animals is a rather recent dynamic in both farm types since the average diversification dates are 2010 and 2013 for sheep and poultry, respectively.

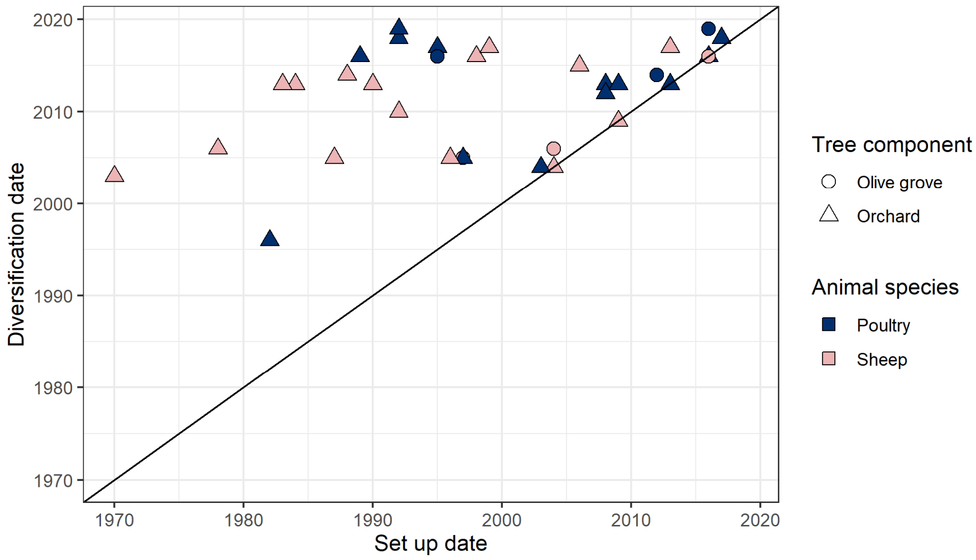
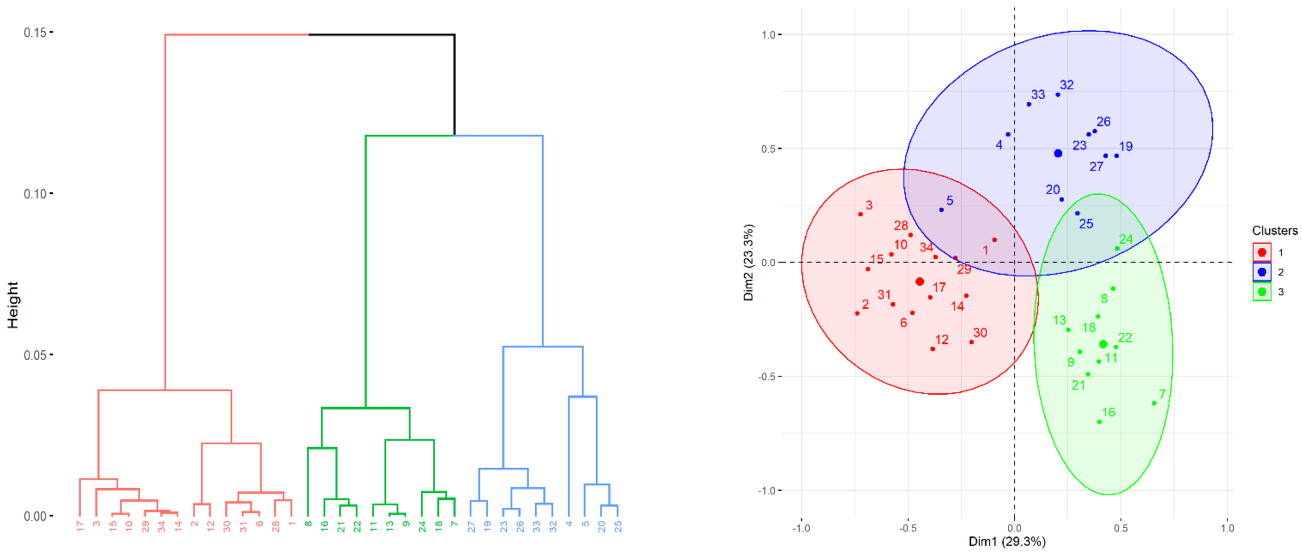


Figure 2. Diversification date as a function of set-up date, livestock species, and orchard type. Points on the bisector represent grazed orchards designed at the set-up date; the points far from the bisector represent diversification trajectories that took place after the set-up date.

3. Results

The multiple correspondence analysis followed by hierarchical clustering resulted in three clusters (Figure 3). The first two MCA dimensions explained 52.6% of the variability among the farms. Dimension 1 contributed to 29.3% of the inertia and is mainly explained by the animal species (animal_species), the utilized agricultural area (UAA), the temporality of tree–livestock integration (Div_duration), and grass management variables (motiv_grass; positive_grass). Dimension 2 contributed to 23.3% of the inertia and is mainly explained by the adaptation of tree management practices (Adapt_trees), time constraints (Limit_time), and livestock ownership (Div_property). The maximization of inertia gains occurred when the clustering resulted in three groups of farmers (see Appendix A, Figures A1 and A2 for statistical analysis details).



(**a**) (**b**)

Figure 3. Distribution and grouping of the 34 farms surveyed; (**a**) cluster dendrogram; (**b**) result of the hierarchical clustering (HCPC). Ellipses are centered on the barycenter of the groups (non-labeled large points). The first two dimensions of the MCA explain 52.6% of the variance (Dimension 1, 29.3%; Dimension 2, 23.3%).

In addition to the statistical interpretation, the typology was analyzed using the expertise gained from the numerous farmer surveys and from about ten seminars, workshops, and field visits organized with farmers, extension services, and researchers to share experiences and to discuss the benefits, conditions, challenges, and levers for the wider integration of livestock into orchards.

3.1. Poultry in Orchards (Group 1)

Group 1 is composed of 14 farms, all of which are involved in poultry farming. Most of the farms in this group ($n = 13$) integrate livestock and fruit trees over small areas (<5 ha; $p < 0.001$) and on a permanent basis ($p < 0.01$). The area allocated for these mixed systems is generally a part of the farm ($n = 12$; $p < 0.05$), and the fruit growers own the animals ($n = 13$; $p < 0.05$). The farmers in Group 1 mainly choose to integrate poultry within their fruit trees to improve the biocontrol ($n = 10$; $p < 0.05$) of pests with a diapause or pupation phase in the soil during their biological cycle (e.g., *Cydia pomonella, Bactrocera oleae, Ceratitis capitata, Grapholita molesta*) or pests that attack the root system (e.g., *Microtus duodecimcostatus*). The positive effects observed on these farms were related to grass management ($n = 9$; $p < 0.05$).

As revealed by the statistical analysis for the first group, pasture management is organized through the rotation of plots throughout the year, which are structured in fixed or mobile pens, and an arduous work of moving mobile henhouses. Farmers mainly chose to integrate poultry to improve the biocontrol of pests (different species of lepidoptera), but this service is highly dependent on the ability of the poultry to explore all of the plots. In practice, it has been found that in windy, hot, or bare ground conditions, this exploration is limited. However, pasture rotation is also designed to preserve the herbaceous layer, a layer that has been reported to be particularly useful in orchards to preserve structure, biological functioning, and soil-bearing capacity. Farmers may also have chosen to diversify their income with an extensive vision of breeding; in particular, this may have been to meet consumer demands for eggs in short food supply chains. Moreover, the orchard tree later represents an environment that offers more comfort to the animals but that can also evolve into a grazing area in a situation where there is limited access to land. The integration of animals has sometimes led to a reversal of the activity hierarchy, putting eggs and even the sale of animals before fruit production.

However, interviews report that this type of system is subject to constraints. For fruit production, the presence of hens implies access to fallback plots to facilitate the main interventions in the orchard. The constraint of moving the animals contributes to reducing technical interventions such as phytosanitary treatments and soil preparation (weeding, decompaction). However, the farmers reported that they do not try to save on feed rations. They provide a standardized ration to secure egg laying regularity. However, both feeding and watering can be done manually, which contributes to additional workloads. Recurrent problems encountered in these systems are predation (foxes, dogs, raptors, etc.), which leads farmers to investing in protective devices. Finally, another constraint that was mentioned is the implementation and compliance with biosecurity, a set of very demanding preventive and regulatory measures aimed at reducing the risks of the propagation and transmission of infectious diseases such as avian influenza.

3.2. Sheep Grazing in Orchard Managed by Fruit Growers (Group 2)

Group 2 is composed of ten farms that all integrate sheep ($p < 0.001$) with fruit trees ($n = 10$; $p < 0.001$), mainly over large areas ($n = 8$; $p < 0.05$). Most of the farmers in Group 2 own their animals ($n = 9$; $p < 0.05$). The initial farmer motivations were mainly focused on grass management ($n = 7$; $p < 0.05$), and positive impacts were indeed observed on grass management ($n = 7$; $p < 0.05$) and biocontrol ($n = 8$; $p < 0.05$). Adaptations occurred in terms of tree training ($n = 9$; $p < 0.001$), buildings ($n = 8$; $p < 0.001$), and phytosanitary treatments ($n = 7$; $p < 0.05$). The disadvantages associated with this form of integration were related to time $n = 8$; $p < 0.001$) and money ($n = 6$; $p < 0.01$).

The fruit growers in Group 2 chose to acquire a flock, often of limited size (a flock with less than 50 sheep on average), in order to benefit from two main agronomic services: (i) to increase their autonomy in terms of weed management through sheep grazing and (ii) to optimize the prophylactic action of sheep on orchard diseases and pests (e.g., *Venturia inequalis*). For example, some farmers graze their flock as early as possible after fruit harvest in order to consume and degrade as much wormy fruit that has fallen on the ground as possible so as to reduce the inoculum. In addition to these agronomic advantages, despite the expenses associated with breeding (purchase of animals, fencing and accessories, veterinary care, shearing, administrative and regulatory costs, etc.), there are also some economic advantages to this diversified system with the sale of lambs, which are sometimes highly sought after for certain breeds (e.g., Shropshire breed).

However, depending on the organization of the grazing under the trees and, in particular, the periodicity (temporary or quasi-permanent over the year), the technical adaptations of the orchard can be null or consequent, such as the optimization of the trellising or the irrigation system for the movement of the animals or the enhancement of fruiting by means of the removal of low branches and the formation of higher trees in order to minimize the risk of loss due to animals and to maintain a stable yield.

Finally, in terms of workload, the presence of the herd becomes an additional factor to consider depending on the nature of the interventions to be conducted in the orchard. Much of the extra work involved in breeding consists of managing the grass resources, organizing rotational grazing under the trees using mobile pens, and observing the animals in order to detect situations where there are insufficient grass resources and to guard against the risk of the animals attacking the tree bark. Breeding also involves more work (e.g., lambing period) and new regulatory and sanitary constraints. It was also necessary for the farmers to open up to new technical networks far from the tree farming sector (veterinarian, shearer, slaughterhouse, etc.).

3.3. Sheep Grazing in Orchards in Cooperation with a Shepherd (Group 3)

Group 3 is composed of ten farms. The grazing animals are sheep ($n = 10$; $p < 0.001$), but most of the farmers in Group 3 do not own the herd ($n = 8$; $p < 0.001$). Grazing is mainly implemented over medium (5–20 ha; $n = 6$; $p < 0.01$) and large areas (>20 ha; $n = 4$; $p < 0.05$) and on a temporary basis ($n = 10$; $p < 0.001$).The entire agricultural area is allocated to grazing ($p < 0.001$). The main motivation for farmers is related to grass management ($n = 10$; $p < 0.001$), and positive impacts can be observed on grass management ($n = 8$; $p < 0.05$) and soil fertility ($n = 7$; $p < 0.05$). Nevertheless, adaptations are required for phytosanitary treatments ($n = 6$; $p < 0.05$).

For the fruit growers in Group 3, in the majority of cases, the decision to make orchards grazeable for sheep very often stemmed from a request from a shepherd looking for grazing areas. The fruit growers discovered the impact of the presence of the animals on their plots while benefiting from the support of a livestock professional at the same time. Depending on local opportunities, shepherds graze their large herds in the orchards from fruit harvest until the bud burst of the fruit trees the following spring in specialized arboricultural areas with the agreement of the landowners. This arrangement benefits both parties: on the one hand, the flock has access to a grass resource, and on the other hand, the flock contributes to the maintenance of the grass cover, eliminating at least on wedding operation.

The main disadvantages of these types of arrangements are organizational. First, after consultation between the shepherd and the fruit grower on the modalities of the presence of the sheep, a set of plots is selected to be grazed. These must offer simplified access to the flock and should include a block of plots that is large enough to constitute a continuous grass resource for several weeks. Second, these plots must have mature trees so as not to compromise the development of young trees. Third, the technical management of the orchard must not require interventions that are incompatible with the presence of the sheep (e.g., phytosanitary treatments, machinery).

Over the years, a trusting relationship was established, and the temporary grazing was renewed annually, resulting in the fruit growers not being required to significantly modify their tree practices or to invest in any specific equipment. In most cases, the initial partnership extended to neighboring tree farms, thus facilitating the breeder's long-term involvement.

3.4. Synthesis on Grazed Orchard Management

The farm typology presented supra (Sections 3.1–3.3) was built on data concerning the structural dimensions of the studied farms, a set of initial farmer motivations, and on the modalities of orchard management practices as well as on the empirical evaluations of the services and disservices resulting from this practice according to the farmers. Concerning the practical aspects, it appears that a certain number of characteristics must be taken into account to optimize the management of grazed orchards, regardless of the groups considered. These are mainly: (i) breeding management by fruit growers and (ii) the pasturing temporality of the animals under the trees (Table 2).

Table 2. Synthesis of the main characteristics of a grazed orchard management system.

Characteristics		Benefits	Limits
Livestock management by fruit growers	Owner of both activities	Flexible management Economic valuation of livestock	Investments Plot structuring Sanitary regulations Workload
	Partnership between fruit grower and herder	Possibility to delegate the entire livestock farming management (no skills required)	Appropriate grazing area Communication and coordination between farmers Adapting orchard operations to the herder's organization
Grazing temporality under trees	Permanent grazing	Better efficiency of grazing and prophylaxis	Grass resource Tree training Animal parasitism Reduction in floral diversity
	Temporary grazing	Simplification of orchard management	Need for fallback plots

Indeed, the time dimension is a factor that appears to be decisive in the management of these systems. Time is not only an indicator of the workload (peaks of activity, on-call duty, etc.), it is also a management lever throughout the seasons. Group 3 breeders assess the duration of grazing according to the abundance of the grass resources. The farmers in Group 2 coordinated the grazing periods with the annual evolutionary cycles of the fruit species on their farms and the biological cycles of pests and diseases. The farmers in Group 1 define the annual frequency at which the animals return to the plots to the plots to preserve the herbaceous layer and the health of the herd.

4. Discussion

4.1. An Exploratory Approach to Record Farmer's Experiences with Fruit Trees and Livestock Integration

Considering the marginal nature of the system studied here, our analysis is based on a limited number of individuals. Indeed, farms were chosen for their diversity rather than for their representativeness. We focused on low-stem orchards, whereas other fruit tree–livestock combinations exist, namely cattle grazing in high-stem orchards [37] or with other perennial crop species such as vineyards [38]. These other forms of livestock integration might provide knowledge and technical references of the benefits and implementation conditions for these systems. For example, the literature describes the advantages of geese or hogs for weeding and fertilizing trees but warns of the damage that they can cause to the trees [14,17,18,39].

The exploratory approach presented in this study is then based on a limited number of variables that were gathered by analyzing surveys, workshops, and visits with various stakeholders. The presented multivariate analysis could explain a large part of the variability, but more situated information was collected and assessed through interviews. For instance, the regulatory aspects (sanitary and pesticide regulations) that could not be taken into account in the statistical analysis were often mentioned by farmers and advisors in workshops. Moreover, the methodology presented here is based on perceptions and narratives of the farmers regarding the advantages and constraints of grazed orchards. These data could be supplemented with quantitative data to more accurately measure the level of integration and support system design according to its expected performance [40,41]. On-farm experimentation on the interaction between animals and the orchard are necessary to provide such data. Concerning the economic aspects in particular, it remains unclear whether the integration of livestock into a highly specialized conventional system is profitable [42]. Research is still needed to prove the concept with a model that reveals some of its limitations.

Another important aspect in the analysis of grazed orchards is their temporality. As shown in Figure 2, these systems are at an early stage of development. The perception and the criteria to assess their benefits and limitations may change depending on how long the practice is used. According to Penvern et al. [26], the longer a practice is implemented, the more benefits mentioned by the farmers. With the experience and knowledge gained after using these systems over longer periods of time, systems can improve, adjust, and thus create new benefits or opportunities. The analysis of the temporal dynamics in the changes in farmer practices may be useful to identify levers of change, constraints to adoption, and adaptations of practices that suit the farmer's own priorities [43,44]. This might also highlight how successive changes in farmer practices lead to a transition of the farm [45,46]. For all of these reasons, regular monitoring of the farms involved in the present study would make it possible to capitalize on their technical trajectories and their impacts on the system properties.

4.2. The Balance between Contraints and Benefits as an Optimal Degree of Integration

The three types of farms described here display different levels of integration according to the livestock management and the grazing temporality of the animals under trees (Table 2), each with different benefits and limits. The systems in Groups 1 and 2 might provide more benefits in terms of pest and disease management (from the grower's perspective) than those in Group 3. Group 2 induces more tree training practice adaptations, whereas the system described in Group 1 results in an increase in the complexity of the management of the herbaceous stratum. Group 3 requires the presence of livestock farms in close proximity and arrangements that can be made to provide fallback plots for the flock at key periods: spring for grass growth and autumn for scab. This overview suggests that multiple solutions and trade-offs can be found in response to a diversity of situations.

Beyond this exploratory survey, technical and economic references are needed to help farmers design their own system that optimizes benefits and risks and to find trade-offs among integration options. While our approach makes it possible to better characterize the coupling between orchards and livestock in mixed systems, it remains unclear whether high or low levels of integration are desirable. This characterization raises a methodological difficulty that lies in the diversity of the definitions of "integrated systems", in which the coupling of several activities can be based on agronomic, economic, structural, capitalist, or labor approaches [7]. The integration of trees and livestock is not an objective in itself but is instead a means to achieve other objectives. Thus, different forms of grazed orchards would not aim at the same objectives, nor have the same environmental or economic performance [40].

In terms of economic and environmental impact, the assessment of mixed farms by their level of integration between crops and livestock showed that an increasing level of integration led to a win-win strategy comprising good economic and environmental performance [5,47]. Moraine et al. [48] refer to the process of substituting inputs with ecosystem services. In our case study, all of these hypotheses still remain to be tested and deserve further investigation. Dynamic models [49,50] seem to offer a useful framework to support the design and dynamic evaluation of mixed system properties [51]. In addition, farm-level simulation tools such as those developed by Pissonnier et al. [42] can be useful for evaluating the properties and conditions for the success of alternative "radical" systems such as orchard–sheep systems.

At the territorial scale, in correspondence with the systems in Group 3, researchers have [10,52] proposed participatory methods based on simulation models to design crop–livestock integration at a regional scale. Indeed, organization at the territory-scale makes it possible to overcome constraints and to bring out similarities between specialized farms in a mixed territory or between closely linked territories, as is the case in the context of transhumance. Upstream of these approaches, the aim is to identify and bring together interested fruit growers and breeders. While shepherds are more often in search of grass for their herds, fruit growers are less familiar with opportunities to build this type of partnership. Spatially explicit matchmaking tools are being developed in some areas where these two types of farming can coexist. However, cooperation between farmers is not only determined by their geographical proximity but also by their social proximity [53]. Collective initiatives are thus useful tools to bring the involved stakeholders together, share objectives, find arrangements, and to build trust and commitment between the interested parties.

4.3. A Gradient of Farm Redesign

Finally, our results show that expected services depend on the extent of the change in the system and on the initial investment, regardless of the group concerned. A more detailed comparative analysis of the case studies within the groups reveals a certain diversity in the trade-off between fruit production and breeding activities, which is highly dependent on the initial objectives of integrating breeding into orchards. Thus, for Group 2 fruit growers, having objectives that are limited to weed management result in breeding management that is similar to the use of a weeding tool. The grazing period and rotation between plots are thus only organized by considerations related to the fruit trees. The economic value of breeding may even be null as long as the agronomic value is present. On the other hand, more global objectives, both economic and environmental, lead to the consideration of breeding as an activity on the farm in its own right. It may even be optimized for the purposes of supplementing fruit production, which remains the main activity.

In reference to Hill and MacRae's framework [54], some farmers may thus prefer and subsequently adopt substitution rather than redesign strategies—strategies that can take place at different points in their trajectories. Animal integration can also be temporary, a technique that can be attempted without jeopardizing the farms, or progressive. This technique can therefore be adapted to all types of more or less specialized systems. Nevertheless, minimum practice adjustments are necessary in all cases to facilitate grazing and to ensure animal health. First, this particularly concerns the use of copper, which is widely used by fruit growers as a fungicide and can be toxic depending on the doses and application conditions. In the face of the legitimate concerns related to copper, no instances of intoxication due to copper applications were reported in our sample. A recent study by Trouillard et al. [55] highlights the protective role of molybdenum against copper toxicity in sheep grazing perennial crops. Despite the presence of risk indicators for intoxication, no clinical symptoms were observed in this study, even after 60 days of grazing. This appears to be favorable for the wider development of this practice in orchards. However, it calls for repetitions in a broader range of situations and for the consideration of other pesticides commonly used in arboriculture in order to fully recommend this practice. In the absence of more stabilized references, farmers use alternatives to this active ingredient (e.g., calcium hydroxide, calcium sulfide) or choose to exclude the animals from the plot for 20 to 30 days after copper application. For more intensive farms, these measures could also be considered by limiting grazing periods to the post-harvest only in order to exclude the spring season, which is prone to numerous phytosanitary treatments. Second, growers seeking to reintegrate animals face challenges stemming from their lack of knowledge about animal husbandry and regulations. As demonstrated by Hilimire [2], these challenges result from a long history of specialization. New regulatory and sanitary constraints must be respected, and new professional networks must be built (veterinarians, shearers, slaughterhouses, etc.). As emphasized by our results, reintegrating animals into orchards may also imply the mastery of a diversity of components, processes, and dimensions. Third, as advocated by many authors [56,57], the diversity of farmer practices and trajectories of change that were revealed in this study reinforces the assertion that advisory services should be adapted to the farmers' local conditions and should be focused on reinforcing the innovation capacities of farmers.

5. Conclusions

Orchard grazing systems are currently experiencing renewed interest among fruit growers and breeders. Traditionally present in agricultural areas with high-stem fruit production, new types of sylvopastoralism are emerging within more intensive fruit-growing systems. These innovative forms of tree and livestock integration raise new questions and present many challenges for farmers. Through the analysis and characterization of 34 farms, we proposed a typology of grazed low-stem orchards in the present study. By describing different tree–livestock integration systems, we highlighted original practices that have been developed by farmers. Our results indicate that the motivations underlying the choices of their practices differ according to the type of integration, and the resulting systems generate different technical adaptations and provide various services and disservices. This exploratory analysis provides a basis for the identification of systems that should be explored to a greater extent through the implementation of measurements in farmer fields or through experimentation. The relationships between practices, motivations, and services provided described in this paper makes it possible to highlight innovative solutions that can be adapted by other farmers or that can be studied in greater depth through agronomic research.

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Appendix A. Results of the Multiple Correspondence Analysis

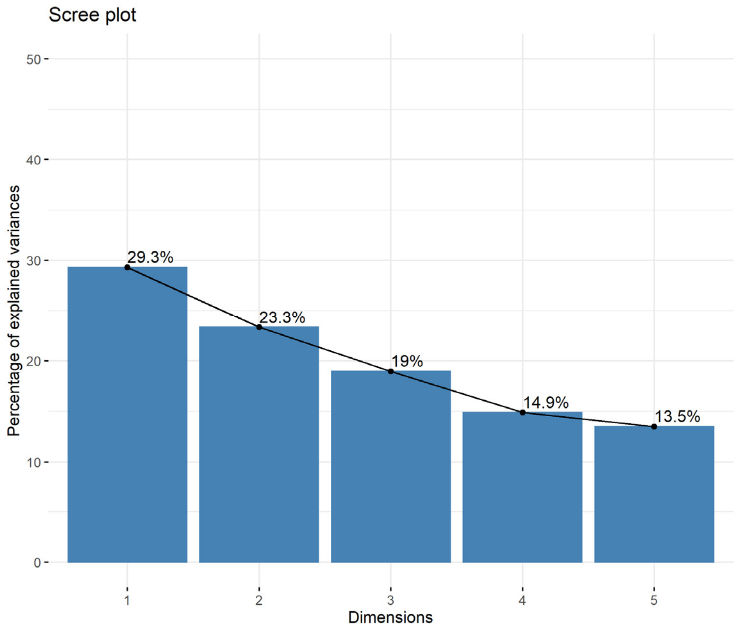

Figure A1. Eigenvalues of factors or principal components in an analysis.

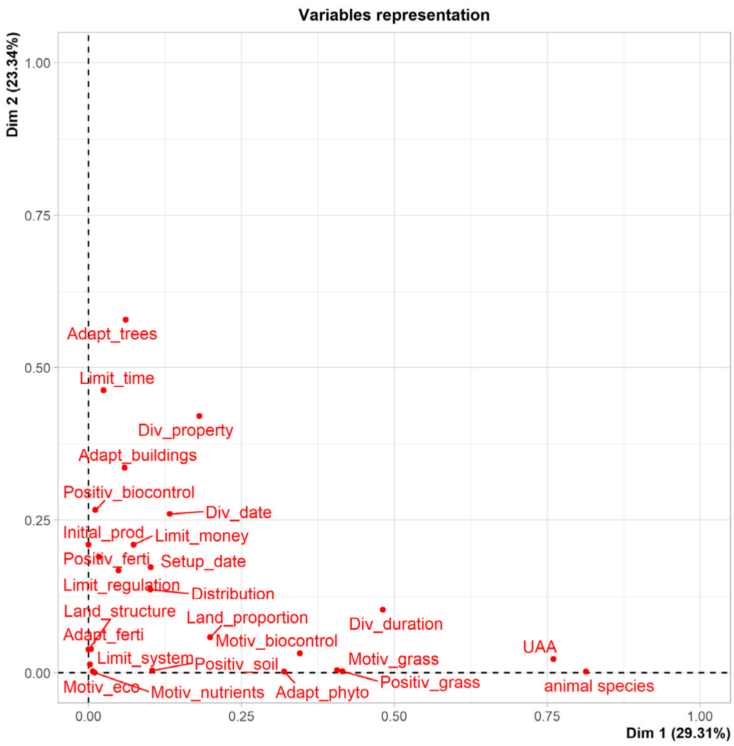

Figure A2. Variable contribution to the first two axes.

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