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Sheep in the Vineyard: First Insights into a New Integrated Crop–Livestock System in Central Europe

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Abstract: The multiple land use of agricultural areas is a building block for increased land use efficiency. Unlike monoculture, integrated crop–livestock systems optimally improve ecosystem services, making it an important field of research and application for adapting land use and food systems that have sustainability deficits. The integration of sheep in viticulture production is described as a promising example of an integrated crop–livestock system. While some studies of the integration of sheep into vineyards are already available for other parts of the world, there is still no research on its implementation in Central European viticulture systems. In order to fill this gap of knowledge, we conducted standardized interviews with 34 winegrowers who already graze sheep in their vineyards. The method allowed a wider overview of the implementation of the integrated crop–livestock system than would have been possible with other approaches. Furthermore, the authors kept sheep in their own vineyard for three years to evaluate the statements of the survey participants. The period during which sheep graze in vineyards is quite heterogeneous in Central Europe. Some farms use sheep only during vine dormancy; others also let sheep graze during a certain period in summer. There are also viticulture training systems where grazing is almost continuously possible. In Central Europe, summer grazing normally requires operational adjustments such as lifting the wires of the training system and branches of the vine; otherwise, the vines could be damaged. This option seems to be tailored to the training system in use. Some interviewees mentioned that sheep not only use the accompanying vegetation as fodder and therefore control the undervine growth, but in some cases, they were also able to replace other work processes, such as defoliating the grape zone or cleaning undesired vine shoots near the ground. However, a high additional workload due to livestock keeping was also mentioned by some survey participants. Some of the interviewees cooperate with shepherds, which could help to solve this challenge. Finally, we summarize possible opportunities and risks of this integrated crop–livestock system. Integrating sheep in vineyards seems to be quite feasible in the period of vine dormancy, whereas more information and considerably more effort is needed to integrate sheep during the vegetation period. Further research is needed to answer open questions especially for the necessary adaptations of the common vine training system or the implementation of alternative systems more suitable to combine with livestock keeping. Some practitioners found opportunities to merchandize the use of sheep in wine sales. This potentially unique selling point could be a solution for a broader consideration of sheep in vineyards.

Keywords: multiple land use; sheep; vineyards; agroecology; sustainable intensification; expert survey

1. Introduction

In recent decades, agriculture has been extremely successful in increasing arable land, yields per hectare, and ensuring sufficient food for a rapidly growing world population. Currently, we are witnessing the worldwide degradation of many ecosystems, putting vital ecosystem services, such as soil fertility, carbon storage, pollination, and pest control, at risk [1]. These challenges can be addressed by changing land use systems [2,3] and adopting better resource-conserving agricultural practices [4].

Greater consideration of multiple use systems, such as integrated crop–livestock systems (ICLS) is a piece in the puzzle of implementing a more sustainable agriculture [5,6]. Integrating sheep in vineyards is one of many possible ICLS. In practice, sheep graze vineyards in the period of vine dormancy, but is also possible to integrate livestock during the vegetation period. Livestock keeping and crop production have been studied in order to develop synergies, but these studies are still typically undertaken in isolation [5,7]. First of all, ICLS are limited by external (but potentially changeable) factors—e.g., by unfavourable subsidy laws under the EU’s Common Agricultural Policy [8]. Another major limiting factor is that conceivable multiple uses are often incompatible with current operational processes or technical–mechanical operating equipment unless adjustments are made. Frequently, such systems also require additional know-how from farmers [9]. Relatively little research has been conducted on ICLS in light of today’s technical and socioeconomic events [10].

Grazing sheep in vineyards is an ICLS which is still very unusual for Central Europe. It is more established in other countries such as New Zealand or Australia [11]. Vineyards are extremely heterogeneous in terms of their history, layout, vine training, row and planting distances, machine use, pesticide applications, and products offered [12]. Sheep farming also varies in its economic importance, land expanse, husbandry, and sheep breeds [13]. Given this background, sheep can (or cannot) be integrated into viticulture in a variety of ways—experience gained in different countries and under different conditions is therefore only transferable to a limited extent.

Potential economic and ecological efficiency gains through the integration of livestock farming and crop production are, on the whole, quite well recorded [14]. To what extent this can be applied to the ICLS in question is, however, unexplored. Ref. [8] examined the benefits, costs, and challenges of sheep grazing in vineyards using a case study of 15 New Zealand wineries. They found that money could be saved because the winegrowers used fewer herbicides and minimised mechanical weed control. Another potentially cost-saving option is to allow sheep to pluck leaves in the grape zone, work which otherwise would have to be performed manually or mechanically for many grape varieties and vineyard sites to ensure grape and vintage quality [15]. There are hints that it can also be advantageous to let sheep eat shoots close to the ground instead of removing them manually, mechanically or with contact herbicides. Furthermore, it is reported that sheep can serve as appealing figures in wine marketing [16]. Research is lacking on the pricing-in of potential positive effects on other ecosystem services [17].

Importantly, there are to date no studies of the implementation of ICLS in Central Europe. Our work offers the first qualitative insights. Our aim is to help further studies by presenting the different ways in which this ICLS is implemented in a Central European context. Therefore, we aim to answer the following questions:

1. What basic grazing methods are used in practice?
2. What key opportunities and risks are associated with ICLS?
3. What are the most urgent research needs?

2. Materials and Methods

Since no census exists of vintners who practice ICLS in Europe, a multi-stage approach was adopted: first, it was assumed that a winery which uses sheep reflects this in its online-marketing. Sheep can be a unique selling point [16]. These operations were identified with a targeted search on Google by using the keywords “sheep in viticulture” and related terms/combinations, such as “four-legged”, “ruminants”, and “animal lawnmowers” or “winegrowing”, “vineyard”, and “vines”. All vintners identified in this way were first contacted by telephone before emailing them an invitation with an embedded link to the online survey. Finally, participants were asked to name other establishments that they know of that also practice ICLS.

Comparable to the study [8] performed in New Zealand, we used a structured online questionnaire, asking practitioners both open- and closed-ended questions. A total of 34 winegrowers from Germany, France, Austria, Switzerland, and Italy participated in the survey. We define them as ‘pioneers’, because they started this ICLS in a deficient information situation. The response rate on the preliminary call and subsequent email was 90%. Twenty-four pioneers had been using sheep in their vineyards for two or more years, four had been practising the ICLS for less than two years, two had given up sheep farming, and another four did not reply to this question. Sixteen participants were operating in France, with ten of them in the Gare and Languedoc-Roussillon départements, as well as fifteen in Germany and one each in Austria, Switzerland, and Italy. A total of 18 operators were fully certified and three were partially certified under the criteria of the EU Eco-Regulation. Ten worked conventionally only (three gave no answer). Sixteen pioneers subjectively classified the topography of their vineyards as “easy” in terms of the cultivation effort required, nine as “medium”, and six as “difficult” (three gave no answer). The 18 operations in German-speaking countries, with one exception, owned the animals they used in the vineyards. In contrast, in France, 14 of 16 operations outsourced the job to independent sheep farmers.

Our research also drew on our first-hand experience of keeping 35 sheep of two breeds (20 Ouessant, 15 Shropshire) in different vine training systems: spalier with Guyot pruning (first wire defining the grape zone with ~90–105 cm; Figure 1), top-wire cordon training (wire at ~160 cm height) (Figure 2), and spalier with minimal pruning (which is quite common in New Zealand and Australia, but rare in Central Europe) with a relatively high grape zone. Our sheep graze in a ~10 ha vineyard all year round. The trial has been taking place in Freiburg and Ihringen (Baden-Wuerttemberg, Germany) since the beginning of 2019. We used our experience gained in this post-disciplinary approach to better assess the answers of the respondents.



Figure 1. Sheep of the Ouessant breed are grazing a spalier training system with Guyot pruning. This training system is widely used in Central Europe. Here, the first wire is at ~90 cm height.



Figure 2. Sheep-grazed vineyard with a top-wire cordon training (hanging cane). Here, the wire is at ~160 cm height.

3. Results

Of the French operators that participated in the survey, 12 out of 16 grazed sheep in the vineyard during the period of vine dormancy (4 gave no answer). Only 3 out of 18 German-speaking operators limited the system to winter grazing (1 gave no answer). Fourteen also kept the sheep in the vines during the growing season. Of the latter, three allowed a potential year-round grazing, meaning that access to the vineyards could be arranged as needed at any time. This also includes phases of vine development that would be problematic in other vineyards. The potential year-round grazing is made possible in one pioneer's case by stringing electrified wires alongside the canopy. The other two use high vine training, so that grapes and leaves are (mostly) out of the animals' reach. Here, this is the case in top-wire cordon training systems. In spalier-systems with Guyot pruning, which are widely used in Central Europe, the browsing-sensitive (critical) phases at least seem to comprise the time from budding to the end of the time berries are goat-sized and then from the veraison (start of the *ripening* of the grapes) through to harvest time [15]. Even in vineyards with very high fruit branches (e.g., top-wire cordon training), sheep do not actually graze on a particular surface all year round—although, from a purely wine-growing perspective, this would be feasible in some cases. Nine operators with summer grazing reported the use of alternative areas outside the vineyards (e.g., meadows, orchards) during critical phases of the vines' phenological development. At least six of them also use the sheep to selectively graze the vines' foliage in the grape zone (leaf plucking).

For exclusively winter grazing, the grazing area of the operations surveyed ranged from 2 to 400 ha (median: 11.5 ha), with between 8 and 2500 sheep (median: 150 animals) in the vines. The summer-grazed dual-use areas covered between 0.2 and 12 ha (median: 1 ha) and were grazed by 4 to 70 sheep (median: ten animals).

The German-speaking pioneers use different breeds than the French do. The latter use whatever breed the cooperating sheep farmer supplies. In vineyards that (also) practise summer grazing, the choice of sheep breed plays an important role, as breed-specific size differences produce disparate results in vine leaf pulling. Nine of the 14 operations conducting summer grazing deployed the Ouessant sheep, listed as the world's smallest breed [18]. Two farms used Shropshire sheep, and one each used Cameroons, German heaths, Blacknoses, "Babydoll" Southdowns, or Suffolks. For a decade now, the Austrian winery Ernst Triebaumer has been cross-breeding sheep to develop traits that are explicitly geared to vineyard use. These traits are robustness, reliability, and that the sheep shed their fleeces naturally. Two of the fourteen wineries with summer grazing keep groups of mixed-breed sheep.

Depending on whether exclusively winter or (in addition) summer grazing was carried out, responses were analysed separately, since viticultural effects differ. First, we asked if using sheep decreased the viticultural workload. Of the 14 wineries with summer grazing (from here on, including those with potential year-round grazing), three pioneers agreed "fully", four others "more than not", three "slightly", and four "not really". The 14 responding wineries with pure winter grazing responded with three agreeing "fully", four "more than not", six "slightly", and one "not really".

The pioneers were asked to identify the two main advantages of using sheep. They were also prompted to mention any other benefits they were aware of (Figure 3). Then, they were asked about the main disadvantages. The pioneers considered the additional expense involved in handling the animals in exclusively winter or summer grazing as the most important drawback (Table 1).

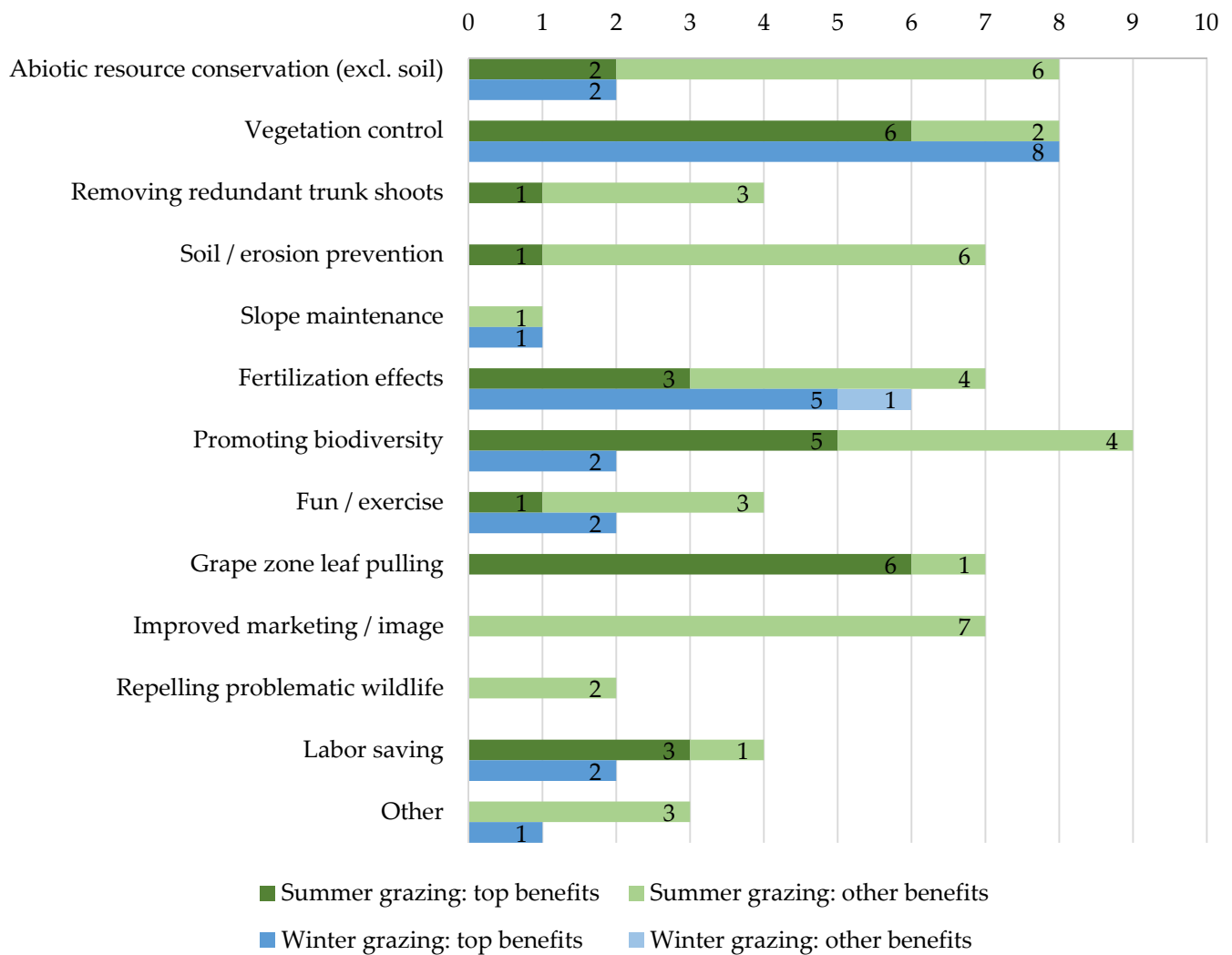


Figure 3. Advantages of the ICLS mentioned by the survey participants (N). Main advantages (top benefits) are indicated by darker colour shades. Each participant could give two answers on the main advantages. Participants could name several answers about other benefits. These are indicated by lighter shades of colour. Responses are broken down according to wineries with exclusively winter grazing ($N_{\text{available}} = 13$; blue colours) and wineries with (additional) summer grazing ($N_{\text{available}} = 14$; green colours). The numerals indicate the number of entries.

Table 1. Answers by survey participants (N) to the question about the main disadvantages of the ICLS. For the category “Additional expense of handling animals”, several subitems were mentioned in some cases. Answers are broken down according to dual use system with exclusively winter grazing ($N_{\text{available}} = 11$) and (additional) summer grazing ($N_{\text{available}} = 11$).

Drawbacks	Number of Mentions (Multiple Entries Allowed)	
	with Summer Grazing	Exclusively Winter Grazing
Stripping the vine cordons	2	1
Soil compaction		2
Financial costs of sheep/equipment	2	
Fostering problem vegetation		1
Conflicts with walkers		2

Table 1. Cont.

Drawbacks	Number of Mentions (Multiple Entries Allowed)	
	with Summer Grazing	Exclusively Winter Grazing
Added costs for:		
-handling animals	11	5
-fencing	7	2
-continuous monitoring	3	1
-watering trough	2	
-shelter	1	
Added cost of protecting young grapes	1	
Potential damage from erosion		1
Stripping/browsing of vines	1	
Risk of penalties for not keeping certification current	1	
Animal health problems		1
Undesirable nutrient removal	1	
Uncertain PSM effect on animals	3	
Having an alternate area available	1	1

The pioneers were then asked about any initial reservations they had about the ICLS that had subsequently been allayed by an in-house trial run. Ten answers were evaluated for this question. Cited three times as allayed reservations were “damage to the vine”, twice for “high effort” and “lack of knowledge”, and once each for “sheep eat immature grapes”, “financial risk”, and “fear of personal embarrassment”. The operators were also asked whether they could recommend specific viticultural modifications for a more efficient implementation of the ICLS. Both the pioneers with exclusively winter grazing and those with (additional) summer grazing most often recommended adjusting the height of fruiting branches by raising the first wire (four and ten mentions, respectively). The recommendations for top-wire cordon training system or spalier with minimal pruning also aimed to achieve the same result (Table 2).

Table 2. Recommendations of the survey participants (N) for a successful implementation of the ICLS; multiple entries allowed, answers are broken down according to exclusively winter grazing ($N_{\text{available}} = 11$) and (additional) summer grazing ($N_{\text{available}} = 14$).

Recommended Measure	Number of Mentions (Multiple Entries Allowed)	
	with Summer Grazing	Exclusively Winter Grazing
Raising the height of fruiting branches	10	4
Adjusting timing sequences	1	3
Solidly fastening vine stock to prevent damage	2	2
Good tying-up to prevent damage to the canopy	3	
No answer		5
No year-round grazing (fosters problem vegetation)		1
Cooperating with sheep farm	1	
Exempting critical growth phases from grazing	1	
Choosing suitable sheep breeds	1	
Protecting with electrified wire during critical growth phases	1	
top-wire cordon or minimal pruning	4	

The production and sale of sheep meat did not play a decisive role for operators who keep their own sheep ($N = 16$). Six of the operators were in principle in favour of marketing it, but had concerns about possible spray residue from vineyards tainting the meat. One pioneer who allowed several weeks of summer grazing reported that his carcasses tested negative for such residues. One organic farm sells its meat exclusively to luxury restaurants “at top prices”. Two others were able to sell their meat. Lamb retailed for 20 EUR/kg in this case. One establishment also reported selling sheepskins at a profit of EUR 160 per skin. Eight participants did not consider selling meat an option. For the 15 operators who cooperated with outside sheep farms it can be assumed that, in those cases, typical sheep farm sales practices prevail [19]. Finally, participants were asked what it would take to expand their use of the ICLS (Table 3).

Table 3. Steps recommended by the survey participants (N) for wider use of ICLS. Multiple entries were possible, answers have been broken down according to exclusively winter grazing ($N_{\text{available}} = 11$) and (additional) summer grazing ($N_{\text{available}} = 10$).

Recommended Steps	Number of Mentions (Multiple Entries Allowed)	
	with Summer Grazing	Exclusively Winter Grazing
Financial support	1	1
Promoting/targeted start-up of sheep farms	1	3
More basic research (e.g., impact on biodiversity)	1	1
Fields must be enlarged	1	1
Tourism has to embrace it	1	
Change vintner thinking	1	
Better information/consulting for practitioners	5	3
Prohibit herbicide use		2
Improve sheep breeds	1	

4. Discussion

We aimed for qualitative insights into the implementation of ICLS in Central Europe. A conclusive evaluation of the ICLS is, however, not possible using the methodological approach of our survey. It seems likely that winegrowers who still practice ICLS tend to communicate the effects more positively. Wineries that have used sheep in the past but discontinued the use due to undesirable developments were not adequately covered by our methodological approach. In the absence of public operational recording, these farms can hardly be identified, if at all. A more holistic evaluation would be possible, for example, through standardized practical trials over several years.

The survey methodology we used is better suited for identifying opportunities in the ICLS than for identifying its limitations. For instance, we found no evidence of sheep browsing berries within the period mentioned above, but our survey methodology is not able to exclude this for every combination of sheep breed in use and type of grape. Further research is needed to rule out potential limitations in different vineyards.

Based on our own experience, winter grazing of vineyards by sheep seems to be more widespread in German-speaking countries than the study results suggest. The marketing potential of winter grazing seems rarely to be publicized, so it is not taken up in the media. This seems to be less the case in the south of France; in the Southeast of France, vines are trained closed to the ground, so that the vineyard is only suitable for grazing during the winter months (Figure 4). This explains the divergent results reported by the German-speaking and French operations.



Figure 4. A typical vine training system in France (Département Ardeche). The first wire is at ~55 cm height, thus the grape zone would be damaged with summer grazing.

A strict distinction must be made between summer and winter grazing. Our study supports the presumption that grazing in winter, during the dormancy of the vines, is much less risky in the common vine training systems of Central Europe. Winter grazing can probably also be carried out more easily with the breeds used by commercially oriented shepherds. The limits of summer grazing are largely determined by vine training such as the height of the wire (defining the grape zone) or the lowest shoot of fruiting branches. Certain kinds of training are therefore in principle unsuitable for grazing during the growing season—e.g., Gobelet training (bush form). In contrast, training systems with vertical shoot positioning can potentially be grazed in summer too, if the canes/cordons are not too low and a suitable sheep breed is used. If the plants in such systems are protected during browsing-sensitive development phases, it seems likely that year-round grazing also becomes possible. Based on the answers to our survey, training systems such as top-wire cordon training (hanging cane) or adapted spalier with minimal pruning do not necessarily go through these critical phases—at least if the sheep breed used is suitable. As the only such study from Central Europe so far, [20] reports an ethological long-term observation of Suffolk lambs in a summer grazing of a vineyard with (quite uncommon) hanging canes (wire at ~170 cm height), which was satisfactory from a viticultural point of view. A detailed description of the training system is crucial for further research papers and practitioners. Without this information, results remain almost worthless due to the variety of systems in use. We have observed this lack of detailed descriptions in some

scientific publications, e.g., [11,15]. Another example of the limited quality of information is that none of these studies discuss veterinary concerns potentially caused by the use of fungicides such as copper [21].

Grazing systems can be conceived of mainly as land rotation systems. An alternative area (on adjacent grassland) or parcelling of the pasture area seems to be necessary for handling the various stages of viticulture and animal husbandry, at least in regions where vineyards are typically small-sized. For some farmers, cooperative systems seem to be a solution to integrating sheep into viticulture. This is especially true for winter grazing, but cooperation with sheep farms in which the animals are used on a vineyard in summer are reported, too. A “brief summer-grazing” can be used for leaf plucking in the grape zone and, on an imaginary scale for the annual single-area grazing period, this forms the opposite pole to continuous year-round grazing. The various differences in stocking time/density per area are also given in other grazing systems. To zero in on the specific grazing form and time within the ICLS, the established literature on grazing should be referred to [22,23].

Our survey provides an insight into the implementation of an ICLS in Central Europe. It supports the assumption that this ICLS is feasible, cf. [8], but it also shows that, in practice, implementation is very diverse and there is a need for basic information for practitioners. Without further investigations, no statements can be made on the extent to which summer grazing can be established in Central Europe. The individual responses of the pioneers show that sheep can also cause damage (e.g., on new plantings that should be protected). The survey provides initial indications that these challenges could effectively be mastered by adaptations in vine training forms and the sheep breed used. The survey revealed the height of the grape zone as the crucial factor. The potential concern that sheep could damage the vascular tissues of the vines by debarking were not confirmed by any of our interviewees. No farm reported sheep feeding on immature grapes before the beginning of the ripening process. The information deficits which the pioneers have highlighted should now be addressed by applied research.

Based on the survey results and our own experiences, we also conclude that the timespan which sheep spend in vineyards is crucial for potential risks. In systems with (mostly) inaccessible fruiting branches, the time sheep are left to graze is at least influenced by the extent of the feed supply. In their study, [18] identified robustness, reliability, natural shedding of fleeces, a low height of the mouth, and the inability to stand on two legs as desirable sheep breed characteristics for Central European viticulture (Figure 5). The authors examined and measured 27 breeds and evaluated the characteristics for adult animals. Only three of them—Danish Shropshire (Figure 6), Southdown (not “Babydoll”), Ouessant—can be considered suitable in principle; none of the breeds examined fulfils all the desired characteristics. None of the three are hair sheep and, additionally, Ouessant are difficult to manage, have a low feeding capacity and they are able to stand on two legs. The last skill is not very important here, because this breed tends to be very small. The authors of [18] also conclude that other breeds, including those common in Europe (e.g., Merino) are suitable for summer grazing for a short period of a few days. The reason for this is that the spalier-systems with Guyot pruning that are typical in Central Europe are normally too low and most breeds would be able to defoliate too high up the vine. Unsuitable characteristics are not only an issue of breed, of course; they can also result from the individual skills of the sheep. Another issue to bear in mind is that climate change (whereby the vines now produce more sugar) has made it possible to shorten the high foliage wall of the vines. This is achieved by raising the lowest wire of the trellis system. This development could have a favourable effect on the possibility of integrating sheep in vineyards. Nevertheless, summer grazing will usually still be limited to non-critical phases in the most common training systems [18].



Figure 5. Most sheep breeds are able to stand on two legs, which is unfavourable in common vine training systems. This skill enables sheep to defoliate too high up the vine. While leaf plucking in the grape zone is highly welcome, defoliating well above the grape zone causes production losses and grape sunburn [15].



Figure 6. Sheep of the Danish Shropshire breed (and at least some of those crossed with the English Shropshire) seem perfect for leaf plucking. The breed is not able to stand on two legs. This was confirmed for adult animals but not yet for lambs [18].

Managing the canopy and the accompanying vegetation growth is work central to viticulture. The interviewees reported that winter grazing and therefore the control of vegetation growth has potential for reducing the use of machinery and of herbicides. This could have implications for abiotic (e.g., reduced use of fossil fuels/climate protection, soil conservation) and biotic resource protection (e.g., dung fauna, soil life). Summer grazing is increasingly complex, as viticulture workflows have to be adapted to sheep farming requirements. In return, however, summer grazing opens up further potentials for reducing machine use (especially control of accompanying vegetation growth), for herbicide application, and for work that must be performed directly on the plant (i.e., leaf plucking in the grape zone and browsing of undesired vine shoots at the trunk).

Based on our survey, the ICLS described above distinguishes itself from others in offering (1) additional opportunities for marketing, and (2) the potential for using the animals as an aid or a substitute in several necessary stages of viticultural work. The potentials are also interesting from a business point of view in the case of steep and terraced vineyards, as the hourly labour costs of working on them are higher and using machines on them is difficult [24]. However, as mentioned above, the statements of our interviewees are only initial evidence. Additional studies will be required to meticulously record the various forms of implementation in terms of hours worked and resources expended.

In Central Europe, vineyards are often located in climatically favourable sites and regions that are of particular interest from a nature conservation point of view. A range of thermophilic species are often located there. Whether the use of sheep actually correlates with improvements in the nature conservation of these habitats and of target species (e.g., the smooth snake) is not least a question of grazing management, which in turn depends on viticulture requirements [20] (Figure 7).



Figure 7. Sheep grazing a vineyard in the period of vine dormancy. In Central Europe, many vineyards have deep terraces. Sheep are able to graze here, so that mulching is no longer required. This is an improvement especially for insect conservation [25].

Intensive grazing does not necessarily correlate with an increase in biodiversity, at least at the level of α -diversity [3]. However, if grazing complements mulch viticulture systems, it is likely to have a positive effect on the β -diversity of the vineyard (e.g., because dung beetles migrate into the system as a new guild). In the interests of species conservation, therefore, the use of veterinary active substances should always be limited to what is absolutely necessary [26].

Many ecosystem services are affected by the use of sheep in the vineyard, but very little evidence-based measurement of the actual impacts exists. ICLS are proven to be able to support sustainability efforts in general [5], but this depends on details. For example, sheep farmers or winegrowers who have to travel by car to look after the animals would create a carbon footprint because of the fossil fuel use; the cost of fossil fuel consumption in that case can exceed the cost savings from the reduced use of machinery in the vineyard. This seems to be especially true if the products of animal husbandry are not used and this aspect of increasing acreage efficiency remains idle.

The pioneer survey indicates that synchronizing the handling of sheep with viticultural requirements can present challenges. These could potentially be overcome by cooperating with professional sheep farms. Nevertheless, for many vineyards of Central Europe, the large, heavy sheep breeds which are mainly used in professional sheep farming could cause problems during the growing season. In many cases, browsers will then be significantly taller than the lowest wire or cane/cordon, resulting in too high defoliation. Sheep incapable of rearing up on two legs are generally not found on professional sheep farms in Central Europe. In the vegetation period, cooperation between shepherds and winegrowers requires good coordination and flexible timing on both sides, which is likely to run up against limits given the relatively narrow time-windows for spraying plant protection products (PPP) in humid climates. In contrast, winter grazing is likely to be of interest to sheep farmers as a source of winter fodder, given favourable site configurations and locations, conceivably even without any costs [27]. On the other hand, summer grazing is, in Central Europe, surely only conceivable as a paid service. It is may well be unappealing for sheep farmers to keep their livestock in vineyards at times when the foraging situation elsewhere is favourable due to good weather conditions.

Our findings are mostly in line with those [8] found in New Zealand. A difference between the situation in New Zealand and Central Europe, however, seems to be the amount of herbicides used. The statements of [8] give the impression that herbicides are more frequently used in New Zealand's vineyards and the cost saving effects of using sheep instead of herbicides is therefore potentially higher. Given the reasons mentioned above, we advise further research, comparing the effects on nature and resource conservation of using sheep in vineyards. Until then, it is likely that the efficiency of a defined site increases due to the additional by-products of the sheep, but the benefits for resource conservation remain situation-related.

Using examples from the food sector, [28] has shown that the current pricing system leads to misinformation about the actual environmental costs of production. This also applies to viticulture. Environmental costs arising from the use of machinery (e.g., soil compaction) and PPP applications are not included in the wine sector's economic accounting. This should receive greater consideration in a political reordering of the food sector, which in turn should favour ICLS [5,25,29]. Ultimately, demands for more sustainable agriculture affect the production of luxury consumables in particular, since their social and ethical legitimacy cannot be justified by calling them basic necessities.

Solutions need to be found on how to make viticulture more sustainable in terms of ensuring ecosystem services. Below, we list research approaches that are of crucial importance in the further development of the ICLS "sheep in vineyards".

- Basic research:
 - How does the ICLS affect biodiversity in comparison with the fully comprehensive use of machines and herbicides?

- How do the soil parameters and the water resources of the vines change under grazing?
- What impact can be expected on the carbon footprint?
- Applied research:
 - An important open research question concerns the effect of PPP on sheep. For example, copper, which is used specifically in organic viticulture as a fungicide, was found to cause chronic copper poisoning in different situations outside of vineyards [21]. Studies are needed on whether and under what conditions such active substances can be dangerous for sheep.
 - To maximize the benefits of the ICLS and effectively reduce the risks, it is necessary to explore how the workflows of the two individual systems can be optimally synchronized. This applies to grazing management including fencing, the choice of breed, possible breeding adjustments, and furthermore, the possibility of cooperation between shepherds and winegrowers.
 - With some forms of vine training, grazing can potentially be carried out year-round without drastic changes. However, many vines must first be adapted or protected for year-round grazing. To this end, the following options are suggested by the survey participants and should be considered in further research:
 - Retraining the vine toward higher branches;
 - Protecting the canopy with electrified wires; and
 - Breeding/using small-framed sheep breeds, absolutely unable to stand on two legs.

The viticultural effects and the economic accounting should be differentiated according to the processing variables of different systems of viticulture and the exigencies or savings potential of using sheep.

The marketing of sheep products should be examined in conjunction with the distribution of viticultural products. However, it will first be necessary to determine if residual PPP substances affect the sheep's carcass.

5. Conclusions

Our research gives initial insights into an ICLS in Central Europe. Grazing is limited in time by the form of the vine-training system, the phenology of the vine, and the breed of sheep in use. If certain precautions are taken, sheep can perform viticultural work, such as pulling leaves in the grape zone or browsing undesired shoots near the ground. The survey revealed a wide variety of types of ICLS being implemented in Central Europe. The adaption of the height of the grape zone is a crucial factor for its success during the vegetation period. Particularly in France, sheep graze vineyards only during vine dormancy. Among French survey respondents, collaborations between shepherds and winemakers were common. The German winegrowers predominantly reported sheep grazing also during the vegetation period and they tend to keep the livestock themselves. In individual cases, it seems possible to keep sheep in vineyards "year-round". This requires a protection of the grape zone or a high vine training. The breeds of sheep used by the survey participants are mostly not those which have been considered most suitable for implementing the ICLS. Our study revealed a lack of in-depth information for practitioners. Interviewees reported that the ICLS improves land use efficiency by producing additional goods. Some winegrowers use the ICLS for wine marketing. The majority of the pioneers surveyed expect positive effects on resource conservation on site, though there is still a lack of evidence-based studies to verify this conclusion. Whether the ICLS can support additional ecosystem services depends on factors such as grazing intensity. It is therefore possible that the potentials of integrating sheep in viticulture are overestimated by practitioners. For instance, the potential toxicity of PPPs for sheep requires further research before promoting the ICLS. In addition, there is a lack of studies

estimating the working time required for livestock keeping within vineyards. However, our study also shows that the ICLS has already convinced some winemakers. Since the integration of the sheep logically implies a higher land use efficiency by using the vegetation as fodder and since the interviewees reported some advantages for the operational process, further research seems sensible. The ICLS could potentially help to promote a more sustainable viticulture.

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