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RESEARCH ARTICLE

Ecological and economic benefits of integrating sheep into viticulture production

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Abstract
The integration of crop and livestock systems has been recognized for its potential to reduce the environmental impacts associated with agriculture and improve farmer livelihoods. However, to date, most research has focused on the integration of cattle into crop and pasture systems. Here, we examine the integration of sheep into vineyards and assess farmers' perceived benefits and costs of the practice. Viticulture expansion has led to significant land use change in recent years and new environmental challenges, particularly with respect to herbicide use. Sheep integration into vineyards offers the potential to utilize the synergies of both systems to reduce external inputs, promote soil health, and increase farmer profit. Our study focuses in New Zealand, the world's 15th largest wine producer, particularly in Marlborough, which produces 75% of the country's wine. As a result, the case study is an excellent representation of New Zealand viticulture, while also providing unique insights into a novel practice. Using a semi-structured interview and survey, we interviewed fifteen farmers representing 5% of total New Zealand wine production to examine ecological and economic benefits of sheep integration in viticulture systems. We find that seasonal integration of sheep during vine dormancy is common, while integration during the growing season is rare. Overall, farmers perceive significantly more benefits than challenges with the integration of sheep into vineyards, particularly reduced mowing (100% of farmers) and herbicide use (66% of farmers). On average, farmers reported 1.3 fewer herbicide applications annually, saving US$56 per hectare. As well, farmers indicated they were doing 2.2 fewer mows annually saving US$64 per hectare. These results suggest that wide-scale adoption of seasonal integration of sheep and viticulture can provide large ecological benefits and higher profitability vis-à-vis conventional viticulture practices; however, further integration of the two systems may provide even greater benefits not currently realized.

Keywords Conservation agriculture · Farmer adoption · Herbicide · Integrated crop livestock systems · Wine

1 Introduction

Balancing the production of agricultural goods, species conservation, and environmental integrity has become a critical concern for the twenty-first century. There remains debate over how to meet growing global agricultural demands, including concepts of land sparing, land sharing (Perfecto and Vandermeer 2010; Phalan et al. 2011), or shifting diets (Godfray et al. 2010). Many argue that intensification of agriculture is needed to increase yields for agricultural production (e.g., Tilman et al. 2011), though there is concern about the potential environmental impacts of intensification that relies on increased use of nitrogen fertilizers, biocides, and genetically modified crops (e.g., Tilman et al. 2001; Vitousek et al. 2009). As such, ecological intensification solutions are sought that can maintain or increase yields, while also reducing environmental and public health impacts (Tittonell et al. 2016).

1.1 Integrated crop and livestock systems

One potential option for the ecological intensification of agricultural systems is the (re)integration of cropland with livestock grazing to achieve integrated crop and livestock systems (ICLS). ICLS can exist across a range of gradients, from low

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external input agricultural systems, with high levels of integration of crops and animals that require fewer inputs but result in lower production and profit (Schiere et al. 2002) to high external input agricultural systems that involve less integration of crop and animals with higher levels of inputs and typically higher production and profit (Bonaudo et al. 2014). While historically common, ICLS became less prevalent as agricultural systems became more specialized, resulting in the de-coupling of animals, crops, and pasture. As a result, current efforts to re-integrate crops and livestock are exploring options across the ICLS gradient, including integration of animals and crops within farms, as well as localized beyond farm exchanges in crop and livestock products between specialized farmers (Ryschawy et al. 2017).

Integrated crop and livestock systems can provide many benefits for both ecosystems and farmers. These benefits include higher yields (e.g., Franzluebbers et al. 2014), reduced inputs of fertilizers (e.g., Poccard-Chapuis et al. 2014) and pesticides (Tracy and Zhang 2008), increased soil carbon (Allen et al. 2012), and potential to mitigate greenhouse gas emissions and help farmers adapt to drought (Franzluebbers et al. 2014). Integrated systems can also increase profits for farmers through reduced costs (e.g., Bell and Moore 2012), labor (Neto et al. 2014), or increased productivity compared with specialized systems (Oliveira et al. 2013), but these outcomes are highly dependent on the region and systems implemented and the broader policy and market context (Garrett et al. 2017a). Each type of integrated system confers different benefits depending on the types of crops and livestock being used and the level of integration (Moore et al. 2015). In some places, integrated systems have proven to be less profitable than specialized crop or livestock systems due to their higher labor requirements and reduced economies of scale (Ryschawy et al. 2017; Martha et al. 2011).

1.2 Sheep integration

These outcomes remain unexplored for many types of crop and livestock integration because to date, most ICLS research has focused primarily on cattle (Garrett et al. 2017b). Yet, opportunities to integrate other types of animals into cropping systems are numerous, including the integration of sheep into vineyard systems. This practice has become increasingly common in New Zealand over the past decade (Gevirtz 2009; personal communication Rob Agnew) and is gaining popularity in other countries including USA (CA) (Meadows 2008). Viticulture occupies a significant, and in many regions, growing amount of agricultural land, with nearly 18 million acres of winegrapes globally (Wine Institute 2014). Additionally, demand for wine continues to rise annually with certain nations predicting double digit growth in the future (Mercer 2016), demonstrating the potential opportunity of ICLS in these systems.

In New Zealand—now the 15th largest wine industry in the world (Wine Institute 2014)—winegrape hectares expanded from 10,197 ha in 2000 to 36,192 ha in 2016, a rise of 255% (New Zealand Winegrowers Association 2016a). New Zealand viticulture has a reputation for sustainability well known through the certification of Sustainable Wine Growing New Zealand (SWNZ) in more than 98% of acreage (New Zealand Winegrowers Association 2016b). Integration of sheep into vineyards provides an opportunity to maximize landscape level production and potentially reduce environmental impact by utilizing both systems synergistically. However, the extent to which these benefits (or potential challenges) are realized will likely depend on the scale of integration (Moore et al. 2015; Ryschawy et al. 2017). Opportunities for integrating sheep into vineyards can take many forms across different scales including:

1. Seasonal integration through the use of sheep in the vineyard during the winter (vine dormancy) to feed on vegetation between rows;
2. Seasonal integration using sheep on short time intervals to pluck leaves from vineyards to open up the grape canopy (Hawkes Bay Winegrowers Association 2010);
3. Year-round integration using sheep during the growing season by training sheep with lithium chloride or fencing to prevent them from feeding on grape leaves (Meadows 2008);
4. Year-round integration using Babydoll sheep, a miniature breed of sheep that enables integration in the vineyard year-round since the animals cannot reach the grape leaves and grapes;
5. Byproduct integration through feeding of grape pomace (leftover solids after pressing) to sheep following harvest.

Despite the seasonal integration of sheep during the dormant season being fairly common in wine-growing regions of New Zealand (personal communication Rob Agnew), we are unaware of any peer-reviewed research to understand the benefits and challenges of integrating sheep into vineyards. We focus on farmers who have integrated sheep into their vineyards, examining their perceived costs and benefits across multiple factors (economic, environmental, labor, production) as a result of integration at varying levels ranging from seasonal to year-round practices.

2 Materials and methods

2.1 Study region

The study takes place in Marlborough, New Zealand, which produces 75% of New Zealand's wine, with 86% of this from the Sauvignon Blanc variety (Wine

Marlborough 2015). This region is thus an important study of focus for understanding the agronomy of viticulture systems in terms of volume alone. However, the case selection of Marlborough is also important for understanding the viability of different pathways to improve the sustainability of viticulture because it is one of the few places where integration of sheep into vineyards occurs on a wide-scale. While seasonal integration during the dormant season is common in New Zealand, this practice is less documented elsewhere, offering a unique opportunity to better understand the potential benefits and challenges associated with this practice for other regions. The choice of New Zealand is also a particularly useful place to examine farmer perceptions of ICLS since there are fewer policy barriers to their adoption, as compared to other regions (Garrett et al. 2017a).

Like the rest of New Zealand, viticulture hectares expanded rapidly in Marlborough during the 2000s. In 2000, viticulture was equivalent to 4054 ha (New Zealand Wine Company 2006); by 2016, this has grown to 24,020, an increase of more than 181% in 13 years. Between 2002 and 2008, Marlborough reported losing 23,121 ha of pasture land, with satellite imaging confirming that the majority (95%) of this new land for viticulture had come from pasture land, likely previously grazing sheep (Marlborough District Council 2008). This significant land use change has resulted in many potential impacts for the region including an increase in irrigation (Niles and Mueller 2016) and a significant increase in herbicide use in viticulture during the 1990s (Dastgheib and Frampton 2000), with estimates that 70% of Marlborough vineyards applied herbicides by 2007 (SHANZ 2011). These changes have resulted in increasing challenges including spray drift (Lammers et al. 2007) and herbicide resistance (Ghanizadeh et al. 2015a). Rye grass resistant to herbicides (glyphosate, glufosinate, and amitrole—the three most common herbicides used in New Zealand vineyards) is also now the first confirmed report of weed species with multiple resistances (Ghanizadeh et al. 2015b).

2.2 Methodological approach

This study employed a mixed methods approach utilizing interviews with a survey instrument, which enabled data to be quantified in some contexts but open-ended questions as well. Institutional Review Board approval was sought from Harvard University (approval number IRB14-0585). The survey instrument was developed in consultation with viticulture industry experts within the region and the experience of the researchers working with viticulturists and winegrape farmers in New Zealand (e.g., Niles et al. 2015, Niles and Muller 2016). We interviewed two different types of people: either farmers, who grow grapes under contract for a winery, or viticulturists (i.e., the managers of winegrape production at a winery). For simplification, we refer to all interviewees as "farmers." Interviewees were sought for their known adoption of integrating sheep into their vineyards across a diversity of farm sizes, management practices, and grape varietals. Interviewees were obtained through collaboration with industry and research contacts and through the use of a snowball effect with individuals that were interviewed.

A total of 20 farmers were originally contacted for inclusion in the study, with five farmers unavailable or unable to be reached (a 75% response rate). In total, 15 interviews were conducted in June 2015 using the survey tool with farmers or viticulturists who had the responsibility of managing production. Among the 15 farmers interviewed, 6 were viticulturists working directly at a winery while 9 were individual contract farmers that sold their grapes to a winery. Interviews ranged between 30 min and 1 hour, approximately. Data were collated and quantified when possible and coded into key themes. These properties collectively were equivalent to 8% of the total grape acreage in Marlborough, New Zealand (1893 ha out of 24,020), or 5% of the total winegrape area in the country (New Zealand Winegrowers Association 2016a, b).

3 Results and discussion

3.1 Farm characteristics

Farm sizes ranged from 14 to 1300 ha (mean = 411). Other common land uses on these farms included sheep and beef pasture, kale, and other brassicas (often used as livestock feed in New Zealand). Total grape hectares ranged from 14 to 420 (mean = 104). Eleven farmers owned their land exclusively, while two farmers were leasing at least some of their land. Two farmers did not indicate their land tenure arrangement. All of the farmers interviewed grew Sauvignon Blanc, with the variety resulting in 49–100% of their total production. Other varieties grown by interviewees included (in order of total prevalence) Pinot Noir, Pinot Gris, Chardonnay, Sauvignon Gris, Riesling, Gewürztraminer, Merlot, Syrah, and Malbec.

3.2 Sheep characteristics and integration

Our results indicate that the integration of sheep in vineyards in Marlborough is largely seasonal, and often occurs as an exchange between specialized systems. There were a range of ways in which animals were integrated into the farms and market arrangements to obtain animals. Seven interviewees managed their own flocks of sheep in concert with winegrape production and eight brought in sheep, usually seasonally, from neighboring farms or from other regions of Marlborough, specifically the Awatere Valley (where sheep production is prominent). Among the seven managing their own flocks, six were farmers who were also sheep/beef farmers and used their own animals within their system and one was a winery that bought their own sheep.

Among the eight interviewees that brought in sheep, the cost for animals in the system varied given the number of different arrangements, many of which occurred through personal relationships or had happened casually. One farmer did not pay for the sheep to be integrated into the vineyard, expressing that the arrangement was a “neighborly agreement” and there were mutual benefits to their winery and the sheep farmer for using the sheep (i.e., the sheep farmer obtained free feed, the winery reduced their mowing and inputs). One winery reported that instead of renting sheep from a nearby neighbor, they bought their own sheep (US$55 each), fattened and sold them within the season to make a profit. However, the most common arrangement for farmers without their own animals was to rent sheep from another farm with the rental costs ranging from 25 cents per sheep per week to 45 cents per sheep per week, representing an exchange between specialized systems.

The timing of sheep integration in vineyards can vary from seasonal to year-round depending on production systems (Fig. 1). The majority of farms integrated sheep into the viticulture system seasonally during the winter dormant season from post-harvest until pre-bud break, typically from May to September (Fig. 2). However, there were several instances where farmers aimed to integrate sheep for a greater part of the year. One farmer experimented with reintegrating sheep in the vineyard again in January until véraison (the onset of ripening). One other farmer suggested that lambs could be reintegrated in the vineyard from about November until flowering period. At the time of interviews, only two farmers indicated they used sheep for leaf plucking; however, one farmer contacted us post-interview to inform us they had used sheep for leaf plucking in 2015–2016 summer and intended to do it again.

3.3 Likely adoption of non-seasonal integration strategies

While all farmers were currently using sheep in their systems seasonally during the dormant period, we also inquired about the use of practices on farm that might enable integration of sheep in more complex ways, for longer periods of time, or of different animals (detailed in Section 1). Our results indicate that longer-term or more complex integration strategies were less common, reported below, out of the total number of respondents (12 farmers responded to questions about longer-term integration and the use of byproducts, 14 responded to questions about different types of animal integration within the vineyard). One farmer was utilizing electric fences to stop sheep eating grape leaves during grazing, which enabled them to use sheep in the vineyard during times of bud-break and leaf growth beyond the dormant season. However, the majority (7/12) indicated they were unlikely to use fences or other aversion training in the future to prevent sheep from eating leaves and integrate sheep outside of the dormant season, while 3/12 were very likely to adopt. The use of Babydoll sheep, which can remain in a vineyard year-round, was not an existing practice for any farmers and 13 indicated they were unlikely or very unlikely to do so in the future while two were very likely. While sheep were the dominant type of animal integrated into systems, three farmers also used cattle in some aspects of their viticulture production and one farmer indicated they had previously used cattle. The use of byproduct integration was uncommon with three farmers (out of 12) indicating they were currently feeding grape pomace to cattle in their systems while another three (out of 12) indicated they had previously used this practice but stopped because of quality or logistics. Others indicated they were very likely (1/12), or unlikely or very unlikely (5/12) to use this practice in the future. The majority of the respondents (9/14) indicated they were unlikely to use cattle in the future while two farmers said they were very likely or likely to do so and two previously integrated cattle.

3.4 Perceived changes: benefits and challenges

Farmers were asked about the extent to which integrating sheep into their vineyards was beneficial, harmful, or challenging. They were also asked whether certain practices had occurred, whether they provided economic, environmental, production, and/or labor benefits or no benefits, and whether the change in practice had been harmful to their farm systems.

3.5 Perceived benefits

Table 1 provides an overview on the total changes observed by practice and the benefits or harms. Among the nine different potential changes, all farmers indicated that they had observed at least one beneficial change. Overall, the largest observed changes were to mowing (100%), herbicide use (66%), nitrogen use and frost protection (27% each), and fuel use (20%). Farmers talked extensively in the interviews about some of these specific benefits. One farmer explained that the sheep were able to get the grass to a shorter level than a traditional mower and they felt this had frost protection benefits by increasing solar radiation absorption by the soil. On herbicide use, one farmer stated that “sheep are as good as herbicides” while another suggested, “It’s a weed clean up: sheep can clean up broadleaf weeds.” Farmers suggested that sheep were particularly good at targeting deep-rooted and woody weeds like mallows that often even herbicides would not be able to kill. Some farmers noted the combined benefits of animal

Fig. 1 Sheep graze during the dormant season in vineyards in Marlborough, New Zealand. Photo Credit: Meredith Niles

integration—a quadruple win of reduced mowing, herbicide use, and fuel and labor costs associated with these practices.

Among farmers suggesting economic benefits, the majority of savings were for input costs and labor, and were reported primarily across mowing and herbicide use changes (Table 2). As one farmer noted, "I used to mow September to February non-stop. I had a guy who would mow 30 hours a week and turn around and started again once he stopped." Savings reported are relevant to farm size and varying input and labor costs; nevertheless, these results suggest that farmers saved on average across all farm sizes US$4931 annually in reduced herbicide use, US$10,394 in costs associated with reduced mowing, and on average US$12,405 in total across both practices. Among the farmers who were using sheep for leaf plucking, this was perceived as a major benefit over hand plucking, which is expensive (Hawkes Bay Winegrowers Association 2010). Among the two farmers utilizing sheep beyond seasonal integration for leaf plucking, one farmer was indicating the cost per vine to use sheep was two cents, while it was five to eight cents for a mechanical plucker, and 20 to 30 cents for hand plucking. The other farmer noted they did not have to do two leaf plucks per

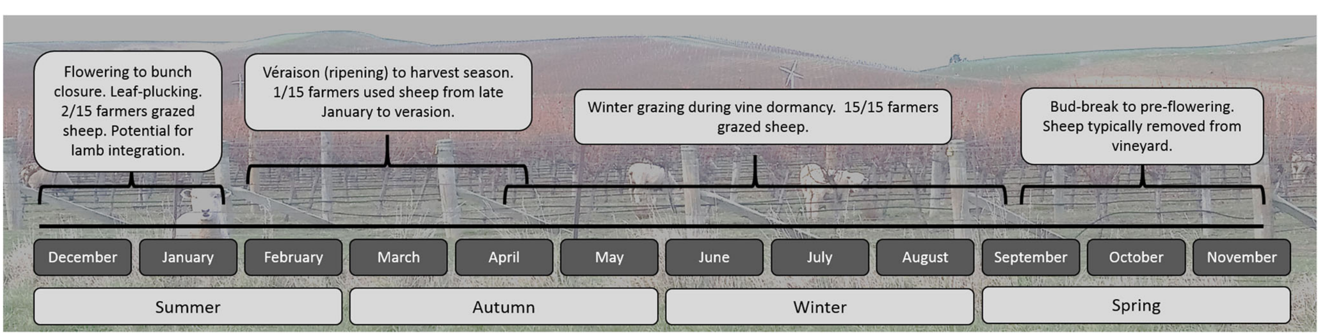

Fig. 2 Timeline of typical times of the integration of sheep into the New Zealand wine growing calendar

Table 1 Interviewees perceived practice changes, benefits, and harm in systems integrating sheep into viticulture systems. Percent of respondents are listed with total number of farmers ($n = 15$) indicating the response in parentheses

Change	Change occurred (%)	Perceived benefits from change (%)				No change/ benefit (%)	Change harmful (%)
		Economic	Environment	Farm production	Labor		
Herbicide use	66 (10)[a]	53 (8)	40 (6)	0 (0)	60 (9)	33 (5)	0 (0)
Nitrogen use	27 (4)	7 (1)	7 (1)	20 (3)	7 (1)	73 (11)	0 (0)
Other input use	13 (2)	7 (1)	7 (1)	0 (0)	7 (1)	53 (8)	0 (0)
Mowing use	100% (15)	87 (13)	20 (3)	0 (0)	87 (13)	0 (0)	0 (0)
Frost protection	27 (4)	7 (1)	13 (2)	7 (1)	0 (0)	73 (11)	0 (0)
Fuel use	20 (3)	13 (2)	13 (2)	0 (0)	13 (2)	7 (1)	0 (0)
Yield	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	80 (12)	13 (2)
Quality	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	87 (13)	0 (0)
Marketing	20 (3)	0 (0)	0 (0)	0 (0)	0 (0)	33 (5)	0 (0)

[a] One farmer did not use herbicides

year as a result of the sheep, and if they have utilized hand plucking, it typically occurs at 1 ha an hour at contract cost rates. In addition to the realized cost savings from sheep integration, farmers who managed their own sheep also mentioned that there were economic benefits from the extra income. As demonstrated by one farmer, "It's not having to mow and the income, it's an opportunity to create extra income from the vineyard and it's substantial if it's your own sheep."

Table 2 Reported observed changes, cost benefits, and cost savings on an annual basis for herbicide and mowing reductions from sheep integration in vineyards. Dashed lines indicate data was either not relevant or was not reported. Farmers reported costs in New Zealand dollars, which have been converted to US dollars based on the time of interviews (June 2015, conversion rate 0.691 USD = $1NZD)

Winery hectares	Herbicide use				Mowing change use				Total cost savings
	Observed change annually	Cost benefit (inputs, labor)/ spray	Average cost savings	Average per hectare	Observed change annually	Cost benefit/mow	Average cost savings	Average per hectare	
14	–	–	–		2 fewer	$553	$1106	$79	$1106
17.2	1–2 fewer	–	–		2 fewer	$532	$1064	$62	$1064
25	1–2 fewer	$1382	$2073	$83	1–2 fewer	$1382	$2073	$83	$4146
30	–	–	–		3 fewer	–	–		–
34	1 fewer	–	–		3 fewer	–	–		–
46	2 fewer	$2073–$2419	$4492	$98	2–3 fewer	$1723	$4319	$94	$8811
63	2 fewer	$1959	$3918	$62	4 fewer	$622	$2488	$39	$6406
72	–	–	–		1–2 fewer	$1575	$2363	$33	$2363
125	–	–	–		1 fewer	$2159	$2159	$17	$2159
140	1 fewer	$2419	$2419	$17	2–3 fewer	$1534	$3835	$28	$6254
150	1 fewer	$10,365	$10,365	$69	–	–	–		$10,365
167	1 fewer	$4616	$4616	$27	3 fewer	$2045	$6136[a]	$37	$10,752
180	1 fewer	$6634	$6634	$37	2 fewer	$5528	$11,056	$61	$17,690
390	–[b]	–	–		1–2 fewer	–	–		–
440	–[b]	–	–		1 fewer	$43,188–$112,288[c]	$77,738	$177	$77,738
Average	1.3	$4232	$4931	$56	2.2	$8671	$10,394	$64	$12,405

[a] Farmer suggested it saved mowing every 2–3 weeks. Estimated at 3 mows for winter

[b] One farmer did not use herbicides, and another indicated a benefit for their organic production

[c] Range given was based on whether farmer used their own labor ($25/h) or hired a contractor ($65/h)

In response to an open-ended question about other consistent benefits, several farmers mentioned the benefit of additional grass for grazing, particularly in the winter when grass on other areas of their farm (especially at higher elevations) might be either dormant, or too wet for grazing. For non-farmers (i.e., wineries), several also mentioned the "neighborly" benefit of helping out farmers with sheep who needed feed during the winter. Finally, several farmers mentioned the potential soil benefits of integrating animals into the vineyard. As one interviewee stated, "The animals do take some nutrients from the ground, but I was of the view that as they process the grass, they would be providing plant available nutrients and probably assisting with a bit of organic matter processing. I thought it would be positive to the soil."

3.6 Perceived challenges

Two key challenges consistently mentioned among many farmers were the potential for sheep to break canes and damage vines and the potential for sheep to chew on wires or drip line irrigation. However, in general, farmers agreed that, "The benefits outweigh the costs." For cane and vine damage, most acknowledged that this could be an issue, especially if the animals were scared and might run through the rows. Breakage might also occur during transport of animals in, out, and between vineyards. Overall, farmers felt this breakage was minimal and not a significant problem, with one grower noting that annual breakage might constitute one-half of a percent of total vines. Many also discussed how sheep like to chew on wires and irrigation line, with one farmer stating, "People believe that sheep chew the dripline; I think it's the rabbits that chew the dripline." Farmers indicated that burying or covering irrigation line was effective at minimizing damage, though sheep might still pull drippers off drip irrigation line.

Several other challenges were mentioned by fewer interviewees such as the need for fencing for animals, providing water for animals, concern over transport of weed seeds via the sheep, having knowledge of chemical withholding periods necessary prior to slaughter, and close monitoring for leaf plucking to ensure animals did not pluck too many leaves or eat grapes. Two farmers also mentioned the need to consider the two systems carefully. As described by one interviewee, "It's the integration of both to complement each other rather than to compete with each other. So many people just put the sheep in and just graze it right down- it might be good for the vineyard, but not for the animal…so you have other issues for the animal. You need to find the balance for the two- they can be competing systems." In the same vein, other farmers mentioned the skill sets necessary to successfully manage both systems, stating, "It's about skills… management skills", noting as well "A lot of people with vineyards don't have that knowledge [about sheep]."

3.7 Implications

This article is the first to outline the perceived and actual benefits, costs, and challenges for the multiple ways of integrating sheep into vineyards. Given the growing demand for wine and the already nearly 18 million acres of winegrapes globally in 2014 (Wine Institute 2014), our results demonstrate the large-scale potential for the seasonal integration of animals into viticulture with potential conservation implications globally. Our results suggest that integration is possible across a range of vineyards—from small to large and with diverse practices for using sheep either seasonally or for longer-term periods. We also demonstrate that wide-scale global adoption of integration of sheep into vineyards has the potential to significantly reduce environmental impact, particularly with reduced herbicide use and mowing, which leads to lower labor costs and higher profits. Our finding that this system of ICLS leads to consistently reported lower labor costs is novel, as others (Ryschawy et al. 2017) have found labor costs increase in ICLS.

Given the widespread use of herbicides in vineyards, as well as the now-identified resistance to herbicides in vineyards, sheep offer the potential to overcome some of these significant environmental challenges. Furthermore, sheep were suggested as particularly useful against the most significant weed identified in the region (mallow, Dastgheib and Frampton 2000). Reduced mowing may also offer additional environmental benefits both through the reduction in fossil fuel use, but also by potentially providing additional habitat for insects and bees that can typically be less common in highly mowed systems (e.g., Garbuzov et al. 2015). Thus, if adopted at a large scale, integrated livestock and viticulture systems have the potential to have widespread conservation benefits globally.

However, our results also suggest that integration as it is currently occurring in New Zealand is not happening to the full extent possible, and is likely occurring in ways that are casual and potentially random, rather than coordinated. These results corroborate results from Sustainable Winegrowing New Zealand that 59% of farmers are integrating sheep into their management (Sustainable Winegrowing New Zealand, personal communication January 2017). While all of the farmers we surveyed were seasonally integrating sheep (and a few cattle), the use of strategies that would enable more holistic and year-round integration was minimal. This suggests that, even for farmers that had both grape and sheep production on their own farm, their systems were still seasonally specialized. For wineries that brought sheep into their systems, these two specialized systems sought to convey benefits to both kinds of farmers through reduced input costs and labor. As suggested by several (Moraine et al. 2016; Moraine et al. 2017; Ryschawy et al. 2017), this kind of integration across specialized systems may be one strategy to enable ICLS benefits, however the coordination and logistics costs, as well as the need for additional skills, can be challenging. This may be particularly true for the expansion of sheep integration into other regions where sheep are not as prominent, which could require greater coordination efforts.

Our results also indicate that for farmers who were practicing longer-term, year-round ways to integrate sheep during leaf plucking or up to harvest, these farmers had greater reductions in labor and input costs associated with either mechanical or hand plucking. This longer-term integration of sheep into New Zealand vineyards may provide greater cost savings and potential environmental benefits, albeit this level of integration likely requires additional skill sets either on farm (Ryschawy et al. 2017), or close consultation with the grazing farmer to ensure grapes are not over leaf plucked or bunches removed.

Given the existing sustainability effort within the New Zealand wine industry, these results provide potential opportunities for the further adoption of seasonal integration of animals in winegrapes as well as the promotion of the practices over longer periods with appropriate skills and training. Given the need to coordinate such efforts (Ryschawy et al. 2017; Moraine et al. 2017), the SWNZ management system could play a prominent role in this effort and provide much-needed trainings to increase the skills necessary to re-integrate animals and crops together. Given the existing infrastructure for sustainability certification, it is possible that one strategy to drive further integration of sheep into vineyards could be through a new set of practices under SWNZ, or a new certification altogether. It is also possible that there is a marketing potential demonstrating to consumers the positive benefits of sheep integration into vineyards, as well as the novelty of the practice. Through a certification system or the use of new marketing strategies, farmers may see additional opportunities to advertise the use of sheep in vineyards and seek a wine premium for their product, potentially driving greater adoption.

3.8 Limitations

These results are reported across a small sample size in New Zealand, though the region in focus produces 75% of New Zealand's wine (New Zealand Winegrowers 2015). Future research should aim to interview a larger, random sample of producers in New Zealand to enable statistical analysis of adoption practices and perspectives. It remains unclear how representative the New Zealand case is for other wine-growing countries, particularly with respect to sheep availability. There were 29 million sheep in New Zealand as of 2015 (Statistics New Zealand 2015). In regions where sheep are less common, such as the USA (5.4 million sheep in 2012, USDA Census 2012), a shortage of animals may present one of the greatest barriers for integration, though greater understanding of cattle integration may prove useful to expand beyond sheep.

4 Conclusion

Growing demand for agricultural products has the potential to continue to shift landscapes and have negative environmental impacts at a global scale. ICLS have shown promise to create synergies between crop and animal systems with demonstrated environmental, yield, and economic benefits. Here, we examine this issue in the first paper globally to look at how farmers perceive the costs and benefits of integrating sheep into vineyard systems. Our results show that sheep integration in New Zealand is largely occurring on a seasonal basis, typically through exchanges between specialized systems, but this type of integration has the potential to provide both ecological and economic benefits to farmers of varying farm sizes and characteristics, in particular by reducing herbicide and mowing needs. In contrast to other forms of crop and livestock integration, using sheep in vineyards can reduce labor needs, resulting in higher profits. Our results also demonstrate that the full potential to integrate sheep into vineyard systems is not yet common, but among those utilizing sheep beyond the winter, additional economic and labor benefits are reported. Importantly, existing research, as well as our own, demonstrate the need for coordination and additional skill sets that would be necessary if farmers seek greater integration on farm rather than across specialized systems.

Finally, our results demonstrate a clear need for additional research in both the social and biophysical sciences related to sheep and viticulture integration. Further agronomic research is needed on the effect of sheep integration on grape yield (perceived as a harm by two farmers), soil structure and diversity, animal health and well-being, input use, and potential conservation benefits. Expansion of farmer surveys into other regions in New Zealand and other countries can better assess whether these perceived benefits and costs are similar, and whether farmers who have not adopted the practice have different perspectives. This paper aims to be a first step in driving this future research agenda to more completely understand the potential benefits and costs of sheep integration in vineyards.

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