The impact of integration of sheep into vineyards in New York State

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By

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Abstract

Integrated (crop + animal) production practices allow for intensified production on limited land while also increasing sustainability. Sheep have successfully been integrated into vineyards in New Zealand for off season grazing but no research is available on grazing sheep in vineyards during the growing season. To understand the viability of incorporating sheep in vineyard management, four separate studies were undertaken: 1) a survey of Northeastern grape growers, 2) a replicated field trial of sheep grazing in a high-trained hybrid vineyard, 3) an observational field trial of sheep grazing in a vertically shoot positioned vinifera vineyard, and 4) an economic analysis of sheep grazing compared to conventional vineyard practices.

Responses from growers to the survey indicated a mixed reception to sheep integration into vineyards, with knowledge of other growers who had implemented the practice strongly influencing respondent willingness to do the same. In high-trained vineyards, sheep effectively suckered vines and mowed the vineyard floor, causing no damage to the vine trunk while allowing for the elimination of herbicide use under the vine. However, yield in grazed plots were markedly lower than in conventionally managed plots. When incorporated into a vertically shoot positioned vineyard, grazing height needed to be limited to the fruiting zone through the use of bird nets so that the sheep could effectively perform fruit zone leaf removal without excessively stripping vegetation from the vine. Economically, season-long grazing of sheep in vineyards was more expensive than conventional practices, but the cost of using sheep for fruit zone leaf removal in vertically shoot positioned vineyards was 3% lower than conventional practices even with the inclusion of bird nets to protect vegetation.

Further research is needed on the long-term effects of sheep grazing in vineyards along with alternative strategies of managing sheep.

Biographical Sketch

Justin Jackson was born in Grapevine, Texas and raised in Granbury, Texas. From an early age, he was interested in growing plants and even convinced his parents to let him tear up part of their yard for a garden. After graduating from Granbury High school in 2015 he attended The University of Texas in Austin and later Texas A&M in College Station. At A&M, Justin studied horticulture with a focus on viticulture. However, a large portion of his time was spent working with cotton through his employment with Agrilife Extension. From this experience, he developed a passion for applied research and helping growers that guided his future education.

After graduating in 2019 with a Bachelor of Science in horticulture and an enology certificate, Justin started his master's degree that summer in Dr. Justine Vanden Heuvel's lab. Upon his graduation, he plans to find a position in extension where he can help growers implement novel strategies for the cultivation of developing crops.

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Introduction

As demand increases for agricultural products, concerns for ecosystem health and conservation alongside growing urban development limits land available for production. Eleven million acres of farm and ranchland were lost to development between 2001 and 2016 in the United States (Freedgood et al. 2020) leaving growers little choice but to intensify production on remaining land. Conventionally, fertilizers, pesticides, and bioengineered crops have been used to increase production per acre. One system practiced less frequently is the integration of livestock and crop production on the same land. In contrast to the specialized high input, high yield systems commonly sought after today, integrated crop and livestock systems (ICLS) combine crop, livestock, and or trees in a rotation or combination on the same land to reduce inputs (Cortner et al., 2019). Integration has been shown to benefit carbon sequestration (Drinkwater et al., 1998), reduce fertilizer inputs through nutrient cycling (Russelle et al., 2007), and increase profit (Anderson and Schatz, 2003).

Incorporating sheep into vineyards is a new and largely unexplored form of ICLS. Sheep have proven to be effective at mowing vineyard floors in New Zealand during the dormant season, reducing the need for winter mowing and intensifying production per acre by reducing the amount of dedicated pasture needed for sheep production (Niles et al. 2018). However, no quantifiable data is available for the effects of sheep grazing on grape vines and no research exists for the efficacy of this production system in the vineyards of Northeastern U.S.

Deep, fertile soils and heavy precipitation complicate grape cultivation in the Northeastern U.S. through increased growth of both ground vegetation and vines. Uncontrolled growth of vineyard floor vegetation can lead to increased pest and disease pressure on plants while excessive vine growth can increase disease pressure and reduce fruit quality (Austin et al., 2011).

Operation costs for a vineyard during the growing season of an average year in the Finger Lakes region of New York State is around $2,762 per acre, with a sizeable portion of those costs allocated to combat problems arising from excessive vigor (Davis et al. 2019). Mowing between vineyard rows ($94/acre), suckering trunks to remove new vine growth ($54/acre), mechanical leaf removal around the clusters ($116/acre), and herbicides under the rows to control weeds ($128/acre) are all integral in conventional management of vineyards (Davis et al. 2019). Through integration, sheep can mow, sucker, and perform leaf removal in vineyards, potentially reducing the cost of production.

Current vineyard practices dictate maintaining bare soil under vines often with herbicides, resulting in increased erosion and run off (Wheeler et al. 2005). Herbicide use in mature vineyards can be eliminated completely as vegetation under mature vines has been shown to have no effect on yield (Chou and Vanden Heuvel, 2019). However, keeping vegetation short under vines is difficult and conventional mowing practices can damage vines, slowing the adoption of herbicide reduction practices. Integration of sheep into vineyards may provide an opportunity for further incorporation of under-vine vegetation since sheep have the potential of mowing vegetation right up to the vine without damaging the vine trunk. Tractor passes for mowing and spraying could be reduced with the introduction of sheep, potentially reducing soil compaction and further benefiting soil health. Natural cycling of nutrients through sheep could not only decrease the need for costly inputs but also increase soil health and microbe diversity. Sheep will not consume immature grapes and desirable canopy can be protected with nets or by nature of the training system, allowing for the introduction of sheep during the growing season.

This study consisted of four parts: a survey of grape growers in New York State, a replicated field trial studying grazing impacts on high trained hybrid (*Vitis* sp.) vines, an unreplicated trial examining grazing impacts on vertically shoot positioned vinifera (*Vitis vinifera* L.), and an economic analysis of vineyard management both with and without grazing.

The objectives of the grower survey were to:

1. Determine grower interest in incorporating sheep into their vineyard.
2. Determine what factors affect the interest of grape growers/wineries in incorporating sheep.
3. Understand growers’ perceived benefits and barriers to adoption for sheep management.

With the replicated field study, we sought to understand how:

1. Sheep interact with the vineyards and their effect on vine health.
2. Fruit yield and composition is affected by the presence of sheep in a vineyard.
3. Soil changed in a vineyard with the introduction of grazing.

The observational trial was used to test the viability of grazing sheep in a vertically shoot positioned vinifera vineyard with the goal of completing fruit zone leaf removal with the use of bird netting to spatially limit the height of grazing.

Through our economic analysis we sought to understand the cost of incorporating sheep into vineyards to perform various management practices.

Materials and Methods

Survey study

Study region

The surveyed area included the four main grape growing regions in New York State: Finger Lakes Region, Southern shore of Lake Erie/Lake Ontario (including Northwestern Pennsylvania), Long Island, and Eastern New York (including the upper and lower Hudson Valley). Western New York is mostly comprised of juice grapes while Finger Lakes, Hudson Valley, and Long Island are focused on wine grapes. New York itself is the third largest producer of grapes in the United States and by far the largest in the Northeastern U.S. with over 35,000 acres under cultivation (USDA 2017). As such, New York provides a good representative sample of cool climate growers in the US.

Environmental factors such as fertile soils and heavy rains lead to excessive growth of grapevines in the region (Wolf, 2008). As a result of the ample precipitation, row middles and sometimes under-vine strips are maintained with vegetation in the form of a cover crop or a mix of weed species. The time and effort that goes into managing this growth (frequent mowing, herbicide use, vine suckering, vine leaf removal) could potentially be alleviated through the introduction of sheep into commercial vineyards. New York also boasts a robust sheep rental industry revolving around grazing solar farms, providing an existing framework for growers to utilize. The goal of this survey was to determine grape growers' perceptions on hosting sheep in their vineyards to perform various services.

Methodological Approach

The survey instrument was a mixed design of 20 questions mainly relying on 18 multiple choice questions in order to increase the potential number of respondents and provide quantifiable data; however, seven open-ended questions were also included. Institutional review was sought from Cornell University (IRB approval number 2004009537). The survey instrument was distributed through program newsletters by regional Cornell Cooperative Extension programs in the four regions previously mentioned. Links to the survey instrument were included in their weekly/bi-weekly newsletters. The survey was distributed to a total of 1121 different email addresses although we are unable to quantify how many users opened/read the newsletter that contained the link to the survey. Qualtrics (Qualtrics, Provo, UT) was used to design and host the survey instrument online.

There were 30 complete – and three partial – responses to the survey. This low level of response may indicate that only those interested in hosting sheep or those with livestock experience responded to the survey, potentially introducing bias in the results.

Replicated field trial

A randomized complete block design study on grazing sheep in a high-wire cordon-trained vineyard was conducted in Geneva, NY in 2019 and 2020. The site (42˚51’56”N 77˚02’56”W) is 0.6 acres of twelve north south oriented rows spaced 2.7m apart (Fig 1). Established in 2007 with one-year-old dormant Noiret vines (Vitis spp.) (Reisch et al., 2006), the experiment was designed as a 2x2x2 split-split plot with training system as the main plot (high wire cordon, low cordon with vertical shoot positioning), vine spacing as the sub-plot (1.8, 2.4 m), and root system (own-rooted, grafted onto 101-14 Mgt) randomized among the sub-plots (Vanden Heuvel et al., 2013). Following the 2010 growing season, the low cordon vines were trained to a high cordon to help alleviate excessive vigor. The soil present at the site is a Honeoye Loam with a lower clay surface, 3 to 8 percent slope, at an elevation of 221 meters.

The entire vineyard block was enclosed with mesh wire netting and further sub-divided into experimental units using electo-net fencing the first year and single strand electrified wire in tandem with cattle panels for the second year. Two replications were created, each with a control and a grazed experimental unit. Experimental unit sizes were uneven and replications low due to vineyard size and design. Fencing bisected row middles leaving experimental units with either one or two full row-middles plus two half-row middles resulting in experimental unit widths of either 5.4 m or 8.1 m. The two control units were managed conventionally and included row middle mowing along with manual suckering of trunks (Wolf, 2008); herbicides were not used to manage under vine growth as it has been shown that under vine growth does not detrimentally impact mature vines (Chou and Vanden Heuvel, 2019; Jordan et al., 2016) resulting in a mix of weed species under vines. Eight panels were chosen per experimental unit for sampling to account for variability in spacing and rootstock. Each experimental unit contained two sample panels of each of the four variable combinations (i.e., two vines per panel own-rooted, two vines per panel grafted, three vines per panel own-rooted, three vines per panel grafted).

Four Katahdin sheep were introduced into the Geneva vineyard on 13, June 2019 which was seven days following mowing; five sheep were introduced on 15 June 2020 with no prior mowing that season. Rotation of the sheep throughout the season occurred between the two grazing experimental units and a separate holding pen for when forage was scarce in the vineyard. Sheep were moved out of a unit when the area visually appeared at risk of over grazing. This was a subjective decision made by examining the height and prevalence of available forage in an experimental unit. In 2019, sheep visited each experimental unit five times with durations lasting around a week and were finally removed from the experiment on 10 September 2019. Starting on 10 June 2020, sheep visited each experimental unit four times for approximately one week at a time and were removed from the experiment on 24 August 2020. Shelter, water, and minerals were provided, along with daily checks on wellbeing.

Vine vegetative growth

After sheep moved off an experimental unit around veraison, measurements were taken in centimeters from the base of vine to the highest point of visible sheep damage on the foliage. Thirty measurements per experimental unit were recorded to give an understanding of the height to which the sheep grazed the vines.

Ten vines per experimental unit were randomly selected after sheep were removed and rated on a scale of 0 to 3 for trunk damage (0=no discernable damage, 1=moderately damaged, 2=heavily damaged, 3=extreme damage). Suckering effectiveness was determined at the same time by rating trunks on a scale of 0 to 2 (0=all suckers remaining, 1=some suckers remaining, 2= all suckers removed).

Pruning weights per vine was recorded at the end of the season by separating the one-year-old cane prunings from older wood and weighing using a hanging scale (Salter weigh-Tronix, Fairmont, MN). Weights were compared with those of the control in the same year to determine the impacts of the treatments on vine vegetative growth.

Vine yield

All fruit was harvested by hand on 30 October 2019 and 9 October 2020. Cluster number and weights were recorded on a per panel basis to determine differences in yield. Weight was determined using a hanging scale (Salter weigh-Tronix, Fairmont, MN) . Average cluster weight was quantified by dividing the total fruit weight by the number of clusters. Ten clusters from each panel were collected and stored at -40˚C for further analysis. In the second year, harvest and data collection were conducted in the same manner with further cluster analysis performed to determine average berry weight and average number of berries per cluster. Ten clusters were sampled per panel; berries were removed, counted, and weighed. Average berry weight was calculated by dividing the total cluster berry weight by number of berries per cluster.

Fruit composition

The ten-cluster sample was thawed at room temperature, crushed by hand, and the slurry pressed through cheese cloth to yield a juice sample. Soluble solids were measured using a temperature compensated refractometer (Abbe ́; ATAGO, Bellevue, WA), pH was measured using a pH meter (Orion 3-Star; Thermo Fisher Scientific, Waltham, MA), and titratable acidity (TA) was determined as tartaric acid equivalents on a 10-mL juice sample by auto titration (Digital Buret; BrandTech Scientific, Essex, CT) using 0.1 M sodium hydroxide to an endpoint of pH 8.2. Primary amino nitrogen (PAN) was measured by spectrophotometry and ammonia (AMM) measured with a ChemWell 2910 Multianalyzer and from (ChemWell 2910 Chemistry Analyzer). Both AMM and PAN were combined to determine YAN.

Soil compaction and composition

Six soil samples, each 1.25" in diameter and six inches in depth were taken at the end of the growing season from row middles in each experimental unit. Samples were pooled for each experimental unit and tested for organic matter content, pH, and nutrients at the Cornell Nutrient Analysis Laboratory. Organic matter content was determined through mass loss on ignition at 500 C. The pH was determined using the Cornell pH test while micro- and macro-nutrients are determined using modified Mehlich or Morgan Extractions.

Soil compaction was determined by taking readings using a penetrometer (Agratronix Soil Compaction Tester, Streetsboro, OH) using the ½” tip. Twenty readings were taken per experimental unit: ten directly in the center of the row middles and ten 32” from the center of the vines to where the tractor tire would pass.

Statistical analysis

A linear fixed effects model was used to analyze the data accounting for the random effects of vine spacing and root system.

Observational trial

An unreplicated observational trial was undertaken in Lansing, NY in the summer of 2020 to determine if sheep could be used to remove leaves from the fruit zone without damaging clusters or shoots in vertically shoot positioned (VSP) vineyards. The observational trial consisted of three plots of roughly 0.3 acres each as described in Table 1.

All plot row middles were mowed once prior to the introduction of sheep with no steps taken to control vegetation under vine. Each plot was fenced using electonet fencing with water provided alongside daily checks. Each vine row had side bird netting installed and rolled up on the top catch wire. Prior to the introduction of sheep to the vineyards, the bird nets on some rows were unrolled and brought down to just above the fruiting zone on both sides of the vines and secured together with zip ties periodically along the row ensuring no large gaps in the netting from below so that the canopy above the fruit zone was protected with the netting. Other vines were left without netting to act as a control. Thirty-one sheep were introduced into plot 1 on 3 July 2020 and moved 9 July 2020 to plot 2. On 15 July 2020, the sheep were removed. On 24 August 2020, five sheep were introduced into plot 3 and removed 14 September 2020.

Economic analysis

An economic model was developed for multiple management strategies of hosting sheep in 1)a high trained interspecific hybrid vineyard and 2)a vertically shoot positioned vinifera vineyard. The approximate cost of hosting sheep was determined by working with shepherds who currently rent out sheep to solar sites for grazing and from Kochendoerfer et al. (2018). This cost included sheep, nutrients, shelter, and the labor of checking the sheep and moving them. Fencing cost was determined on a square acre basis then divided by the average lifetime of the fence (seven years) to determine a yearly cost. This economic return per acre was compared to a traditional management structure that included mowing, suckering, and herbicide use. (Davis et al.,2019; Tang et al., 2013). Labor hours and cost were compared among models. Grape harvest values were obtained from our replicated field trial in Geneva with grape pricing from reports made by the Finger Lakes Regional Grape Program (Griffin, 2019; 2020).

Results and discussion

Survey study

Vineyards

Vineyard size of respondents ranged from 1 to 130 acres with an average size of approximately 27 acres (Table 2). These were categorized into small (<10 acres) medium (>10 acres and <20 acres) and large (>20 acres). Collectively, respondents farmed a total of 1116 acres. Four vineyards were located in Western New York /Northwest Pennsylvania, one in South Shore Lake Ontario, ten in the Finger Lakes region, four in the Hudson valley, one in Northern New York, eight on Long Island, two in Vermont, one in Maine, and one in Massachusetts (Table 2). With only two large vineyards responding from Western and Northern New York, we can be certain that the majority of our respondents produce grapes for wine rather than juice. Cabernet Franc was the most planted grape cultivar amongst respondents with 13 vineyards having some planted followed closely by Chardonnay in vineyards. Concord was the most planted cultivar with 403 acres although only five vineyards reported plantings. Nineteen out of 29 respondents reported using 75-100% of their grapes to make wine on premise.

Vineyard Management

Out of 15 respondents, two indicated they followed organic practices but did not have certification. Four were part of Long Island Sustainable Winegrowers and one was certified organic/biodynamic. Fifty percent of vineyards reported using herbicides to manage under vine vegetation, 33% used mechanical methods such as cultivation, 7% planted cover crops, and 10% performed no management practices allowing natural vegetation (i.e., weeds) to grow. Labor to sucker vines was difficult to find for 13 out of 28 vineyards and easy to find for nine vineyards. Four vineyards either did not sucker or did not use hand labor to sucker their vines.

Most vineyards (61%) reported grape quality to be the most important factor in their vineyards' success, with 19% reporting grape yield, followed by profit (13%), ease of management (6.5%), and public perception (0%). Seventy seven percent of vineyards reported an above average risk tolerance for adopting new practices, again suggesting that the respondents may have skewed towards growers with a particular interest in the integration of sheep into vineyards or a specific interest in adopting new practices. Ten percent reported an average risk tolerance while 13% reported to have a below average risk tolerance towards adoption of new practices.

Sheep Integration

Of 30 respondents, 12 stated that they had minimal experience managing livestock, seven moderate experience, one significant experience, and three extensive experience. Seven respondents had no experience with managing livestock. Eighty three percent of respondents had heard of others integrating sheep into their vineyard management regime. Of those, 61% were for early season mowing, 43% for season-long mowing, 38% to sucker vines, 28% for winter mowing, and 19% for leaf removal.

Twenty eight percent of vineyards indicated that they would likely integrate sheep to sucker vines at the beginning of the season, 64% to mow vineyards at the beginning of the season, 34% to mow vineyards over winter, 41% to mow vineyards year-round, and 34% to leaf pluck through the fruit zone. When asked to rank factors in terms of importance when considering adopting sheep into their vineyards, 39% ranked ease of management as their number one concern. Grape quality was ranked first by 30% followed by public perception at 17%, with grape yield, and profit both listed as the primary concern by 4% of respondents.

Respondents were asked if they thought integrating sheep into their management practices would be beneficial, have no effect, or be harmful in various categories. In response, 77% thought they would experience a beneficial change in herbicide use, 66% thought there would be a beneficial change in their use of nitrogen, and 50% thought there would be beneficial change in other inputs with 13% predicting a negative change. Eighty five percent of respondents predicted a positive change to mowing in their vineyard, 17% to frost protection with 4% predicting harm in frost protection. Seventy eight percent of respondents perceived benefit in fuel use from hosting sheep and 4% perceived harm. Sheep were perceived to benefit yield by 32% of respondents while 28% predicted a reduction in yield with sheep integration. Thirty five percent predicted a benefit to the quality of grapes with 19% viewing sheep as harmful to grape quality. The change that sheep could bring the marketing of a vineyard was viewed by 63% of respondents as beneficial.

Open ended questions

Participants were asked about their perceived benefits of incorporating sheep grazing into their vineyards. These responses were categorized into environmental, economic, and public perception with some responses counting twice in separate categories. Fifty five percent of those that perceived benefit in hosting sheep predicted an environmental benefit and 77% thought that sheep would convey economic benefit. Sixteen percent predicted a benefit to public perception which contradicts findings in the earlier multiple-choice question where 63% of respondents thought sheep would benefit their public perception.

Participant responses were grouped into four categories (cost, management complexity, damage to vines/yield, animal health) when asked about their concerns relating to hosting sheep in their vineyard. Some answers were recorded in multiple groups. Thirty five percent of respondents who had concerns about hosting sheep were worried about cost. Forty two percent, 58%, and 32% were worried about management complexity, damage to vines/yield, and animal health, respectively.

Correlations

Table 3 and Table 4 report correlations between multiple factors and their effect on willingness to incorporate sheep into a vineyard. Only two of these were found to have statistically significant correlations. Those with knowledge of others adopting sheep into vineyards were more likely to incorporate sheep in their management practices to mow at the start of the season ($p=0.047$). Those without reported organic certifications were more likely to incorporate sheep for early season mowing in their vineyards ($p=0.022$).

Replicated field trial

Plant vegetative growth

In both years, sheep grazed the vines to an average height of 45 inches removing all vegetation below this height including trunk suckers. Trunks were evaluated on 17 July 2019 and 21 July 2020 for discernible damage that could lead to infections or girdling but none was noted. Grazing height was dependent on the height of the sheep and would vary with other breeds. No evidence was found for sheep consuming grapes, and often grazing would occur around clusters leaving them exposed (Fig 2).

Indiscriminate consumption of suckers by the sheep may be problematic for vineyards that maintain a single sucker through the season for trunk renewal; growers wishing to maintain a sucker would need to provide protection for it such as a tree guard.

Cumulatively, pruning weights were reduced by 48% in plots grazed by sheep than those that were conventionally managed (Table 5). This decrease in weight is attributed to the consumption of green shoot growth within reach of the sheep.

Vine yield

Grazed plots in 2019 had 35% less yield per panel than the ungrazed control treatment. In 2020 yield in the grazed plots was reduced by 34% per panel, but the difference between the two treatments was not statistically different from zero. Average cluster weights and number of clusters per vine also trended lower in grazed plots with insignificant statistical differences of 14% and 21%, respectively (Table 5). Average berry weight was 6% lower in grazed plots in 2020. The noted reductions in cluster and berry weights were expected due to the reduction of leaf area. The reduction in cluster number per panel in the second year of the study can likely be explained by the same reduction in leaf area leading to lower carbohydrate availability; however, reduced leaf area cannot explain the sizeable but not statistically significant reduction in cluster numbers (157.5 in control, 132.5 in grazed) in the first year of the experiment since clusters are formed in the previous growing season. Uncovering the cause of the yield reduction and finding a system that will prohibit it is the key to unlocking the economic potential of sheep in vineyards.

Grape chemistry

PH, Brix, YAN and TA did not differ between treatment and control. AMM displayed a non-significant trend with a reduction of 47% in the grazed compared to control plots. PAN was reduced by 18% in grazed plots when compared to control (Table 6), likely due to the reduction in leaf area.

Ground vegetation

Under-vine vegetation along with vegetative row middles were effectively mown by the sheep during the duration of their residence in the vineyard. The length of time sheep spent in an area determined what they would eat starting with new green growth moving to older lignified grasses as preferential forage became scarce. Thistle proved an exception to the rule never being touched by sheep. Sheep grazing resulted in two fewer mechanical mowing passes during the season.

Soil compaction and composition

No differences were found between the grazed and control plots in soil chemistry (data not shown). Organic matter would be expected to be higher in treatment plots if the grazing continued for several more years. Aluminum, calcium copper, pH, and iron were all within the acceptable range found in Wine Grape Production Guide for Eastern North America (Wolf, 2008). Iron, potassium, magnesium molybdenum, and phosphorus were all lower than recommended. No difference was noted in the soil compaction between treatments; however, given further years of grazing, there would be an expected reduction in compaction in the tire track area due to reduced mechanical mowing passes.

Observational Trial

Plant vegetative growth

Bird nets successfully inhibited the grazing height of sheep on vines when secured tightly at the bottom (Fig. 3). However, if tie points were loose or far apart, sheep were able to reach inside the nets to graze above the desired level. Using shorter sheep (for example, baby dolls) would reduce the risk of excessive grazing above the cluster zone. Grazing occurred around the clusters removing vegetative growth without any damage. All vegetative suckers were removed without damage to the trunk. The effective suckering of trunks is problematic as keeping renewal suckers is a common practice in wine grape vineyards in the Northeastern U.S., particularly for V. *vinifera.*

Ground vegetation

Sheep mowed most vegetation in row middles and vegetation that emerged in the unsprayed undervine area. The length of time sheep spent in an area determined what they would eat starting with new green growth moving to older lignified grasses as preferential forage became scarce. Thistle proved an exception to the rule never being touched by sheep.

Economic analysis

Production costs of introducing sheep for the growing season in a hybrid vineyard were 6% ($105.04 per acre) higher than management with herbicides and 13% higher than management with undervine vegetation (the control in this experiment) (Table 7). The main cost savings from conventional to grazed were from the reduction in chemical weed controls at $128 although this savings is also captured through allowing undervine vegetation to grow. Early season mowing, which had the highest level of interest in the survey, cost 7% more than conventional, and post-harvest mowing cost 9% more (Table 7). Sheep provided no management cost savings in these practices aside from a single mowing less from early season grazing. The cost increase in these practices come from the hiring of sheep and maintaining and moving fencing. Other economic benefits that we lack data on may be present such as a reduction in fertilizer applications or an increased price per ton growers could receive. A price increase on grapes produced with sheep is not unreasonable as a 2012 paper found that consumers were willing to pay 13% to 14% more per bottle if they were made using “environmentally friendly practices” (Schmit et al., 2013). If yield were not reduced through grazing during the growing season a price of only $708 ($48 more) per ton rather than the average of $660 would be needed to account for the increased cost of introducing sheep through the growing season, a 7% premium (Table 8).

Net income was markedly lower in grazed hybrid plots with losses of $474 and $342 in 2019 and 2020 due to the reduction in yield in the grazed plots. To net the same revenue from a grazed acre of Noiret compared to a plot with no undervine management, grapes would have to sell for $1142 ($482 more) and $1062 ($402 more) per ton for 2019 and 2020 respectively (Table 8) compared to the average of $660 reported by the Finger Lakes Grape Program (Griffin, 2019; 2020).

For vertically shoot positioned vinifera vineyards introducing sheep for grazing, pre-bud break and post-harvest were 5% and 6% more expensive respectively than traditional management due to the cost of rental and fencing while providing no management cost savings aside from a pre-budbreak mowing (Table 9). Grazing sheep during the growing season was only 2% more costly than conventional management providing expected savings in weed control, suckering, and leaf removal. Introducing sheep for a short time for leaf removal around the fruiting zone proved to be the most effective with respect to cost at 3% less than traditional management despite the extra time spent moving bird nets to protect the vegetation above the fruit zone. This practice provided the same cost savings as grazing for the entire season aside from a single mowing, but with the shorter time of sheep grazing in the vineyard proved far more cost effective (Table 9).

Discussion

Of all the proposed methods of incorporating sheep into vineyards, most interest seems to be in sheep integration for vineyard floor mowing at the start of the season. Sixty four percent of respondents stated they would be willing to incorporate sheep into their vineyard for this purpose. Unfortunately, this practice has a 21% higher management cost than conventional due to the price of renting sheep and fencing. The second highest amount of interest was in trunk suckering at the start of the growing season with 41% of respondents indicating an interest in adopting the practice. From this result, it seems that growers are concerned about the presence of sheep in their vineyard concurrently with fruiting vines.

Fortunately, sheep will not eat grapes until after version when sugar starts to accumulate. Before then sheep will eat vegetation around the cluster without eating the grapes themselves (Fig 3). However, in our research with Noiret we witnessed a significant decrease in yield resulting in a net loss per acre in revenue, although since the most significant decrease was in cluster number and occurred in the first year of the study (before the noted decrease in vine vegetation due to sheep consumption could impact cluster number), it's unclear whether the yield decrease is wholly attributable to the sheep grazing treatments since sheep consumption of clusters was not observed, nor was sheep removal of whole shoots (the bearing unit for clusters). Unfortunately, most of the cost saving functions performed by sheep in vineyards such as mowing and leaf removal occur during the growing season. To create a system that growers will want to adopt and will be economically beneficial, further research into the impacts of sheep grazing on grapevine yield must be undertaken.

Prior knowledge of other growers incorporating sheep heavily influenced growers' willingness to adopt a practice. Of the 22 respondents who had knowledge of others incorporating sheep into their vineyard, 16 were willing to do the same. Encouraging grape growers to consider integrated production practices will require education on the topic, as 32% of respondents worried about sheep health and/or the cleanliness of having sheep in a vineyard. However, proposed management practices involve removing sheep prior to spraying and holding them out of the vineyards longer than recommended reentry times for their health. Wine grapes are currently exempt from the FDAs Final Rule on Produce Safety as wine making is consider a kill step for bacteria.

We found the economically most successful management practice of grazing sheep to be a short period in tandem with lowered bird nets to remove leaves around the fruiting zone, but this practice was one of the least likely to be considered for adoption by growers. Either from not having heard of others implementing this practice or fear of reduced yield, it makes clear that cooperation with growers to demonstrate effectiveness as well as further outreach to elucidate benefits is integral to the adoption of this practice.

Most concerns reported by respondents were around the risk to vines, reduction of yield, and cost of integrating sheep into vineyards. The loss of renewal suckers is a legitimate concern due to indiscriminate grazing of the sheep, as well as the reduced yield noted in unprotected full season grazing. Over grazing in unprotected vertically shoot positioned vines is also a potential problem if bird nets are not securely tied to protect the upper canopy as sheep will consume all leaf area they can reach. Overgrazing in vertically shoot positioned vineyards is a solvable problem with the help of physical hindrances to sheep grazing as we proved in our observational study which also proved to be less expensive than mechanical leaf removal. However, further research is needed to develop integrated vineyard-sheep systems that are economical and overcome these challenges.

Overall, survey responses on willingness to adopt sheep in the vineyard were mixed among growers. Only 64% would be willing to introduce sheep for grazing early in the season with other proposed practices having much lower interest. Conversely, over 70% thought their vineyards could benefit from sheep to reduce their herbicide use and fuel use while more than 60% thought the nitrogen status of the vines would benefit. As unmanaged undervine vegetation can be adopted into mature vineyards without a significant reduction in vine size or yield, sheep do indeed provide a significant savings on herbicides. Fewer mowings along with fewer sprays and no mechanical leaf removal provide the savings in fuel. Longer trials of grazing are needed to see the effects on vine nitrogen status.

Further experimentation is needed on different management strategies to find one that would work well with growers. Incorporating sheep for shorter grazing periods in combination with physical hindrances to the sheep’s grazing could be a way to accomplish mowing and leaf plucking while overcoming growers concerns about managing sheep for long periods, damage to their vines, and harm to the sheep from pesticide sprays. More education is also needed to explain the benefits and challenges of sheep grazing to quell unwarranted worries and improving awareness.

Row <- North

Plot 1	1	1-2 own	3-4-5 grafted	6-7-8 grafted	9-10-11 grafted	12-13-14 grafted	15-16-17 grafted	18-19-20 grafted	21-22-23 grafted	24-25-26 grafted	27-28 own	Grazed
	2	1 own	2-3 grafted	4-5 grafted	6-7 own	8-9 own	10-11-12 grafted	13-14-15 grafted	16-17-18 own	19-20-21 own	22-23 own	
	3	1-2 own	3-4-5 grafted	6-7-8 grafted	9-10 own	11-12 own	13-14-15 own	16-17-18 own	19-20 grafted	21-22 grafted	23 own	
	4	1 own	2-3 grafted	4-5 grafted	6-7-8 own	9-10-11 own	12-13 grafted	14-15-16 grafted	17-18 own	19-20 own	21 own	
Plot 2	5	1-2 own	3-4-5 own	6-7-8 own	9-10-11 grafted	12-13-14 grafted	15-16 grafted	17-18 grafted	19-20 own	21-22 own	23 own	Control
Plot 3	6	1-2 own	2-4-5 grafted	6-7-8 grafted	9-10 own	11-12 own	13-14 grafted	15-16 grafted	17-18-19 own	20-21-22 own	23-24 own	Grazed
	7	1 own	2-3 own	4-5 own	6-7-8 grafted	9-10-11 grafted	12-13-14 own	15-16-17 own	18-19 grafted	20-21 grafted	22 own	
	8	1 own	2-3 grafted	4-5 grafted	6-7-8 own	9-10-11 own	12-13-14 grafted	15-16-17 grafted	18-19 own	20-21 own	22 own	
	9	1 own	2-4 grafted	4-6 grafted	6-7-9 own	9-10-12 own	12-13-15 grafted	15-16-18 grafted	18-20 own	20-22 own	23 own	
Plot 4	10	1-2 own	3-4-5 grafted	6-7-8 grafted	9-10 grafted	11-12 grafted	13-14-15 own	16-17-18 own	19-20 own	21-22 own	23 own	Control
	11	1 own	2-3 own	4-5 own	6-7 grafted	8-9 grafted	10-11-12 grafted	13-14-15 grafted	16-17-18 own	19-20-21 own	22-23 own	
	12	1-2 own	3-4-5 grafted	6-7-8 grafted	9-10-11 grafted	12-13-14 grafted	15-16 grafted	17-18-19 grafted	20-21-22 grafted	23-24-25 grafted	26-27 own	

Fig 1. Geneva vineyard where sheep trials were conducted in 2019 and 2020. Each cell represents a panel and each number inside a cell a vine. Grapes were either grafted or own rooted with two or three vines per panel based on vine spacing. The vineyard is divided into four experimental units with two grazed trials and two controls. Gray boxes represent panels that were sampled throughout the study.

Fig 2. Grazed(A) and control (B) experimental units of high trained Noiret.

Fig 3. Riesling grapes with bird nets secured just above the fruiting zone. Pre introduction of sheep (A) post leaf removal and grazing (B and C).

Table 1. Characteristics of the three plots used in observational trial to study the use of sheep to perform fruit zone leaf removal.

Plot #	Cultivar	Vine training	Vines per row	Number of rows	Soil	Slope	Days grazed	Number of sheep
1	Riesling	Pendelbogen, converted to spur pruned	140	3	Ovid silt loam	0-6%	23	5
2	Cabernet Franc	Low cordon, Spur pruned	24	8	Hudson-Cayuga silt loams	12-20%	6	31
3	Cabernet Franc	Low cordon, Spur pruned	24	9	Hudson-Cayuga silt loams	12-20%	6	31

Table 2- Number of respondents from each area in the survey and the size of their vineyard.

Size of vineyard	Finger Lakes (n=9)	Long Island (n=7)	Northern New York (n=2)	Western New York (n=3)	Hudson Valley (n=4)	Massachusetts (n=1)	Main (n=1)	Vermont (n=2)
Small[z] (n=10)	1	1	1	0	4	0	1	2
Medium (n=3)	0	1	1	1	0	0	0	0
Large (n=14)	7	5	0	2	0	1	0	0

[z] Small (<10 acres) medium (>10 acres <20 acres) and large (<20 acres)

Table 3- Number of respondents who reported to meet the criterial in the left-hand column who are likely to incorporate the sheep management practice listed at the top of the column.

	Sucker vines at beginning of season	Mow vineyard floor at beginning of season	Mow vineyard floor over winter	Mow vineyard floor all year long	Leaf removal on Vines
Over 50% of grapes turned into wine on premise (n=17)	7 (p=1.00) [z]	12 (p=0.67)	8 (p=0.39)	8 (p=0.68)	8 (p=0.09)
Small vineyard[y] (n=10)	4 (p=0.35)	5 (p=0.19)	2 (p=0.16)	4 (p=0.35)	3 (p=0.28)
Medium Vineyard (n=3)	0 (p=0.35)	1 (p=0.19)	0 (p=0.16)	0 (p=0.35)	0 (p=0.28)
Large Vineyard (n=14)	7 (p=0.35)	11 (p=0.19)	7 (p=0.16)	7 (p=0.35)	7 (p=0.28)
Mechanical destruction of undervine (n=10)	4 (p=0.15)	8 (p=0.14)	4 (p=0.52)	4 (p=0.68)	3 (p=0.63)
Chemical destruction of undervine (n=14)	5 (p=0.15)	6 (p=0.14)	4 (p=0.52)	4 (p=0.68)	5 (p=0.63)
Undervine allowed to grow (n=3)	3 (p=0.15)	3 (p=0.14)	2 (p=0.52)	2 (p=0.68)	2 (p=0.63)
Cover Crops planted Under vine (n=2)	3 (p=0.15)	1 (p=0.14)	0 (p=0.52)	1 (p=0.68)	0 (p=0.63)
Organic Certification (n=6)	1 (p=0.35)	1 (p=0.02)	2 (p=1.00)	1 (p=0.35)	2 (p=1.00)
Difficulty finding labor to sucker vines (n=12)	5 (p=1.00)	9 (p=1.00)	4 (p=0.65)	5 (p=1.00)	3 (p=0.36)
Above average risk tolerance (n=20)	7 (p=0.37)	12 (p=0.18)	9 (p=0.29)	8 (p=1.00)	7 (p=1.00)
Knowledge of others using sheep in vineyards (n=22)	11 (p=0.06)	16 (p=0.05)	10 (p=0.12)	9 (p=1.00)	9 (p=0.14)

[z] *P*-values represent the strength of correlation between the metric on the left and the management practice above. The lower the P value the stronger a metric affected vineyards willingness to adopt a management practice.

Table 4- Number of respondents who reported to meet the criterial in the left-hand column who are likely to incorporate the sheep management practice listed at the top of the column.

	Sucker vines at beginning of season	Mow vineyard floor at beginning of season	Mow vineyard floor over winter	Mow vineyard floor all year long	Leaf removal on Vines
Most important factor for winery success					
Ease of management (n=3)	0 (*p*=0.50)	1 (*p*=0.76)	1 (*p*=0.19)	1 (*p*=0.76)	0 (*p*=0.43)
Grape quality (n=17)	8 (*p*=0.50)	11 (*p*=0.76)	7 (*p*=0.19)	8 (*p*=0.76)	8 (*p*=0.43)
Profit (n=3)	2 (*p*=0.50)	2 (*p*=0.76)	2 (*p*=0.19)	1 (*p*=0.76)	1 (*p*=0.43)
Grape yield (n=5)	2 (*p*=0.50)	4 (*p*=0.76)	0 (*p*=0.19)	1 (*p*=0.76)	1 (*p*=0.43)

Table 5. Harvest data of Noiret grapevines either grazed with sheep or conventionally managed from 2019 and 2020 in Geneva, NY. Values are means of two repetitions per treatment.

	Pruning weight (kg/vine)			Average cluster weight (kg cluster)		
Treatment	2019	2020	2-year mean	2019	2020	2-year mean
Control	2.5±0.51	2.4±.046	2.7±0.42	157.5±29.54	135.3±26.14	147.1±23.13
Grazed	1.3±0.62	1.3±0.52	1.4±0.51	132.5±17.30	119.5±16.40	126.4±14.18
P value	0.2278	0.0873	0.0418	0.2020	0.3760	0.1982
	Yield (kg/panel)			Cluster number/vine		
Treatment	2019	2020	2-year mean	2019	2020	2-year mean
Control	21.3±2.15	21.3±4.32	21.3±2.22	186.9±22.35	179.4±23.33	180.4±14.18
Grazed	13.7±2.15	14.0±5.24	14.2±2.38	138.6±23.10	135.7±27.44	142.6±15.41
P value	0.0013	0.2126	0.0615	0.1400	0.1642	0.1338

Table 6. Fruit composition of Noiret grapevines either grazed with sheep or conventionally managed from 2019 and 2020 in Geneva, NY. Values are means of two repetitions per treatment.

	pH			Soluble solids (°Brix)		
Treatment	2019	2020	2-year mean	2019	2020	2-year mean
Control	2.97±0.041	3.25±0.038	3.11±0.035	19.3±0.41	20.0±0.45	19.6±0.40
Grazed	2.95±0.035	3.24±0.044	3.09±0.035	19.2±0.52	19.9±0.59	19.6±0.53
P value	0.5883	0.4420	0.5280	0.8867	0.9117	0.9972
	Titratable acidity (g/L)			YAN (mg/L)		
Treatment	2019	2020	2-year mean	2019	2020	2-year mean
Control	9.6±0.61	7.2±0.29	8.4±0.37	183.2±17.6	177.8±25.54	185.4±18.79
Grazed	9.4±0.81	7.0±0.35	8.3±0.46	121.2±19.93	156.0±27.98	140.2±20.89
P value	0.6709	0.5921	0.8787	0.0891	0.5173	0.1738
	AMM (mg/L)			PAN (mg/L)		
Treatment	2019	2020	2-year mean	2019	2020	2-year mean
Control	51.9±15.46	32.5±6.86	40.5±9.95	143.2±13.65	151.3±21.08	147.2±12.70
Grazed	32.0±19.22	11.4±6.97	21.4±12.43	95.0±13.77	146.8±22.06	120.9±12.70
P value	0.4124	0.0278	0.2645	0.0728	0.8564	0.0424

Table 7- Cost analysis ($/acre) for high trained hybrid management systems with and without sheep grazing. Costs were calculated and found in Davis et al., 2019. Both Labor and material is included in cost where applicable.

Static Cost	Conventional	Conventional cover crop	Early season grazing	Post-harvest grazing	Graze throughout growing season
Costs that are constant across management systems					
Pruning +bush Pulling	311	311	311	311	311
Brush chopping	45	45	45	45	45
Trellis maintenance	127	127	127	127	127
Tying renewal	162	162	162	162	162
Vine replacement	63	63	63	63	63
Take away (de-hilling)	105	105	105	105	105
Bird control	60	60	60	60	60
Spray 1	39	39	39	39	39
Spray 2	41.	41	41	41	41
Spray 3	43	43	43	43	43
Spray 4	43	43	43	43	43
Spray 5	67	67	67	67	67
Spray 6	67	67	67	67	67
Lime (1 in 5 years)	16	16	16	16	16
Pickup truck [z]	75	75	75	75	75
Petiole sampling [y]	3	3	3	3	3
Soil sampling [w]	5	5	5	5	5
Hilling- up	61	61	61	61	61
Fall fertilization	49	49	49	49	49
Crop insurance	109	109	109	109	109
Total cost, constant	1491	1491	1491	1491	1491
Costs that differ by management system					
Chem. weed control	94	-	94	94	-
Spot herbicide treatment	34	-	34	34	-
Suckering	54	54	54	54	-
Mowing	94	94	70	70	47
Sheep rental 10 weeks [x]	-	-	20	60	200
Sheep fencing [v]	-	-	130	130	130
Total cost, differ	276	148	402	442	377
Total Cost	1,767	1,639	1,893	1,933	1,868
% Differential costs of total costs	16%	9%	21%	23%	20%
% Change in total cost from conventional	-	-7%	7%	9%	6%

[z] 10,000 miles for 50 ac/year
[y] $88 for every 2 years
[w] Every 5 years
[x] Annualized 7-year useful life.
[v] Rental cost were calculated using numbers from Kochendoerfer et al., 2018 and duration of grazing.

Table 8 – Economic breakdown of harvested Noiret grapes in Geneva NY over 2019 and 2020 including yield, revenue, and income. Price premium is the cost per ton so that the net income per acre is equivalent to Noiret with undervine management with given yields.

Parameter	Noiret Conventional	Noiret undervine vegetation	Noiret Grazed
Total Cost	$2,161.41	$2,011.45	$2,216.49
Yield 2019 (per acre)	4.26 Tons**	4.26 Tons	2.64 Tons
Yield 2020 (per acre)	4.26 Tons**	4.26 Tons	2.84 Tons
Market Price (per ton) *	$660	$660	$660
Revenue 2019	$2811.60	$2811.60	$1742.4
Revenue 2020	$2811.60	$2811.60	$1874.4
Net Income 2019	$650.19	$800.15	$-474.09
Net Income 2020	$650.19	$800.15	$-342.09
Price premium 2019	$695.20	-	$1142.67
Price premium 2020	$695.20	-	$1062.20
Price premium (Yield = 4.26 tons/acre)	$695.20	-	$708.13

*Market price is the average price paid per ton of Noiret Grapes in 2019 and 2020 as reported by the Finger Lakes Regional Grape Program.

**Assumed yield would be the same for Noiret grapes with undervine vegetation and conventional management based on Karl et al., 2016.

Table 9- Cost analysis ($/acre) for low trained Vinifera management systems with and without sheep grazing. Costs were calculated and found in Davis et al., 2019. Both Labor and material is included in cost where applicable.

Static Cost	Conventional	Conventional Undervine vegetation	Midseason grazing for leaf removal	Early season grazing	Post-harvest grazing	Graze throughout growing season
Costs that are constant across management systems						
Pruning, bush pulling	452	452	452	452	452	452
Brush chopping	49	49	49	49	49	49
Trellis maintenance	137	137	137	137	137	137
Tying renewal	230	230	230	230	230	230
Vine replacement	158	158	158	158	158	158
Cluster removal	70	70	70	70	70	70
Shoot thinning	105	105	105	105	105	105
Take away (de-hilling)	117	117	117	117	117	117
Bird control	69	69	69	69	69	69
Spray 1	42	42	42	42	42	42
Spray 2	42	42	42	42	42	42
Spray 3	45	45	45	45	45	45
Spray 4	82	82	82	82	82	82
Spray 5	30	30	30	30	30	30
Spray 6	62	62	62	62	62	62
Spray 7	77	77	77	77	77	77
Spray 8	122	122	122	122	122	122
Spray 9	87	87	87	87	87	87
Spray 10	73	73	73	73	73	73
Spray 11	67	67	67	67	67	67
Lime (1 in 5 years)	17	17	17	17	17	17
Truck usage [z]	71	71	71	71	71	71
1st shoot positioning [y]	105	105	105	105	105	105
2nd shoot positioning [y]	105	105	105	105	105	105
Summer pruning (2X)	110	110	110	110	110	110
Petiole sampling [x]	6	6	6	6	6	6
Soil sampling [w]	3	3	3	3	3	3
Hilling up	68	68	68	68	68	68
Fall fertilization	39	39	39	39	39	39
Crop insurance	109	109	109	109	109	109
Total costs, constant	2749	2749	2749	2749	2749	2749

Static Cost	Conventional	Conventional Undervine vegetation	Midseason grazing for leaf removal	Early season grazing	Post-harvest grazing	Graze throughout growing season
Costs that differ by management system						
Chemical weed control	117	-	-	117	117	-
Spot herbicide	28	-	-	28	28	-
Mowing	97	97	73	73	73	49
Suckering	70	70	-	70	70	-
Mech. leaf removal	116	116	-	116	116	-
Moving nets for sheep	-	-	69	-	-	69
Sheep fencing [v]	-	-	170	170	170	170
Sheep rental [u]	-	-	20	20	60	200
Total costs, differ	428	283	332	594	634	488
Total cost	3,177	3,032	3,081	3,343	3,383	3,237
% differential costs of total costs	13%	9%	11%	18%	19%	15%
% change in total costs from conventional	-	-5%	-3%	5%	6%	2%

[z] 10,000 miles for 50 ac/year

[y] Shoot positioning includes moving catch wires.

[x] $88 for every 2 years

[w] Every 5 years

[v] Annualized 7-year useful life.

[u] Rental cost were calculated using numbers from Kochendoerfer et al., 2018 and duration of grazing.

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