AgriScience Program - Cluster Component

Final Performance Report

This template covers the annual performance reporting for the final year of the activity and two additional questions to satisfy the final performance reporting requirements.

Section A: Annual Performance Reporting

This section is the same as previous Annual Reports completed to date, and is intended to capture only those results that were achieved during the final year of the activity.

Name of Recipient: Canadian Grapevine Certification Network	
Project Title: Fostering sustainable Growth of the Canadian Grape and Wine Sector	
Project Number: ASC-12	**Final Period Covered by the Report**: 2022/04/01 to 2023/03/31
Activity #: 8 **Name of Activity:** Canopy Management to Reduce Disease Pressure / Gestion de la canopée pour réduire la pression des maladies fongiques	**Principal Investigator:** Odile Carisse and Caroline Provost
Activity Start Date: 2018/04/01	**Activity End Date:** 2023/03/31

1. Activity Summary

Please provide a high-level summary of this activity that includes an introduction, objectives, methodology, deliverables, results and discussion. Technical language can be used in this section.

Plain language summary

As a first step, leaf removal in the cluster zone was evaluated for its effect on downy mildew, powdery mildew and botrytis bunch rot. The following five practices of leaf removal were: on 1) one side of the row at nouaison (BBCH 17); 2) two sides of the row at nouaison ; 3) one side of the row at veraison (BBCH 27); 4) two sides of the row at veraison; 5) no leaf removal (control). Microclimate and fungicide penetration were monitored within the cluster zone. The effect of leaf removal was evaluated based on disease progress and disease severity at harvest. Overall, lower disease severity was observed when leaves were removed on both sides of rows and when leaves were removed at nouaison. For most year and sites, significantly lower diseases severity was observed in plots where leaves were removed on both sides of rows at nouaison than in plots were leaves were not removed. No effect on airborne inoculum and within canopy temperature and relative humidity were observed. However, solar radiation and wind speed (aeration) were higher in the plots with leaf removal. The most important effect in terms of disease development was a decrease in the duration of leaf and berry wetness. Fungicide penetration was higher in plots were leaves were removed on both sides of rows.

As a second step, we studied the effect of leaf removal in the cluster zone on disease management. The following fungicide application schemes were evaluated: 1) a calendar-based scheme, with fungicides applied at predefined times; 2) a calendar-based scheme with leaf removal at fruit set on both sides of the rows; 3) a disease risk-based scheme with disease risks estimated according to the phenological stage (vine receptivity) and weather conditions in the vineyard; 4) a disease risk-based scheme with disease risks estimated as in treatment 3 with leaf removal at fruit set on both sides of the rows; 5) a disease risk-based scheme with disease risks estimated according to the phenological stage and weather conditions (microclimate) in the canopy (grape cluster zone) with leaf removal at fruit set on both sides of the rows; 6) a control without fungicide applications. In all the plots with leaf removal, leafing was repeated about 3-4 weeks after the first leaf removal done at fruit set in order to avoid the grapevine compensation. Disease severity at harvest was lower in all plots with leaf removal, however, less fungicide applications were needed in plots where fungicides were applied based on disease risk. However, it would have been possible to improve the positioning of fungicide applications if the risk of disease development had been based on the microclimate (shorter wetness period in leaf removal treatments). In other words it would have been possible to get more benefit from leaf removal.

As a third step, integration of leaf removal in integrated anthracnose management was studied. First, the effect of timing (stage 17 or 27) and intensity (one or two sides of rows) of leaf removal on the progression of anthracnose and the microclimate was studied. Overall, at both sites and in both years, anthracnose on leaves was more severe in plots without cluster zone leaf removal. Regardless of the time of leaf removal, severity of anthracnose on leaves and incidences of infected berries at harvest were significantly lower in plots where leaves were removed on both sides of the rows compared to one side only. Also, management programs with leaf removal combined or not with disease risk estimation were evaluated. All anthracnose management programs including leaf removal in the cluster zone reduced anthracnose development compared to the standard program without leaf removal. The overall mean leaf anthracnose severity, severity at harvest, and anthracnose incidence on cluster at harvest were significantly lower in plots with leaf removal than in the standard program, but not significantly between each other. More fungicide applications were made in the plots managed based on standard programs with 13 applications compare to plots managed based on using weather-risk of anthracnose with 9, and 10 application at site 1 and site

2 for the risk-based program, respectively and 5 and 7 at site 1 and site 2, respectively, when microclimate within the cluster zone was considered. The results of this study clearly showed the importance of leaf removal in the management of grape anthracnose.

In conclusion, leaf removal in the cluster zone as a method of controlling the main grapevine diseases alone has not made it possible to significantly reduce the development of diseases as well as yield losses in terms of both quantity and quality. However, when leafing was combined with tools for estimating disease risks, particularly when risks were estimated from weather conditions in the microclimate (cluster zone), this practice made it possible to significantly reduce the number of fungicide treatments while maintaining the yields. The results obtained tend to demonstrate the importance of integrated pest management and the effect of methods which alone do not provide acceptable control but which when combined make it possible to achieve an acceptable level of control while reducing the use synthetic fungicides.

A cost-benefit analysis vas conducted for anthracnose management since we have collected data on fungicide reduction in plots with and without leaf removal. In the plots without leaf removal a total of 11 fungicide applications were made at a total cost of $1543/ha (product and labor). In the plots with leaf removal but without consideration of microclimate change due to leaf removal, the total cost (product and labor) was $ 2018/ha and $ 1738/ha, for manual and mechanical leaf removal, respectively. In the plots with leaf removal and consideration of the microclimate the total cost (product and labor) was $1748/ha and $1468/ha, for manual and mechanical leaf removal, respectively. Therefore, if we consider only the benefits of leaf removal on anthracnose management, leaf removal is profitable. Other benefits of leaf removal include better management of several diseases, grape quality, potential reduction of fungicide treatments, and increased ecological services. However, leaf removal also has its share of disadvantages including sunburn and the demand for skilled labor.

Section 1 Introduction

The grapevine canopy includes all the above the ground parts; such as leaves, fruit, primary and secondary (lateral) shoot stems, and tendrils (Fig. 1). Managing the canopy is a labor intensive process requiring a range of practices such as winter pruning, shoot and cluster thinning, shoot positioning, hedging, and cluster-zone leaf removal. The density of the grapevine canopy influences the microclimate; a dense canopy favors low light levels, less air circulation which favors prolonged wet periods and low fungicide penetration. It therefore seems logical to include canopy management in disease control programs. For large and dense vine canopies with shaded clusters, canopy management practices are recommended. Although many studies have demonstrated the positive and sometimes negative effects of leaf removal (see references list), the real value of this practice in northern production conditions remains to be demonstrated.

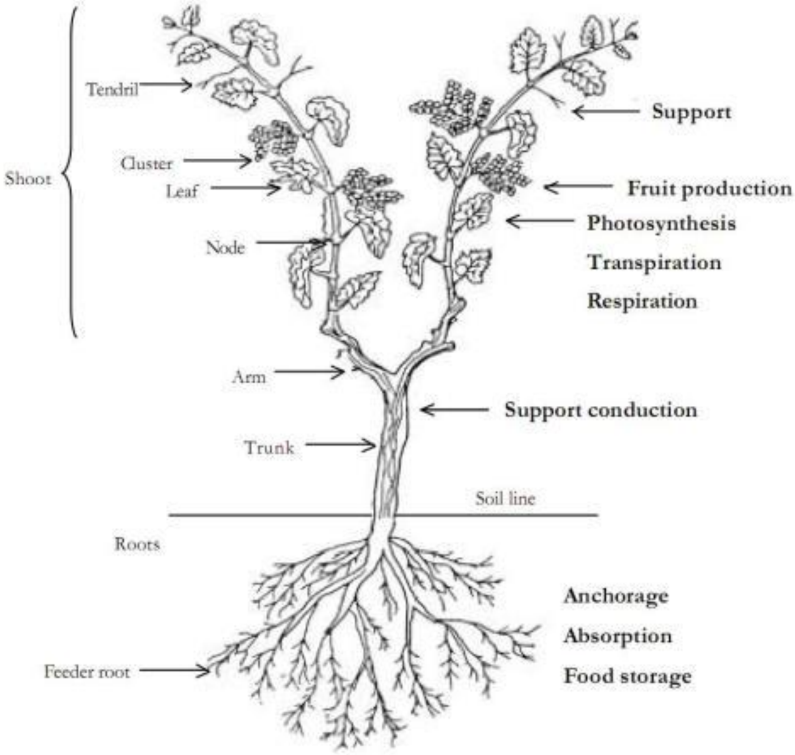

Figure 1. Schematic description of the grapevine

This project focused mostly on the effect of cluster zone leaf removal (hereafter call leaf removal) on severity and progress of the main grapevine diseases present in Eastern Canada.

Leaf removal consists of removing all or almost all leaves from the fruit-bearing zone. Originally used just before harvest to improve yield and to facilitate harvest, leaf removal has a direct influence on the quality of the grapes (berries) and consequently on the vine to be produced. Leaf removal improves the quality of grapes at harvest, by promoting the aeration of the bunches and the penetration of fungicides used to manage fungal diseases such as *Botrytis cinerea* (Botrytis bunch rot), *Erysiphe necator* (powdery mildew), *Plasmopara viticola* (downy mildew), and *Elsinoe ampelina* (anthracnose). Leaf removal improves the synthesis of polyphenols (tannins, anthocyanins) on red grapes and the stability of the polyphenolic potential during the aging of red wines, increases the fruity notes and decreases the vegetal aromas (pyrazine). However, leaf removal must be reasoned according to the result that one wishes to obtain: limitation of diseases, gain in polyphenols, quality of the wines.

Leaf removal in grapevines is typically performed between fruit set and bunch closure to create an aerated microclimate unfavorable to fungal diseases (Zoecklein et al. 1992; Percival et al. 1994; Maigre 2004; Sternad Lemut et al. 2015). However, there is a growing interest in the effect of leaf removal before fruit set. Practiced as early as at the phenological stage 57 (BBCH scale), pre-flowering leaf removal would have additional advantages. In particular, it would limit yields (Poni et al. 2006; Palliotti et al. 2012; Basile et al. 2015) and would lead to significant changes in berries, both in terms of structure (film thickness, juice-to-skin ratio) and composition (sugar-acid balance, polyphenol accumulation) (Dokoozlian and Kliewer 1996; Palliotti et al. 2012; Risco et al. 2014; Suklje et al. 2014; Komm and Moyer 2015; Verdenal et al. 2017). However, the consequences of this operation depend on many factors such as the grapevine variety, soil and climatic conditions, timing and the intensity of leaf removal (Verdenal et al. 2017), and could affect vine vigor under certain conditions (Risco et al. 2014; Uriarte et al. 2012).

Although several studies have been conducted in Europe, in the United States, Australia, and in Western Canada, few studies have been conducted in Eastern Canada, thus under northern viticulture conditions. In a context where it becomes essential to reduce the dependence of viticulture on pesticides, leaf removal is a practice that deserves to be studied and possibly integrated into a less demanding control program in terms of fungicides.

Integrating leaf removal practices into a disease management program poses several challenges. Considering that the main effect of leaf removal is a reduction in the duration of leaf and berry wetness and therefore the risk of infection by fungal pathogens, leaf removal should be done early in the season when inflorescences and young berries are susceptible. However, early season leaf removal may cause excessive lateral shoot growth and therefore make a second leaf removal necessary, which will increase production costs. Also, to get the most out of leaf removal, the weather data used to estimate the risk of infection, namely temperature and tissue wetness, should be monitored within the canopy. Unfortunately, to a very large extent, the weather data used to estimate the risk of disease development come from regional stations, rarely from the vineyard and almost never from within the canopy. Another challenge involves predicting the wetting period and the temperature during wetting in order to apply fungicides as a preventive measure (before a predicted infection period) and thus avoid treating with curative fungicides, which are more costly and generally more prone to resistance development.

In northern viticulture, leaf removal is commonly used to improve microclimate conditions in excessively dense grapevine canopies and to enhance fruit ripening. The impact on disease development is often considered as an added benefit, leaf removal is rarely considered a control method. One factor that explains this is that the effectiveness of leaf removal varies depending on the cultivar and weather conditions. In very dry seasons caused by infrequent rainfall and in rainy seasons, leaf removal will be less effective. Nevertheless, leaf removal is a practice that brings many benefits especially for grapevine diseases management.

Section 2 Report summary for 2018-2023

Objective 1. Investigate the influence of canopy and fruit zone management practices on microclimate, fungicide penetration (efficiency of coverage), disease progress, pathogen populations and yield losses (damages).

Year 2019. Practices of fruit zone management were evaluated for their effect on disease management. The practices were leaf removal around the cluster zone on 1) one side of the row at nouaison; 2) two sides of the row at nouaison; 3) one side of the row at veraison; 4) two sides of the row at veraison; 5) no leaf removal (control). Microclimate (Temperature and relative humidity) was monitored within the fruit zone and fungicide penetration was measured with hydrosensitive paper. Downy mildew caused by *Plasmopara viticola*, powdery mildew caused by *Erysiphe necator,* were assessed weekly on leaves and at harvest on clusters, while and botrytis bunch rot caused by *Botrytis cinerea* was assessed only at harvest on clusters. Disease pressure (pathogen populations) was monitored using rotating-arms samples The number of airborne spores of *P. viticola*, *E. necator* and *B. cinerea* was determined using a previously developed qPCR assay (Carisse et al., 2014). Regardless of the treatment, the effect of fruit zone management practices was small but significant. For both timing of cluster zone leaf removal, nouaison and veraison, lower disease severity was observed when leaves were removed on both sides of rows. Overall, lowers disease severity was observed when leaves were removed at veraison as compare with nouaison. However, there was no significant difference in airborne inoculum. The difference in disease severity may be explained by lower humidity and better fungicide penetration in the canopy in sub-plots where leaves around the clusters were removed on both sides of rows at veraison.

Year 2020 and 2021. In 2019, the trial was carried out at the Agriculture and Agrifood Canada experimental farm located at Frelighsburg, in a plot planted with the grape variety Chancellor (*Vitis vinifera*). In order to broaden the scope of the study and to ensure the presence of the three main targeted diseases, in 2020, the trials were carried out in two commercial vineyards in plots planted with the grape cultivars Vidal blanc (hybrid varieties) and Seyval blanc (non-*viniferea* hybrids). Practices of leaf removal were evaluated for their effect on downy mildew in plots planted with Vidal blanc and on powdery mildew and Botrytis bunch rot in plots planted with Seyval blanc. At both sites and for both grape cultivars, the following five practices of leaf removal in the cluster zone were: on 1) one side of the row at nouaison; 2) two sides of the row at nouaison ; 3) one side of the row at veraison; 4) two sides of the row at veraison; 5) no leaf removal (control). Microclimate (temperature, relative humidity, leaf wetness, solar radiation) was monitored within the fruit zone and fungicide penetration was measured with hydrosensitive paper. Downy mildew caused by *Plasmopara viticola*, powdery mildew caused by *Erysiphe necator*, were assessed weekly on leaves and at harvest on clusters, while and botrytis bunch rot caused by *Botrytis cinerea* was assessed only at harvest on clusters. Disease pressure (pathogen's airborne inoculum) was monitored using rotating-arms samplers The number of spores of *P. viticola*, *E. necator* and *B. cinerea* per sampling period was determined using a previously developed qPCR assay. The influence of leaf removal treatments on the different variables were analysed using ANOVA. Downy mildew progressed at a lower rate in plots where leaf removal was done at nouaison. there was no significant effect of leaf removal practices on downy mildew severity on cluster except for plots where leaf removal was done on two sides of the row at nouaison. The data on powdery mildew obtained in 2020 suggest a significant effect of leaf removal at nouaison on disease progress and severity on clusters at harvest. The data on botrytis bunch rot obtained in 2020 suggest a significant effect of leaf removal at nouaison (both sides) and at veraison disease severity on clusters at harvest.

Objective 2. Adaptation of disease management decisions for canopy and fruit zone management practices.

In 2021, we conducted the first year of the study to evaluate the contribution of leaf removal in the fruiting zone for the control of major grapevine diseases in northern climate. The trial was conducted at two sites planted with Vidal and Seyval blanc grape cultivars. The experimental units consisted of 5 rows of 30 m length and the set-up included three replications per treatment. A total of 6 fungicide application schemes were evaluated based on the number of fungicide applications. The following fungicide application schemes were evaluated: 1) a calendar-based scheme, with fungicides applied at predefined times; 2) a calendar-based scheme with leaf removal at fruit set on both sides of the rows; 3) a disease risk-based scheme with disease risks estimated according to the phenological stage (vine receptivity) and weather conditions in the vineyard; 4) a disease risk-based scheme with disease risks estimated as in treatment 3 with leaf removal at fruit set on both sides of the rows; 5) a disease risk-based scheme with disease risks estimated according to the phenological stage and weather conditions (microclimate) in the canopy (grape cluster zone) with leaf removal at fruit set on both sides of the rows; 6) a control without fungicide applications. In all the plots with leaf removal, leafing was repeated about 3-4 weeks after the first leaf removal done at fruit set in order to avoid the grapevine compensation.

Years 2020-22. The first objective of this study was to measure the effect of leaf removal in the cluster zone on anthracnose development and microclimate in the cluster zone. Subsequently, the second objective was to investigate how leaf removal in th**e** cluster zone can be integrated into a risk-based anthracnose management program. Anthracnose caused by *Elsinoe ampelina* is an important disease on some hardy and semi-hardy grapevines cultivars. The control of this disease requires repeated application of fungicides, which has financial and environmental consequences. In order to facilitate integrated anthracnose management, the role of leaf removal in the cluster area has been studied. First, the effect of timing (stage 17 or 27) and intensity (one or two sides of rows) of leaf removal on the progression of anthracnose and the microclimate was studied in plots planted with Vidal blanc at two sites in both 2020 and 2021. Overall, at both sites and in both years, anthracnose on leaves was more severe in plots without cluster zone leaf removal. Regardless of the time of leaf removal, severity of anthracnose on leaves and incidences of infected berries at harvest were significantly lower in plots where leaves were removed on both sides of the rows compared to one side only. Secondly, management programs with leaf removal combined or not with disease risk estimation were evaluated. All anthracnose management programs including leaf removal in the cluster zone reduced anthracnose development compared to the standard program without leaf removal. The overall mean leaf anthracnose severity, severity at harvest, and anthracnose incidence on cluster at harvest were significantly lower in plots with leaf removal than in the standard program, but not significantly between each other. More fungicide applications were made in the plots managed based on standard programs with 13 applications compare to plots managed based on using weather-risk of anthracnose with 9, and 10 application at site 1 and site 2 for the risk-based program, respectively and 5 and 7 at site 1 and site 2, respectively, when microclimate within the cluster zone was considered. The results of this study clearly showed the importance of leaf removal in the management of grape anthracnose.

Objective 3. Survey of the Quebec grape industry to evaluate the current canopy management practices including timing, level of exposure and the grower's expected benefit. (3.1 and 3.2 conducted by Provost. Provost also conducts 3.3. at separate sites).

Year 2018. A portrait of the Quebec grape industry was made to evaluate the current canopy management practices including timing, level of exposure and the grower's expected benefit. A questionnaire (survey) was developed to evaluate grape grower's practices related to canopy and fruit zone management, equipment used, time required/ha, timing, impact on their disease management program, and their expected outcomes. The questionnaire was validated by several crop advisers (see Annexe).

Surveys was conducted as a web version or in person with a follow up site on selected vineyards, based on CM and FZM practices used by the growers. Agronomists were also involved in this activity to facilitate links with growers and to complete the information. Particular attention was paid to obtain vineyards in several regions (Québec), with different grape varieties and diversified cultural practices. Overall 62 grape growers from 11 growing regions of Quebec answered which allow us to make a very good portrait of the industry.

Objective 4. Determine the economics of canopy management practices for disease management and fruit quality using cost/benefit analysis.

The cost-benefit analysis was done using data on the influence of leaf removal on the management of grapevine anthracnose caused by *Elsinoe ampelina* (see Objective 2). Considering that the number of sprays, the application rate, and the product used varies according to the susceptibility of the grape cultivars, the season, and the yield objectives of the grower, it is virtually impossible to make a cost-benefit analysis that applies to all situations. Therefore, we present here the results for anthracnose management since we have collected data on fungicide reduction in plots with and without leaf removal.

In the plots without leaf removal a total of 11 fungicide applications were made at a total cost of \$1543/ha (product and labor). In the plots with leaf removal but without consideration of microclimate change due to leaf removal, the total cost (product and labor) was \$ 2018/ha and \$

1738/ha, for manual and mechanical leaf removal, respectively. In the plots with leaf removal and consideration of the microclimate the total cost (product and labor) was $1748/ha and $1468/ha, for manual and mechanical leaf removal, respectively. Therefore, if we consider only the benefits of leaf removal on anthracnose management, leaf removal is profitable. On the other hand, leaf removal provides other benefits on the management of more than one disease and on the quality of the grape. However, leaf removal also has its share of disadvantages including sunburn and the demand for skilled labor.

Section 3 Methodology for 2018-2022

Objective 1. Investigate the influence of canopy and fruit zone management practices on microclimate, fungicide penetration (efficiency of coverage), disease progress, pathogen populations and yield losses (damages).

2019 Methodology. At the experimental farm, the experiment was conducted in an experimental vineyard planted in 2003 with Chancellor, a cultivar highly susceptible to downy and powdery mildew and moderately susceptible to botrytis bunch rot. The experimental vineyard consists in a total of 16 subplots, each measuring 12 × 12 m, arranged in a Latin square with each subplot separated by 6 m without vines. A total of four practices plus one control were assessed in three replicates for a total of 15 sub-plots. The practices were leaf removal around the cluster zone on 1) one side of the row at nouaison; 2) two sides of the row at nouaison; 3) one side of the row at veraison; 4) two sides of the row at veraison; 5) no leaf removal (control). In each sub-plot, hourly temperature (^{o}C) and % relative humidity in the cluster zone was assessed using Hobo sensors. Fungicide penetration was assessed using hydro sensitive papers placed in the cluster zone. Grape downy and powdery mildew was assessed weekly from bud break (mid-May) until harvest (mid to late September) by looking at two shoots on eight vines per sub-plot, selected randomly at each sampling. At each sampling, the total number of leaves and the percent leaf area diseased were recorded. The percent leaf area diseased was estimated using a scale that was divided into eight classes corresponding to 0%, >0% to 1%, >1% to 5%, >5% to 10%, >10% to 20%, >20% to 40%, >40% to 80%, and >80% to 100% leaf area diseased. Downy and powdery mildew and botrytis bunch rot were assessed at harvest by estimating the percent cluster infected on all clusters of on eight vines per sub-plot. To measure disease pressure (pathogen's populations), a spore sampler was installed in each sub-plot to monitor *P. viticola*, *E. necator* and *B. cinerea* airborne inoculum. The samplers ran two times weekly from 8:00 to 18:00 10 min per hour. The number of spores per sampling period was determined using previously developed qPCR assays (Carisse et al., 2014, 2021).

Equipment used to monitor airborne inoculum, microclimate and fungicide penetration in the cluster zone.

For downy and powdery mildew, the area under the disease progress curves (AUDPC) was calculated for each sub-plot (average of the 8 vines). For all diseases the area under the disease progress curves (AUDPC) was calculated for each sub-plot. The are influence of leaf removal treatments on the different variables were analysed using ANOVA. The area under the disease progress curves standardized for the epidemic duration ($AUDPC_{std}$) was calculated using the following equation (1):

$$AUDPC = \sum_{i}^{n-1}\left(\frac{PLAD_i + PLAD_{i+1}}{2}\right) \times (t_{i+1} - t_i) \quad (1)$$

where n is the number of assessments and $PLAD_i$ is the percent leaf area diseased at time t_i. Because epidemics and are expected to be of different durations in each year, the AUDPC were standardized by dividing that area by the total duration of the epidemics in days.

2020 and 2021 Methodology. In order to broaden the scope of the study and to ensure the presence of the three main targeted diseases, the trials were carried out in two commercial vineyards in plots planted with the grape cultivars Vidal blanc (hybrid varieties) and Seyval blanc. Practices of fruit zone management were evaluated for their effect on downy mildew in plots planted with Vidal blanc and on powdery mildew and Botrytis bunch rot in plots planted with Seyval blanc. Vineyard 1 (2ha) was planted in 2006 while vineyard 2 (1ha) was planted in 2008 both vineyards with the cultivars Seyval blanc and Vidal blanc. For both cultivars, rows were spaced 3 m apart, and vines spaced 0.9-1 m within rows (gobelet training system). At both sites and for both grape cultivars, the vineyard was divided into 15 sub-plots of 5 rows x 15 m. Practices of leaf removal in the cluster zone were evaluated following a completely randomized designed with five practices and three repetitions. The following five practices of leaf removal around the cluster zone were: on 1) one side of the row at nouaison; 2) two sides of the row at nouaison; 3) one side of the row at veraison; 4) two sides of the row at veraison; 5) no leaf removal (control). Canopy density was assessed by measuring cluster exposure layer (number of shading layers between clusters and the nearest canopy boundary). Microclimate (temperature, relative humidity, leaf wetness, solar radiation in the cluster zone was assessed using Hobo sensors. Fungicide penetration was assessed using hydro sensitive papers placed in the cluster zone. Within each sub-plots, diseases were assessed on eight vines, two shoots per vine, in the three central rows. Downy mildew and powdery mildew, were assessed weekly on leaves and at harvest on clusters, while Botrytis bunch rot was assessed only at harvest on clusters. At each sampling, the total number of leaves and the percent leaf area diseased were recorded. The percent leaf area diseased was estimated using a scale that was divided into eight classes corresponding to 0%, >0% to 1%, >1% to 5%, >5% to 10%, >10% to 20%, >20% to 40%, >40% to 80%, and >80% to 100% leaf area diseased. Downy and powdery mildew and botrytis bunch rot were assessed at harvest by estimating the percent cluster surfaces infected on all clusters on eight vines per sub-plot. To measure disease pressure (pathogen populations), a spore sampler was installed in the centre of each sub-plot to monitor *P. viticola*, *E. necator* and *B. cinerea* airborne inoculum. The samplers ran two times weekly from 8:00 to 18:00 10 min per hour. The number of spores per sampling period was determined using previously developed qPCR assays (Carisse et al., 2014, 2021). For downy and powdery mildew, the area under the disease progress curves (AUDPC) was calculated for each sub-plot (average of the 8 vines). The influence of leaf removal treatments on the different variables were analysed using ANOVA and contrast analysis (means comparison with the control (no leaf removal)). Area under the disease progress curves standardized for the epidemic duration ($AUDPC_{std}$) was calculated using equation 1.

Objective 2. Adaptation of disease management decisions for canopy and fruit zone management practices.

Influence of leaf removal in the cluster zone on downy mildew, powdery mildew and botrytis bunch rot. In 2021, we conducted a study to evaluate the contribution of leaf removal in the fruiting zone for the control of major grapevine diseases in northern climate. The trial was conducted at two sites planted with Vidal and Seyval blanc grape cultivars. The experimental units consisted of 5 rows of 30 m length and the set-up included three replications per treatment. A total of 6 fungicide application schemes were evaluated based on the number of fungicide applications and yields both in terms of quantity (bunch weight) and quality (% disease and brix). The following fungicide application schemes were evaluated: 1) a calendar-based scheme, with fungicides applied at predefined times; 2) a calendar-based scheme with leaf removal at fruit set on both sides of the rows; 3) a disease risk-based scheme with disease risks estimated according to the phenological stage (vine receptivity) and weather conditions in the vineyard; 4) a disease risk-based scheme with disease risks estimated as in treatment 3 with leaf removal at fruit set on both sides of the rows; 5) a disease risk-based scheme with disease risks estimated according to the phenological stage and weather conditions (microclimate) in the canopy (grape cluster zone) with leaf removal at fruit set on both sides of the rows; 6) a control without fungicide applications. In all the plots with leaf removal, leafing was repeated about 3-4 weeks after the first leaf removal done at fruit set in order to avoid the grapevine compensation.

Years 2020-22. Influence of leaf removal in the cluster zone on anthracnose progress. The experiment was conducted in 2020 and 2021 at two commercial vineyards. Both vineyards are located in the Montérégie region (southwest of Montreal), have a history of anthracnose, and are planted with the anthracnose-susceptible grapevine cultivar Vidal blanc. Consequently, an artificial inoculum was not introduced to any of the vineyards. At site 1, the section of the vineyard used to evaluate the influence of leaf removal consisted of 45 rows (135 m) extending 30 m in length, for a total of 0.41 ha. The vineyard was planted in 2010 with rows spaced 3.0 m apart and vines spaced 1.0 m apart within rows and trained using the gobelet training system. The vineyard section used for the study was separated into 15 plots of 5 rows with a length of 5 m, each one surrounded by a buffer zone of 5 rows extending 5 m. At site 2, the vineyard was planted in 2008 with rows spaced 3.0 m apart and vines spaced 0.9 m apart within rows and trained using the gobelet training system. The section of the vineyard used for the study consisted of 30 rows (90 m) extending 54 m in length, for a total of 0.48 ha. The vineyard was separated into 15 plots of 5 rows with a length of 5.4 m, each one surrounded by a buffer zone also consisting of 5 rows each 5.4 m in length. At both sites, the following five treatments were arranged as a randomized complete block design (five treatments and three replicates): treatment 1 (LR17-1S) leaves were removed on one side of the rows at stage 17 on the BBCH scale; treatment 2 (LR17-2S) leaves were removed on both sides of the rows at stage 17 on the BBCH scale; treatment 3 (LR27-1S) leaves were removed on one side of the rows at stage 27 on the BBCH scale; treatment 4 (LR27-2S) leaves were removed on both sides of the rows at stage 27 on the BBCH scale; and treatment 5 (NOLR) leaves were not removed (control). Stages 17 and 27 on the BBCH scale correspond to the stages described as 'inflorescence fully developed' and 'fruit set,' respectively (Lorenz et al. 1995). In plots with leaf removal, all leaves and small laterals were removed by hand from the cane origin to the most distal cluster, resulting in 90% to 100% removal of leaves in the cluster zone.

Integration of leaf removal into risk-based anthracnose management programs. The experiment was conducted in 2022 at the vineyards described above. A new section of the vineyards was used for the experiment and split into 12 plots of five rows 10 m long at site 1 and five rows 10.8 m long at site 2. Each plot was separated by a buffer zone of the same size. Within each plot, the following four treatments were arranged as a randomized complete block design (four treatments and three replicates): 1) standard program (STD) where anthracnose was managed from stage 13 to 14 on the BBCH scale (2 to 3 leaves unfolded and shoots 2 to 4 cm long) to two weeks before harvest by spraying at intervals of 7 to 14 days depending on rain frequency, and leaves in the cluster zone were not removed; 2) standard program with leaf removal (STDLR) where anthracnose was managed as in the standard program but leaves in the cluster zone were removed on both sides of the rows at both stage 17 (inflorescence fully developed) and stage 27 (fruit set); 3) risk-based anthracnose management program (RISK) where anthracnose was managed from stage 13 to 14 to two weeks before harvest through fungicide sprays timed based on 72 h forecast temperature and tissue wetness duration as well as estimated risk of infection from the model proposed by Carisse et al. (2020), and leaves in the cluster zone were removed on both sides of the rows at stage 17 and stage 27; 4) microclimate risk-based anthracnose management program (MRISK) where anthracnose was managed the same as in the risk-based anthracnose management program (RISK) but tissue wetness duration was corrected for shorter tissue wetness duration (30% reduction) due to leaf removal in the cluster zone. For both risk-based programs, fungicides were applied when the predicted risk of infection was moderate or severe, which corresponds to predicted relative disease severity above 5% but below 25% and more than 25% leaf area diseased, respectively. The fungicides used to manage anthracnose were the following, applied on a rotating basis: myclobutanil (Nova; FRAC group 3; at a rate of 340 g/ha), cyprodinil and difenoconazole (Inspire SUPER; FRAC group 9/3; at a rate of 1,000 ml/ha), and boscalid and pyraclostrobin (PristineWG; FRAC group 7/11; at a rate of 550 g/ha). The fungicides used to manage downy mildew were Ridomil Gold MZ 68WG (64% mancozeb and 4% metalaxyl-M;

FRAC group M03/4; at a rate of 2.5 kg/ha) and Guardsman Copper Oxychloride 50 (Copper Oxychloride 50%; FRAC group M01; at a rate of 3.0 kg/ha). No fungicides were applied specifically to control powdery mildew (*Erysiphe necator*) or botrytis bunch rot (*Botrytis cinerea*) because Vidal blanc is considered not very susceptible to either powdery mildew or botrytis bunch rot. Hence, control was achieved by the fungicides used to control anthracnose.

Data collected. For both experiments, at both sites, starting at vine growth stage 11 (first expanded leaves), five vines and two shoots per vine in each vineyard plot were randomly selected, tagged, and assessed twice weekly for anthracnose severity. Anthracnose severity expressed as percent leaf area diseased (PLAD) was visually estimated on a 0% to 100% severity scale with 5% increments (0, 5, 10, 15…100%). Anthracnose incidence on clusters was estimated at harvest on one cluster per shoot selected for estimation of leaf anthracnose severity, for a total of 10 clusters per plot. Cluster anthracnose incidence was estimated by counting the proportion of infected berries per cluster (Carisse et al. 2021). At each site, weather data were monitored within the cluster zone with an automated micro weather station (Hobo Micro Station Data; Hoskin Scientific, Saint-Laurent, Quebec, Canada). Each year, at each site, the micro stations were installed in a plot representing each treatment (five and four plots per site for experiments I and II, respectively). The weather data collected were hourly air temperature (°C), relative humidity, and leaf wetness. Weather data monitored within the cluster zone were used to estimate the risk of infection using the models described by Carisse et al. (2020). Light, moderate, and severe risk of infection corresponded to a predicted disease severity of $>1\%$ and $\leq 5\%$; $> 5\%$ and $\leq 25\%$; and $> 25\%$ leaf area diseased. For experiment II, fungicide penetration was measured using hydrosensitive cards (Syngenta Crop Protection AG, Basel, Switzerland) placed in the cluster zone (5 cards per plot). The hydrosensitive cards were put in place within one hour before spraying with fungicides and removed as soon as possible after spraying, when they were dry which took approximately 2 hours. Fungicide penetration (percent card surface coloration) was estimated using the software ASSESS (Assess 2.0: Image Analysis Software for Plant Disease Quantification, American Phytopathological Society). Contrast analysis and analysis of variance (ANOVA) were used to test the effect of cluster zone leaf removal and anthracnose management programs on the area under the disease progress curves (AUDPC), mean anthracnose severity on leaves, anthracnose severity on leaves at harvest, and incidence of infected berries per cluster at harvest, as well as fungicide penetration for experiment II.

Objective 3. Survey of the Quebec grape industry to evaluate the current canopy management practices including timing, level of exposure and the grower's expected benefit.

A questionnaire (survey) was developed to evaluate grape grower's practices related to canopy and fruit zone management, equipment used, time required/ha, timing, impact on their disease management program, and their expected outcomes. The questionnaire was validated by several crop advisers (see appendix I for the survey questions).

Surveys was conducted as a web version or in person with a follow up site on selected vineyards, based on CM and FZM practices used by the growers. Agronomists were also involved in this activity to facilitate links with growers and to complete the information. Particular attention was paid to obtain vineyards in several regions (Québec), with different grape varieties and diversified cultural practices.

Objective 4. Determine the economics of canopy management practices for disease management and fruit quality using cost/benefit analysis.

The cost-benefit analysis was done using data on the influence of leaf removal on the management of grapevine anthracnose caused by *Elsinoe ampelina* (see Objective 2).
The premises of the analysis are:
1) Leaf removal reduces the number of fungicide treatments by 20-40%; therefore an average of 30% was used for this analysis
2) Leaf removal on both sides of the row can be done manually :
   a. at a rate of 30 hours per hectare
   b. a cost of $15/hour
   c. for a total of 450$ per pass,
   d. two passes for a grand total of $900.
3) Leaf removal on both sides of the row can be done mechanically
   a. four hours per hectare per pass
   b. a cost of $15/hour
   c. for a total of $60 per pass
   d. two passes for a grand total of $120 in labor
   e. the machinery has a purchase cost of $25,000
   f. the machinery is amortized over a period of 25 years
   g. the machinery is used on a minimum area of 2 hectares
   h. for an annual cost of $500 for the machinery
   i. for a total cost of $620
4) The price of fungicides varies according to the product
   a. Lime Sulphur: $40.00/ha
   b. Nova (Myclobutanil): $90
   c. Inspire SUPER (cyprodinil and difenoconazole: 113$/ha

d. PristineWG (Boscalid and pyraclostrobin): $72/ha
e. METTLE 125 ME (tetraconazole): $70/ha
f. Sovran (Kresoxim-Methyl): $132/ha
g. Flint (Trifloxystrobin): $95/ha
h. Copper 53W: $60/ha

Section 3 results for 2018-2022 activities

Objective 1. Investigate the influence of canopy and fruit zone management practices on microclimate, fungicide penetration (efficiency of coverage), disease progress, pathogen populations and yield losses (damages).

Results obtained in 2019.

Regardless of the treatment, the effect of fruit zone management practices was relatively small (Figure 2). For both timing of leaf removal, nouaison and veraison, lower disease severity was observed when leaves were removed on both sides of rows. Overall, lower disease severity was observed when leaves were removed at nouaison as compare to veraison. For powdery mildew, 9.3%, 9.8%, 3.6% 6.6%, 4.1%, and disease severity were observed in sub-plots managed based on no leaf removal, 1-side leaf removal at nouaison, -2-sides leaf removal at nouaison, 1-side leaf removal at veraison, 2-sides leaf removal at veraison, respectively. For downy mildew, 26.2%, 11.3%, 7.2%, 21.0%, 18.1% percent disease severity were observed in sub-plots managed based on no leaf removal, 1-side leaf removal at nouaison, -2-sides leaf removal at nouaison, 1-side leaf removal at veraison, 2-sides leaf removal at veraison, respectively. Similarly, Botrytis bunch rot severity at harvest was 29.9%, 19.3%, 4.1%, 10.9%, 9.8%, in sub-plots managed based on no leaf removal, 1-side leaf removal at nouaison, -2-sides leaf removal at nouaison, 1-side leaf removal at veraison, 2-sides leaf removal at veraison, respectively. However, there was no significant difference in airborne inoculum of *P. viticola*, *E. necator* and *B. cinerea*. The difference in disease severity may be explained by lower humidity, shorter duration of tissues wetness and better fungicide penetration in the canopy in sub-plots where leaves around the clusters were removed on both sides of rows. For most tissues wetness event, the duration was significantly shorter in plots where leaf were removed on both sides at nouaison and at veraison. The removal of leaves from the fruiting area promotes the penetration of fungicides during a localized treatment but also of general coverage. The quantity of fungicides found on the bunches was about 50% higher than that deposited on the bunches of a row without leaf removal.

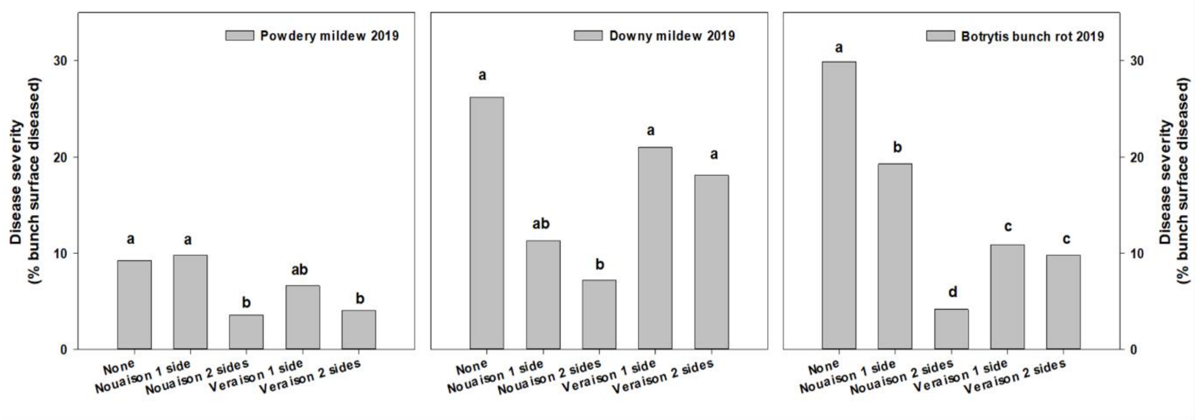

Figure 2. Severity of powdery mildew (*Erysiphe necator*), downy mildew (*Plasmopara viticola*) and Botrytis bunch rot (*Botrytis cinerea*) at harvest in plots with different leaf removal treatments around the cluster zone. Bar with the same letter are not significantly different according to an LSD test at the 0.05 level of confidence

Results obtained in 2020

Grape downy mildew. Because downy mildew was assessed weekly on leaves, it was possible to build downy mildew progress curves and to calculate the area under the curves (AUDPC) which represents disease severity during the entire season (assessment period). The AUDPC was calculated with Equation 1 separately for each leaf removal treatment, each vineyard, and each repetition (average of 8 vines). The AUDPC was 10.3, 7.0, 4.7, 7.8, and 9.2 in plots with leaf removal practices: no leaf removal (control), one side of the row at nouaison; two sides of the row at nouaison ; one side of the row at veraison; and two sides of the row at veraison; respectively (Fig. 3). Based on the ANOVA, the AUDPC in plots with no leaf removal and with leaf removal at veraison on one and two sides were not significantly different. However, the AUDPC in plots where leaf removal was done at nouaison was significantly different than the AUDPC in plots with no leaf removal or with leaf removal at veraison on one and two sides (Fig. 3). In practice, this means that downy mildew progressed at a lower rate in plots where leaf removal was done at nouaison (Fig.3).

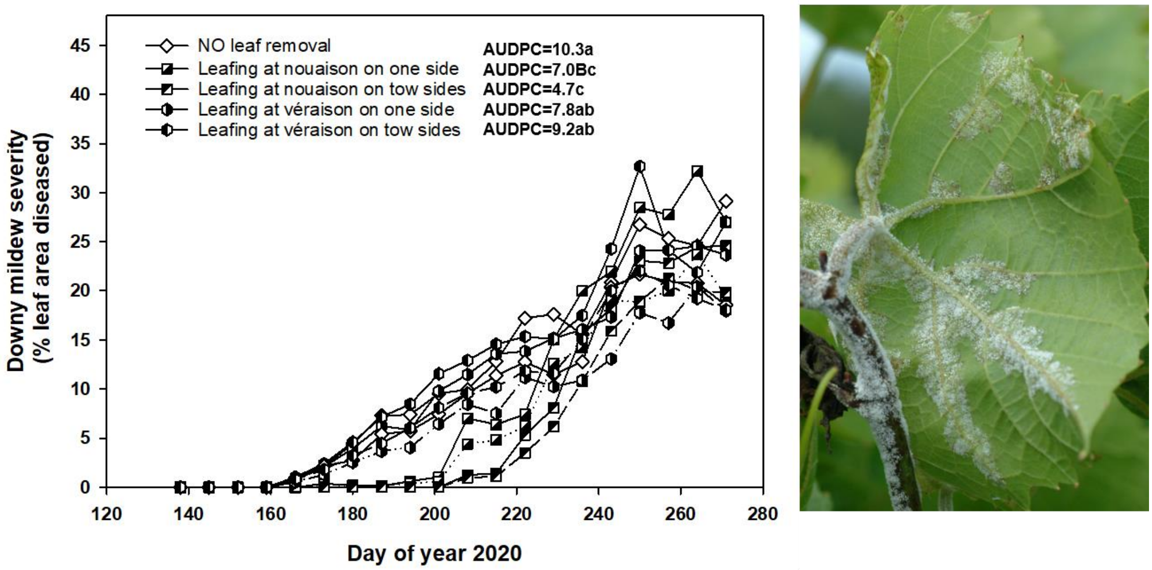

Figure 3. Progress of downy mildew on leaves of the grapevine cultivar Vidal. The values are average (2 vineyards x 3 repetitions x 8 vines). The values of the area under the disease progress curves (AUDPC) with the same letters are not significantly different at the 0.05 level of confidence based on a Tukey test.

At the end of the growing season the severity of downy mildew expressed at percent leaf area diseased (averages of 2 vineyards x 3 repetitions x 8 vines) was 23.8%, 23.2%, 22.2%, 20.8%, and 22.5% in plots with leaf removal practices: no leaf removal (control), one side of the row at nouaison; two sides of the row at nouaison; one side of the row at veraison; and two sides of the row at veraison; respectively (Fig. 4). Based on the ANOVA, there was no significant effect of leaf removal practices on final downy mildew severity on leaves. On cluster, severity of downy mildew expressed at percent cluster area diseased (averages of 2 vineyards x 3 repetitions x 8 vines) was 34.5%, 29.6%, 20.3%, 33.9%, and 31.7% in plots with leaf removal practices: no leaf removal (control), one side of the row at nouaison; two sides of the row at nouaison ; one side of the row at veraison; and two sides of the row at veraison; respectively (Fig. 4). Based on the ANOVA, there was no significant effect of leaf removal practices on downy mildew severity on cluster except for plots where leaf removal was done on two sides of the row at nouaison (Fig. 4).

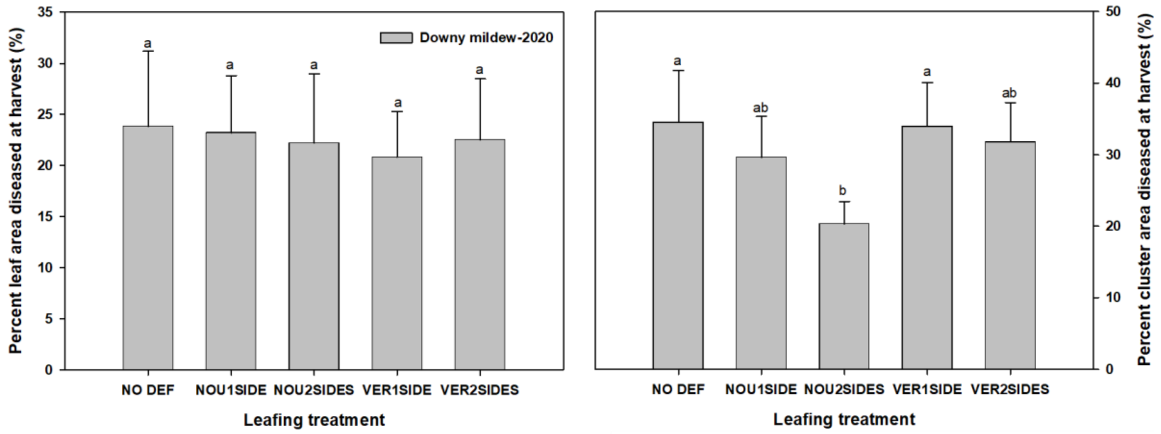

Figure 4. Severity of downy mildew at harvest on leaves (left) and clusters (right) of the grapevine cultivar Vidal. The values are averages (2 vineyards x 3 repetitions x 8 vines) and bars with the same letters are not significantly different at the 0.05 level of confidence based on a Tukey test.

No significant differences were observed in airborne sporangia concentration between the different plots. The data on downy mildew obtained in 2020 suggest a small but significant effect of leaf removal at nouaison on disease progress and severity on clusters at harvest.

Grape powdery mildew. As for downy mildew, severity of powdery mildew on leaves was assessed weekly, hence it was possible to build powdery mildew progress curves and to calculate the area under the curves (AUDPC) which represents disease severity during the entire season (assessment period). The AUDPC was calculated with Equation 1 separately for each leaf removal treatment, each vineyard, and each repetition (average of 8 vines). The AUDPC was 5.8, 2.6, 4.0, 6.4, and 3.5 in plots with leaf removal practices: no leaf removal (control), one side of the row at nouaison; two sides of the row at nouaison ; one side of the row at veraison; and two sides of the row at veraison; respectively (Fig. 5). Based on the ANOVA, the AUDPC in plots with no leaf removal and with leaf removal at veraison on one were not significantly different. Similarly, the AUDPC in plots with leaf removal at done at nouaison on one sides and at veraison on two sides were not significantly different. Lowest AUDPC were observed in plots where leaf removal was done on both sides of rows regardless of the timing, nouaison or veraison (Fig. 5).

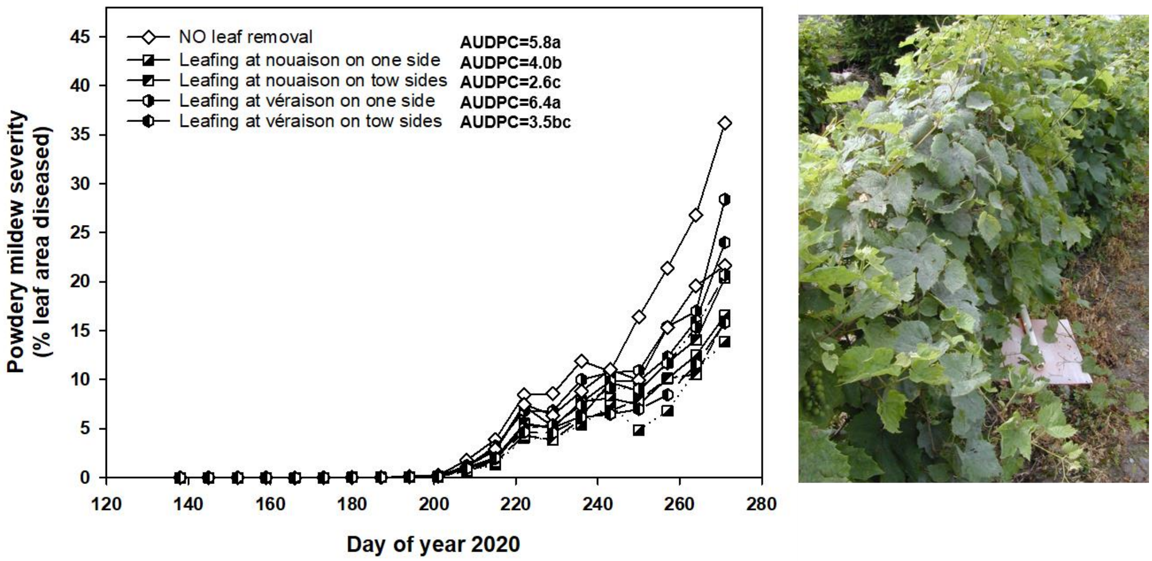

Figure 5. Progress of powdery mildew on leaves of the grapevine cultivar Seyval. The values are average (2 vineyards x 3 repetitions x 8 vines). The values of the area under the disease progress curves (AUDPC) with the same letters are not significantly different at the 0.05 level of confidence based on a Tukey test.

At the end of the growing season the severity of powdery mildew expressed at percent leaf area diseased (averages of 2 vineyards x 3 repetitions x 8 vines) was 28.9%, 15.2%, 18.1%, 24.5%, and 19.9% in plots with leaf removal practices: no leaf removal (control), one side of the row at nouaison; two sides of the row at nouaison; one side of the row at veraison; and two sides of the row at veraison; respectively (Fig. 2020.4). Based on the ANOVA, there was no significant effect of leaf removal practices on final powdery mildew severity in plots with no leaf removal and when leaf removal was done at veraison. However, the final powdery mildew severity was significantly lower in plots where leaf removal was done at nouaison (Fig. 6).

On cluster, severity of powdery mildew expressed at percent cluster area diseased (averages of 2 vineyards x 3 repetitions x 8 vines) was 22.7%, 6.1%, 3.1%, 15.5%, and 10.7% in plots with leaf removal practices: no leaf removal (control), one side of the row at nouaison; two sides of the row at nouaison ; one side of the row at veraison; and two sides of the row at veraison; respectively (Fig. 6). Based on the ANOVA, percent cluster area diseased were lower in plots where leaf removal was done at nouaison on one or two sides of rows and when done at veraison on both sides of row (Fig. 6).

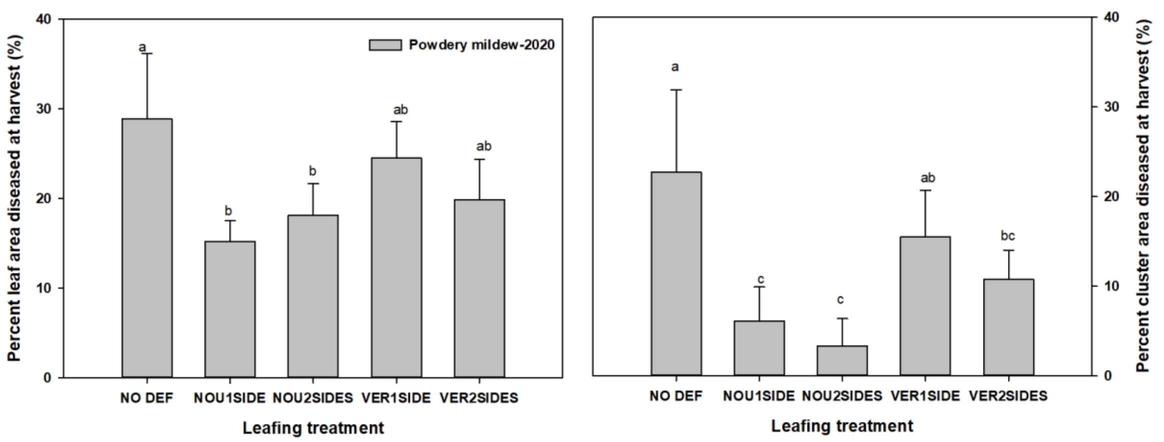

Figure 6. Severity of powdery mildew at harvest on leaves (left) and clusters (right) of the grapevine cultivar Seyval. The values are averages (2 vineyards x 3 repetitions x 8 vines) and bars with the same letters are not significantly different at the 0.05 level of confidence based on a Tukey test.

Small, but significant differences were observed in airborne conidia concentration monitored in plots where leaf removal was done at nouaison as compare with no leaf removal or leaf removal done at veraison. The data on powdery mildew obtained in 2020 suggest a significant effect of leaf removal at nouaison on disease progress and severity on clusters at harvest.

Botrytis bunch rot (*Botrytis cinerea*). At harvest the severity of botrytis bunch rot expressed at percent cluster area diseased (averages of 2 vineyards x 3 repetitions x 8 vines) was 28.8%, 20.6%, 4.2%, 15.5%, and 10.7% in plots with leaf removal practices: no leaf removal (control), one side of the row at nouaison; two sides of the row at nouaison ; one side of the row at veraison; and two sides of the row at veraison; respectively (Fig. 7). Based on the ANOVA, percent cluster area diseased were lower in plots where leaf removal was done at nouaison on two sides of rows and when done at veraison on one or two sides of row (Fig. 7).

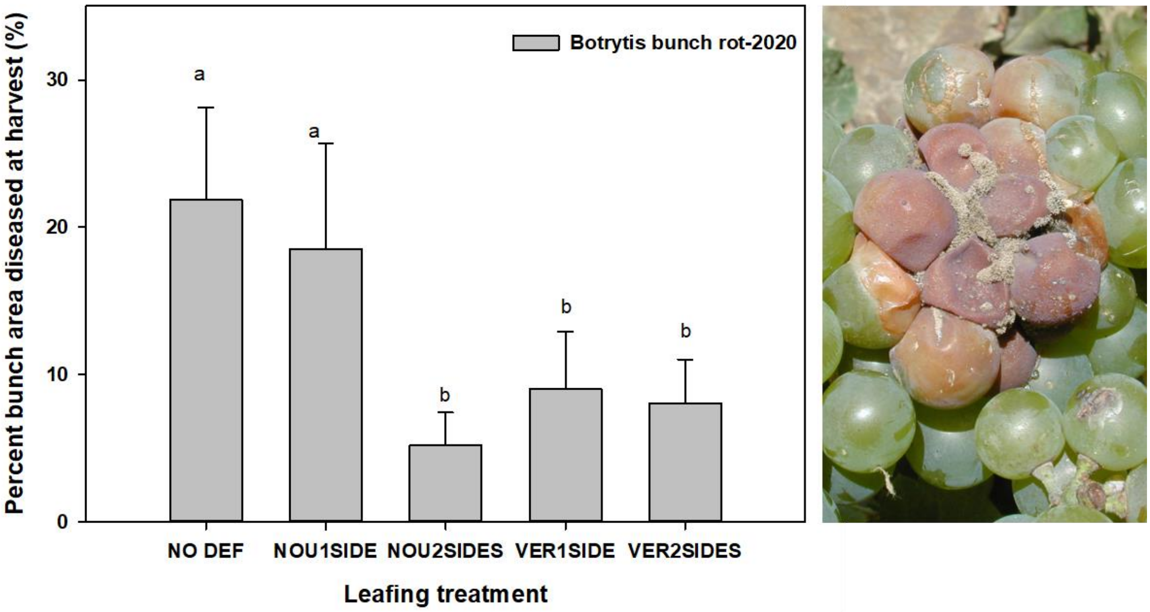

Figure 7. Severity of botrytis bunch rot at harvest on clusters of the grapevine cultivar Seyval. The values are averages (2 vineyards x 3 repetitions x 8 vines) and bars with the same letters are not significantly different at the 0.05 level of confidence based on a Tukey test.

Small, but significant differences were observed in airborne conidia concentration monitored in plots where leaf removal was done at nouaison on two sides of rows and at veraison as compare with no leaf removal or leaf removal done at nouaison on one side of rows. The data on botrytis bunch rot obtained in 2020 suggest a significant effect of leaf removal at nouaison (both sides) and at veraison disease severity on clusters at harvest.

Overall, the season 2020 was characterized by several periods without rain, hence number and duration of wet periods (infection by *P. viticola* and *B. cinerea*) were low, especially in May, June and July. Consequently there were only small differences between canopy wetness among the leaf removal treatments. However, it was different in August and in September where significantly shorter wetness period were observed in plots where leaf removal was done at nouaison on both sides and at veraison on one or two sides.

Results obtained in 2021

Grape downy mildew. Because downy mildew was assessed weekly on leaves, it was possible to build downy mildew progress curves and to calculate the area under the curves (AUDPC) which represents disease severity during the entire season (assessment period). The AUDPC was calculated separately for each leafing treatment, each vineyard, and each repetition (average of 8 vines). The AUDPC was 12.9, 8.7, 4.7, 7.8, and 8.5 in plots with leafing practices: no leafing (control), one side of the row at nouaison; two sides of the row at nouaison; one side of the row at veraison; and two sides of the row at veraison; respectively (Fig. 8). Based on the ANOVA, the AUDPC in plots with no leafing and with leafing at nouaison on one and veraison two sides were not significantly different. However, the AUDPC in plots where leafing was done at nouaison on two sides and at veraison on one side were significantly different than the AUDPC in plots with no leafing (Fig. 8). However, when leafing was done at nouaison, we observed a delay in downy mildew development (Fig. 8).

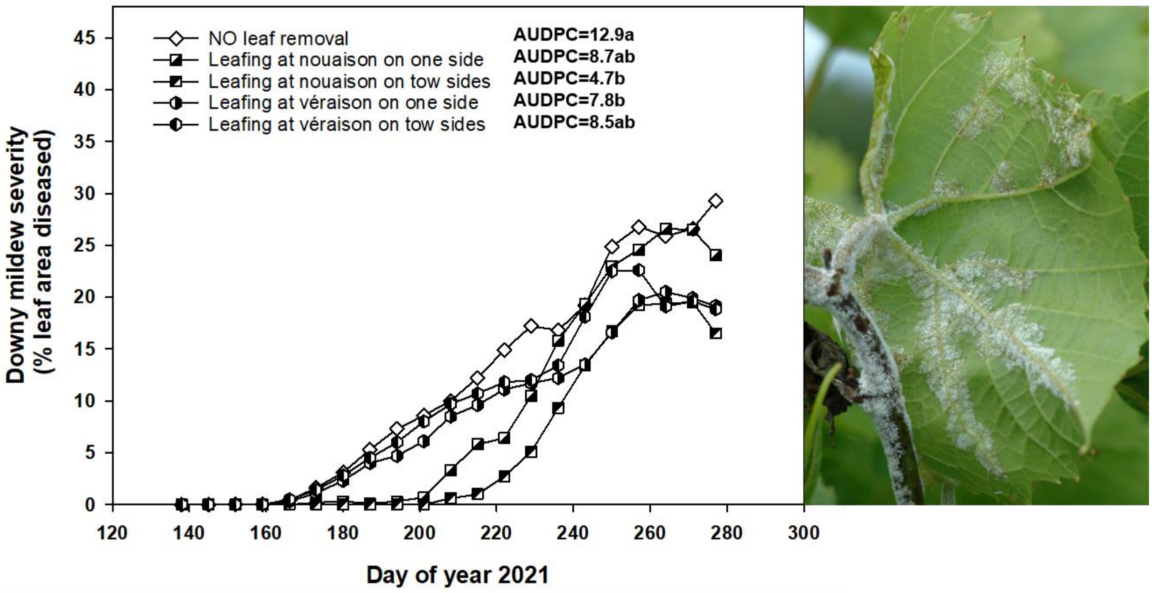

Figure 8. Progress of downy mildew on leaves of the grapevine cultivar Vidal. The values are average (2 vineyards x 3 repetitions x 8 vines). The values of the area under the disease progress curves (AUDPC) with the same letters are not significantly different at the 0.05 level of confidence based on a Tukey test.

At the end of the growing season the severity of downy mildew expressed at percent leaf area diseased (averages of 2 vineyards x 3 repetitions x 8 vines) was 29.3%, 24.1%, 16.5%, 19.1%, and 18.8% in plots with leafing practices: no leafing (control), one side of the row at nouaison; two sides of the row at nouaison; one side of the row at veraison; and two sides of the row at veraison; respectively (Fig. 9). Based on the ANOVA, there was no significant effect of leafing practices on final downy mildew severity on leaves except in plots where leafing was done at nouaison on both sides of rows. On cluster, severity of downy mildew expressed at percent cluster area diseased (averages of 2 vineyards x 3 repetitions x 8 vines) was 33.1%, 29.3%, 20.5%, 36.2%, and 30.3 in plots with leafing practices: no leafing (control), one side of the row at nouaison; two sides of the row at nouaison ; one side of the row at veraison; and two sides of the row at veraison; respectively

(Fig. 9). Based on the ANOVA, there was no significant effect of leafing practices on downy mildew severity on cluster except for plots where leafing was done on two sides of the row at nouaison (Fig. 9).

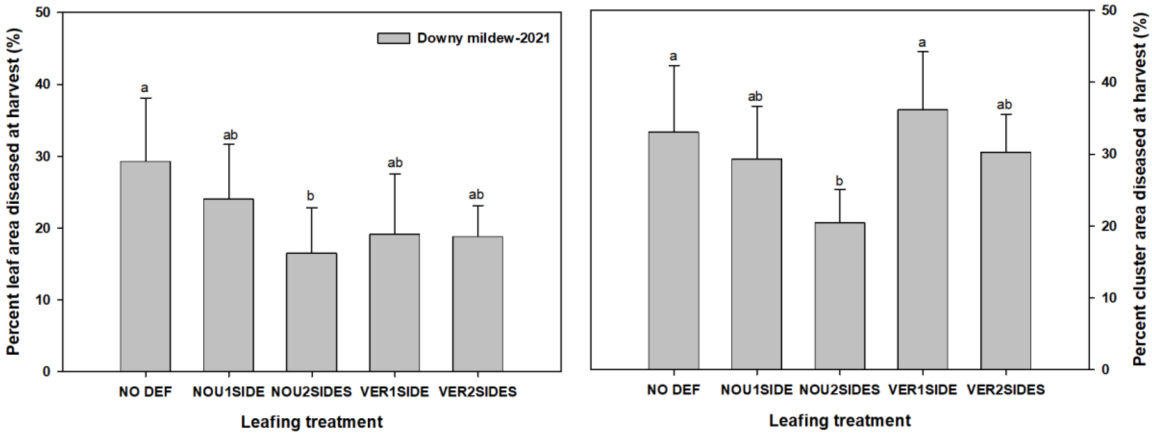

Figure 9. Severity of downy mildew at harvest on leaves (left) and clusters (right) of the grapevine cultivar Vidal. The values are averages (2 vineyards x 3 repetitions x 8 vines) and bars with the same letters are not significantly different at the 0.05 level of confidence based on a Tukey test.

No significant differences were observed in airborne sporangia concentration between the different plots. The data on downy mildew obtained in 2021 suggest a small but significant effect of leafing at nouaison on disease progress and severity on clusters at harvest.

Grape powdery mildew. As for downy mildew, severity of powdery mildew on leaves was assessed weekly, hence it was possible to build powdery mildew progress curves and to calculate the area under the curves (AUDPC) which represents disease severity during the entire season (assessment period). The AUDPC was calculated with Equation 1 separately for each leafing treatment, each vineyard, and each repetition (average of 8 vines). The AUDPC was 5.5, 3.3, 2.9, 4.3, and 3.5 in plots with leafing practices: no leafing (control), one side of the row at nouaison; two sides of the row at nouaison ; one side of the row at veraison; and two sides of the row at veraison; respectively (Fig. 10). Based on the ANOVA, the AUDPC in plots with no leafing and with leafing at veraison were not significantly different. However, the AUDPC in plots with leafing at nouaison were significantly different than in plots without leafing(Fig. 10).

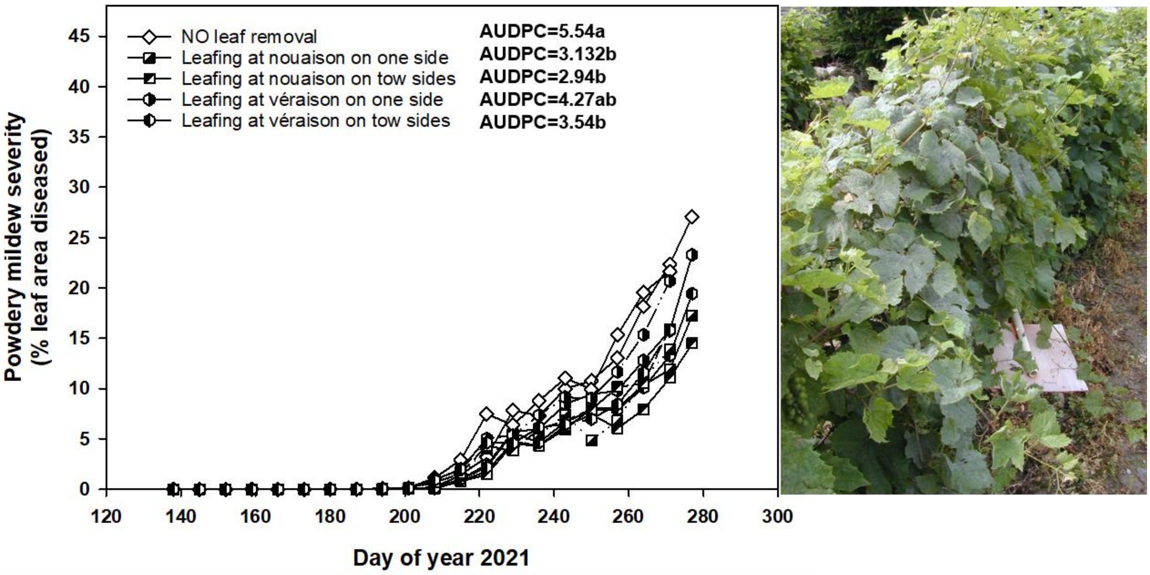

Figure 10. Progress of powdery mildew on leaves of the grapevine cultivar Seyval. The values are average (2 vineyards x 3 repetitions x 8 vines). The values of the area under the disease progress curves (AUDPC) with the same letters are not significantly different at the 0.05 level of confidence based on a Tukey test.

At the end of the growing season the severity of powdery mildew expressed at percent leaf area diseased (averages of 2 vineyards x 3 repetitions x 8 vines) was 27.1%, 14.5%, 17.2%, 23.3%, and 19.4% in plots with leafing practices: no leafing (control), one side of the row at nouaison; two sides of the row at nouaison; one side of the row at veraison; and two sides of the row at veraison; respectively (Fig. 11). Based on the ANOVA, the severity of powdery mildew at harvest in plots with no leafing and with leafing at veraison were not significantly different. However, the severity in plots with leafing at nouaison were significantly different than in plots without leafing (Fig. 2021.4). On cluster, severity of powdery mildew expressed at percent cluster area diseased (averages of 2 vineyards x 3 repetitions x 8 vines) was 23.2%, 13.8%, 9.5%, 15.6%, and 15.0% in plots with leafing practices: no leafing (control), one side of the row at nouaison; two sides of the row at nouaison ; one side of the row at veraison; and two sides of the row at veraison; respectively (Fig. 11). Based on the ANOVA, percent cluster area diseased were lower in plots where leafing was done at nouaison and at veraison on one and two sides of row (Fig. 11).

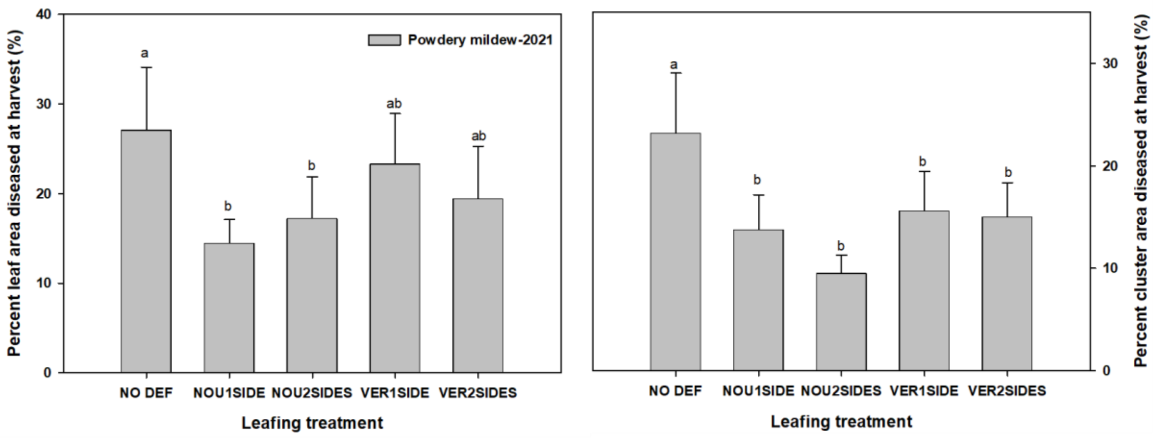

Figure 11. Severity of powdery mildew at harvest on leaves (left) and clusters (right) of the grapevine cultivar Seyval. The values are averages (2 vineyards x 3 repetitions x 8 vines) and bars with the same letters are not significantly different at the 0.05 level of confidence based on a Tukey test.

No significant differences were observed in airborne conidia concentration between the different plots. The data on powdery mildew obtained in 2021 suggest a small but significant effect of leafing at nouaison on disease progress and severity on clusters at harvest.

Botrytis bunch rot (*Botrytis cinerea*)

At harvest the severity of botrytis bunch rot expressed at percent cluster area diseased (averages of 2 vineyards x 3 repetitions x 8 vines) was 14.2%, 12.3%, 3.4%, 6.0%, and 5.4% in plots with leafing practices: no leafing (control), one side of the row at nouaison; two sides of the row at nouaison ; one side of the row at veraison; and two sides of the row at veraison; respectively (Fig. 12). Based on the ANOVA, percent cluster area diseased were lower in plots where leafing was done at nouaison on two sides of rows and when done at veraison on one or two sides of row (Fig. 12).

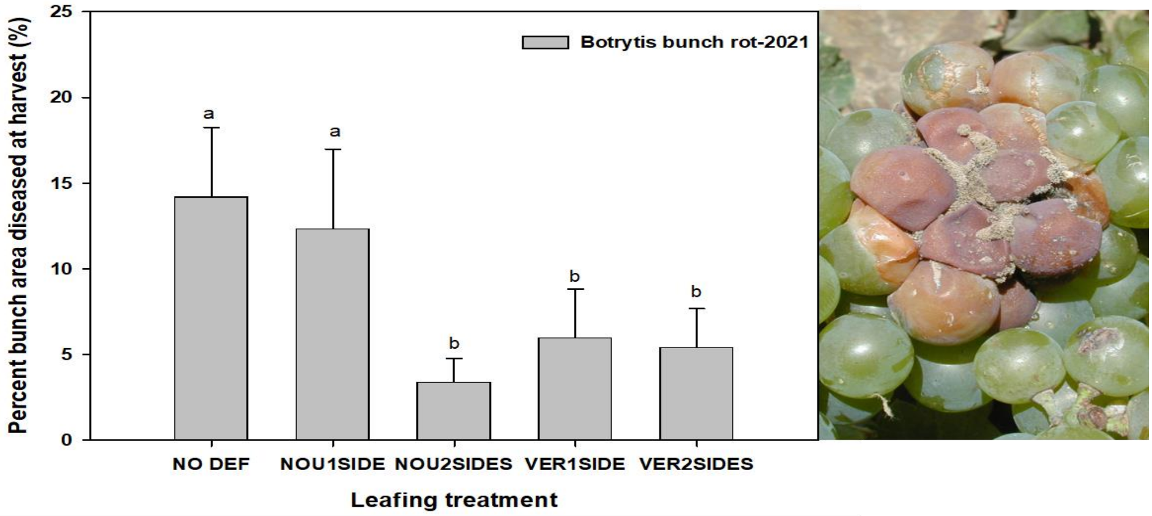

Figure 12. Severity of botrytis bunch rot at harvest on clusters of the grapevine cultivar Seyval. The values are averages (2 vineyards x 3 repetitions x 8 vines) and bars with the same letters are not significantly different at the 0.05 level of confidence based on a Tukey test.

Overall effect of leaf removal on airborne inoculum, microclimate and fungicide penetration.

Regardless of year, site, grape variety, or phytopathogenic fungi (*P. viticola*, *E. necator* or *B. cinerea*) we did not observe significant differences in airborne inoculum concentration between treatments. These results can most probably be due to the size of the plots and the fact that the aerial inoculum moves through the air.

In general, leaf wetness periods were shorter in plots with leaf removal. For both sites on average, 12, 8, 5, 9, and 7 leaf wetness periods of more than 5 hours were measured in the plots with no leafing (control), one side of the row at nouaison; two sides of the row at nouaison; one side of the row at veraison; and two sides of the row at veraison; respectively (Fig. 13). However, this phenomenon was only observed for about one month after leaf removal. Similarly, higher solar radiation and wind speed within the canopy (cluster zone) were observed in plots with leafing (Fig.14).

Before leaf removal, fungicide penetration into the canopy varied from 44.9 to 51.2%. However, after leaf removal this percentage increased to 70-90% (Table 1). However, 3-4 weeks after leaf removal this percentage decreased to 50-75% depending on the plot (Table 1). These results suggest that leaf removal has an effect for a few weeks and therefore must be repeated to maintain the benefits.

Table 1 Percent pesticide penetration into the canopy (cluster zone) for the different leafing treatments

Penetration within the canopy (%)	Before leafing (stage 25)	After leafing at nouaison (stage 29)	After leafing at nouaison (stade 31-33)	After leafing at véraison (stade 35+)	After leafing at véraison (stade 38)
Control	46.7a	44.8	42.1c	37.8c	39.6c
Nouaison one side	51.2a	69.6bc	58.7b	51.6b	48.9c
Nouaison two sides	47.8a	89.4a	74.6a	64.1b	58.7b
Veraison one side	44.9a	39.6c	44.3c	79.6a	62.4b
Veraison two sides	48.3a	41.2c	48.3c	88.5a	76.3a

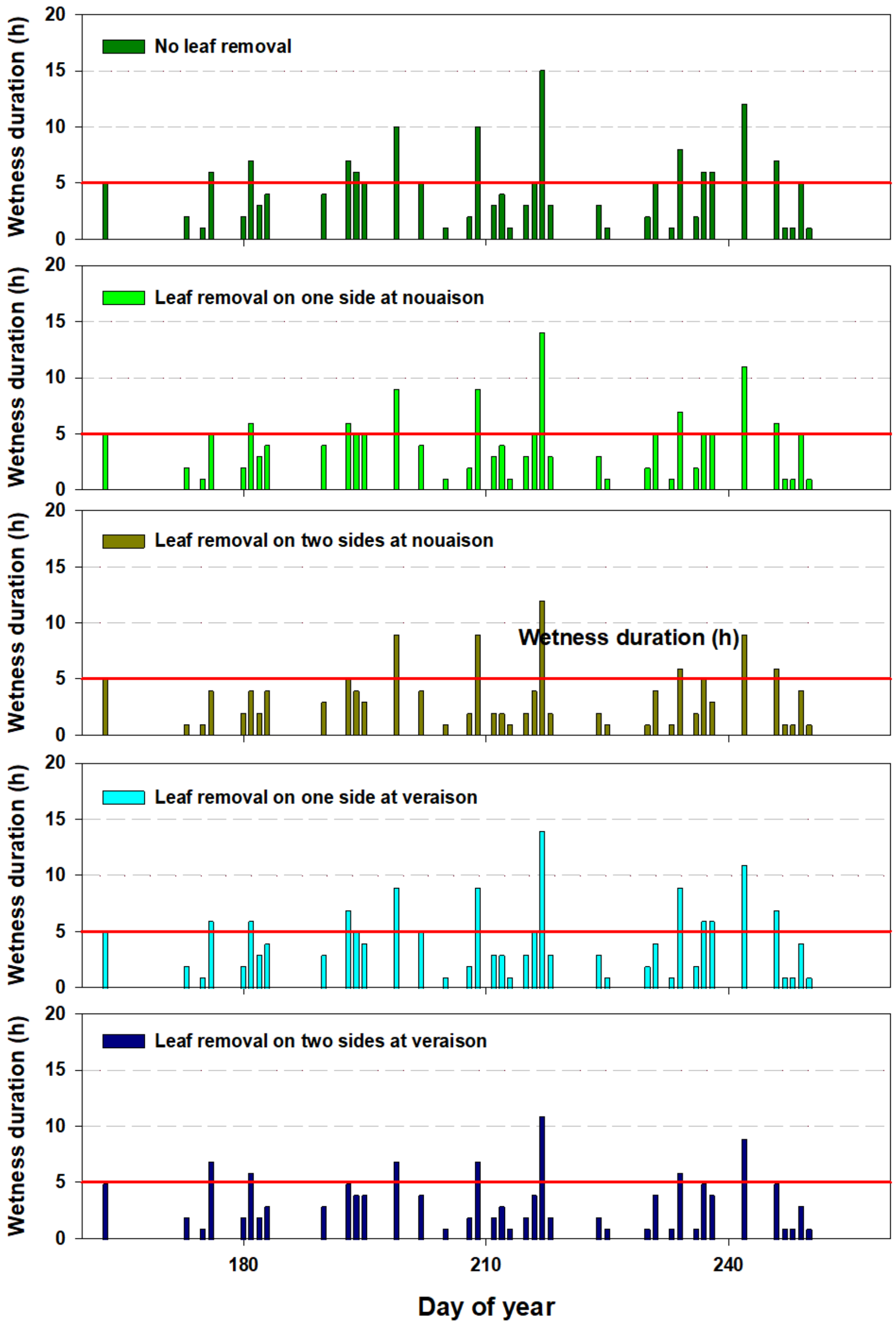

Figure 14. Duration of leaf and berry wetness within the cluster zone in plots with different lesf removal treatments.

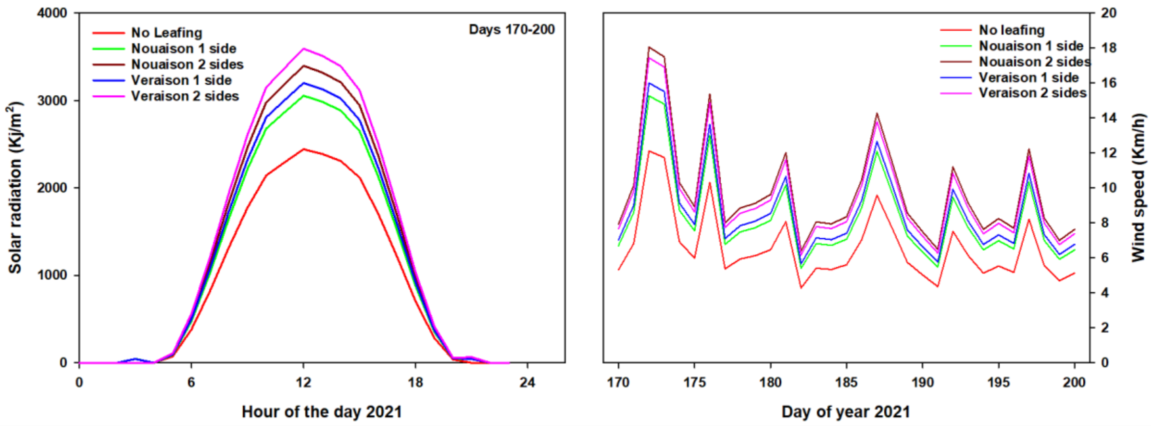

Figure 14. Solar radiation (left) and wind speed (right) monitored within the canopy (cluster zone) in 2021 (average of both sites).

Objective 2. Adaptation of disease management decisions for canopy and fruit zone management practices.

Results obtained in 2021

For downy mildew, the essays were conducted in plots planted with the grapevine cultivar Vidal. On average for both sites, when fungicide applications were made on a calendar basis with or without leaf removal, a total of 8.5 applications were made during the season. The number of applications decreased to 6.5 when the applications were made taking into account the risk of downy mildew and to 5.5 when the microclimate in the cluster zone was used to estimate the risk of downy mildew (Table 2).

Table 2. Summary of the number of fungicide applications used to manage downy mildew (*Plasmopara viticola*) under different disease management schemes.

Disease management scheme	Site 1	Site 2	Mean
Control (no fungicide)	0	0	0
Scheme 1: Calendar	8	9	8.5
Scheme 2: Calendar + leafing	8	9	8.5
Scheme 3: Risk-based	6	7	6.5
Scheme 4: Risk-based+ leafing	6	7	6.5
Scheme 5: Risk-based (microclimate) + leafing	5	6	5.5

Although fewer fungicide applications were made in the plots with application made according to the risk of downy mildew development (phenological stage and microclimate) with leaf removal, overall the severity of downy mildew on the bunches was significantly lower, and the weight of the bunches as well as the brix were equivalent to those obtained in the other plots where more fungicides were applied (Fig.15).

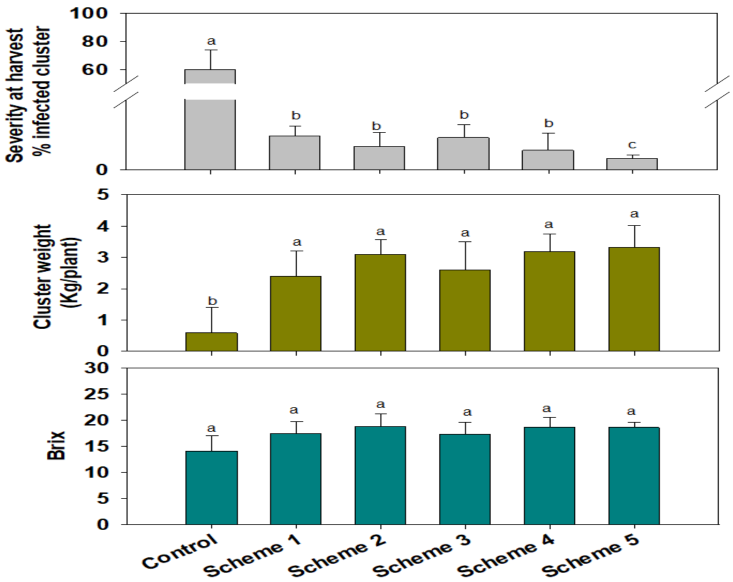

Figure 15. Yield expressed as percent downy mildew severity (top), cluster weight (middle), and brix (bottom) for the grapevine cultivar Vidal. The values are average (2 vineyards x 3 repetitions x 8 vines). The values with the same letters are not significantly different at the 0.05 level of confidence based on a Tukey test.

For powdery mildew and Botrytis bunch rot, the essays were conducted in plots planted with the grapevine cultivar Seyval blanc. On average for both sites, when fungicide applications were made on a calendar basis with or without leaf removal, a total of 7.5 applications were made during the season. The number of applications decreased to 6.5 when the applications were made taking into account the risk of powdery mildew and Botrytis bunch rot and to 5 when the microclimate was used to estimate the risk of mildew (Table 3).

Table 3 Summary of the number of fungicide application used to manage powdery mildew (*Erysiphe necator*) and Botrytis bunch rot (*Botrytis cinerea*) under different disease management schemes.

Disease management scheme	Site 1	Site 2	Mean
Control (no fungicide)	0	0	0
Scheme 1: Calendar	7	8	8.5
Scheme 2: Calendar + leafing	7	8	8.5
Scheme 3: Risk-based	6	7	6.5
Scheme 4: Risk-based+ leafing	6	7	6.5
Scheme 5: Risk-based (microclimate) + leafing	5	5	5.0

Although fewer fungicide applications were made in the plots treated according to the risk of powdery mildew and Botrytis bunch rot development (phenological stage and microclimate) with leaf removal, overall disease severity on bunches, weight of the bunches as well as the brix were equivalent to those obtained in the other plots.

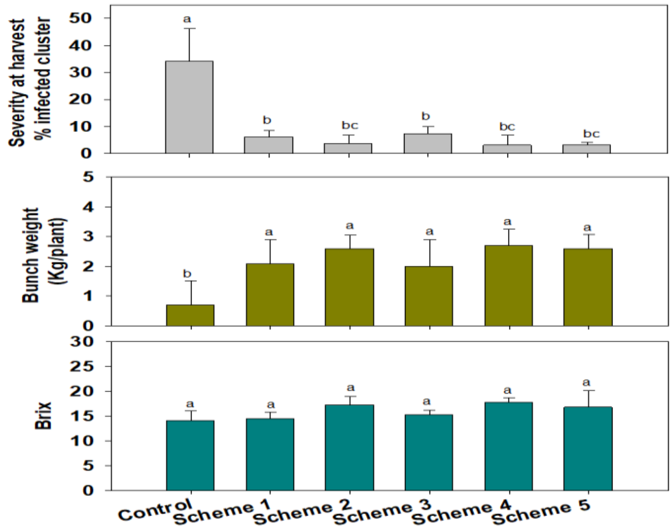

Figure 16. Yield expressed as percent powdery mildew and Botrytis bunch rot severity (top), cluster weight (middle), and brix (bottom) for the grapevine cultivar Seyval blanc. The values are average (2 vineyards x 3 repetitions x 8 vines). The values with the same letters are not significantly different at the 0.05 level of confidence based on a Tukey test.

In conclusion for 2021, leaf removal in the cluster zone as a method of controlling the main grapevine diseases alone has not made it possible to significantly reduce the development of diseases as well as yield losses in terms of both quantity and quality. However, when leafing was combined with tools for estimating disease risks, particularly when risks were estimated from weather conditions in the microclimate (cluster zone), this practice made it possible to significantly reduce the number of fungicide treatments while maintaining the yields. The results obtained in 2021 tend to demonstrate the importance of integrated pest management and the effect of methods which alone do not provide acceptable control but which when combined make it possible to achieve an acceptable level of control while reducing the use synthetic fungicides.

Influence of leaf removal in the cluster zone on anthracnose progress. In 2020, the first symptoms of anthracnose on leaves were observed at the end of May (Day 152), anthracnose severity on leaves then progressed very rapidly from June onwards, and then more slowly with percent leaf area diseased varying between 20% and 48% (Fig. 178A-B). In 2021, the first symptoms were observed at the very beginning of June, then progressed very quickly in only a few days, and then stabilized at a severity level of between 24% and 40% leaf area diseased (Fig. 17C-D). Overall, at both sites and in both years, anthracnose on leaves was more severe in plots without cluster zone leaf removal (Fig. 17A-D). However, the temporal development pattern was quite similar (Fig. 17A-D). The area under the disease progress curves adjusted for the number of sampling days was 24.52, 20.48, 26.16, 21.78 and 31.61, respectively, for treatment LR17-1S where leaves were removed on one side of the rows at stage 17 on the BBCH scale; treatment LR17-2S where leaves were removed on both sides of the rows at stage 17 on the BBCH scale; treatment LR27-1S where leaves were removed on one side of the rows at stage 27 on the BBCH scale; treatment LR27-2S where leaves were removed on both sides of the rows at stage 27 on the BBCH scale; and treatment NOLR where no leaves were removed (control). Based on the contrast analysis, the area under the disease progress curves was significantly different (P <0.0001) between plots with leaf removal and control plots without leaf removal (Fig. 18A). Regardless of the timing of leaf removal, whether at the 'inflorescence fully developed' stage or at the 'fruit set' stage, the area under the disease progress curves was significantly lower in plots where leaves were removed on both sides of the rows compared to one side only (Fig. 18A). The results of both the contrast analysis and the analysis of variance were similar for overall mean anthracnose severity on leaves, with 24.32%, 20.27%, 25.95%, 21.63%, and 31.44% leaf area diseased for the treatments LR 17-1S, LR17-2S, LR 27-1S, LR27-2S, and NOLR, respectively (Fig. 18B). Anthracnose leaf severity at harvest was significantly lower in all leaf removal treatments compared to the control, with 31.94%, 23.72%, 34.41%, 29.85%, and 46.55% leaf area diseased for the treatments LR 17-1S, LR17-2S, LR 27-1S, LR27-2S, and NOLR, respectively (Fig. 18C). Similarly, incidence of diseased berries per cluster was significantly lower in all leaf removal treatments compared to the control, with 43.67%, 27.63%, 42.16%, 34.48%, and 59.75%, for the treatments LR 17-1S, LR17-2S, LR 27-1S, LR27-2S, and NOLR, respectively (Fig. 18D). Overall, the incidence of diseased berries per cluster was reduced by 26.9%, 53.8%, 29.5%, and 42.3% as compared to the control where no leaves were removed. No differences in air temperature within the canopy were observed between the different treatments (data not shown). However, leaf wetness duration was generally shorter in plots with leaf removal than in the control (Table 4), which resulted in a fewer light infection periods, with 17.0, 13.5, 16.5, 13.0, and 35.5 light infection periods for the treatments LR 17-1S, LR17-2S, LR 27-1S, LR27-2S, and NOLR, respectively (Table 4). Smaller differences in moderate infection periods were observed between leaf removal treatments, with 6.8, 9.0, 7.3, 8.8, and 10.8 moderate infection periods for the treatments LR 17-1S, LR17-2S, LR 27-1S, LR27-2S, and NOLR, respectively (Table 4). However, for severe infections, about 50% fewer infection periods were observed in plots with leaf removal on both sides of the rows, with 6.8, 4.0, 7.0, 4.8, and 8.5 severe infection periods (Table 4).

Table 4. Number of infection periods estimated from the duration of tissue wetness and temperature during wetness periods using the equations provided by Carisse et al (2020) for different leaf removal treatments.

		Leaf removal treatments[y]				
Site/year	Infection risk[z]	LR 17-1S	LR17-2S	LR 27-1S	LR27-2S	NOLR
Site 1-2020	Light	15.0	11.0	13.0	11.0	29.0
Site 1-2021	Light	18.0	14.0	18.0	13.0	38.0
Site 2-2020	Light	18.0	14.0	18.0	14.0	32.0
Site 2-2021	Light	17.0	15.0	17.0	14.0	43.0
	Mean	17.0	13.5	16.5	13.0	35.5
Site 1-2020	Moderate	9.0	11.0	12.0	10.0	14.0
Site 1-2021	Moderate	5.0	8.0	5.0	8.0	9.0
Site 2-2020	Moderate	4.0	8.0	4.0	7.0	10.0
Site 2-2021	Moderate	9.0	9.0	8.0	10.0	10.0
	Mean	6.8	9.0	7.3	8.8	10.8
Site 1-2020	Severe	6.0	4.0	6.0	5.0	7.0
Site 1-2021	Severe	8.0	4.0	8.0	5.0	9.0
Site 2-2020	Severe	8.0	4.0	8.0	5.0	9.0
Site 2-2021	Severe	5.0	4.0	6.0	4.0	9.0
	Mean	6.8	4.0	7.0	4.8	8.5

[y] The leaf removal treatments were LR17-1S, LR17-2S, LR27-1S, LR27-2S, and NOLR which correspond to leaves removed on one side of the rows at stage 17, leaves removed on both sides of the rows at stage 17, leaves removed on one side of the rows at stage 27, leaves removed on both sides of the rows at stage 27, and no leaf removal (control), respectively.

[z] Infection risk was calculated based on equations provided by Carisse et al (2020). Light, moderate, and severe risk of infection, corresponding to a predicted disease severity of >1% and ≤ 5%; > 5% and ≤25%; > 25% leaf area diseased .

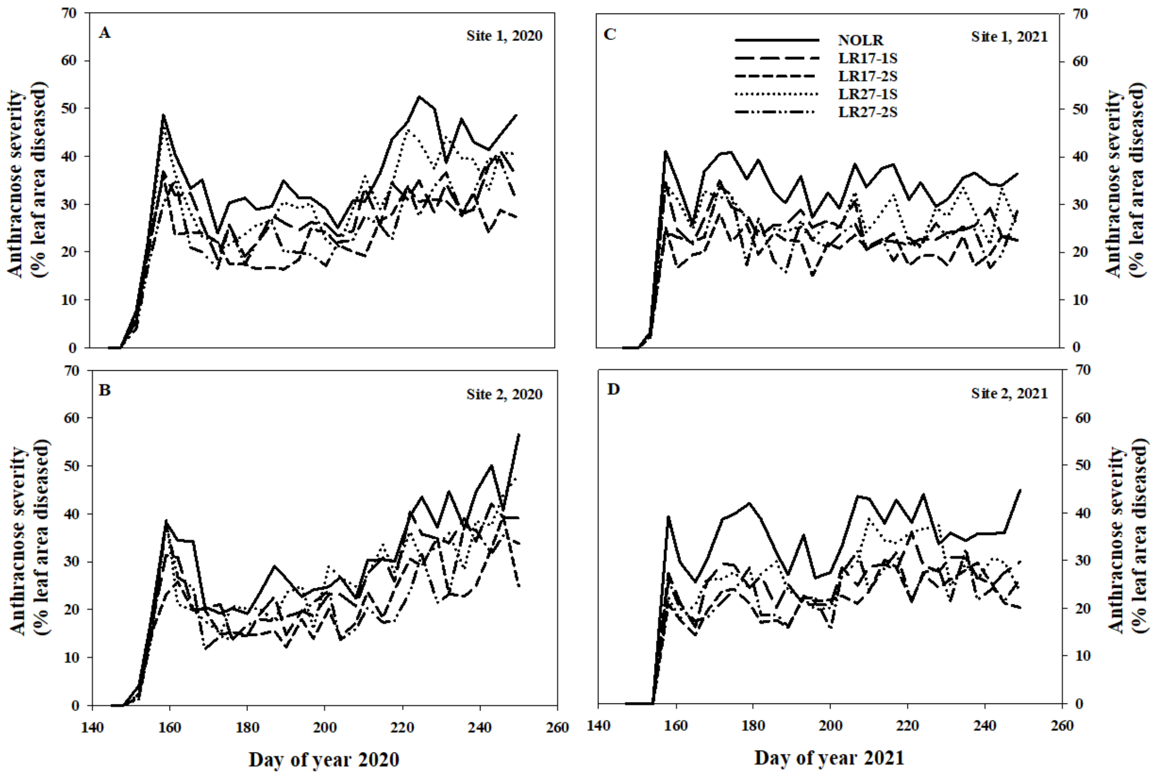

Figure 17. Influence of leaf removal treatments in the cluster zone on anthracnose (caused by *Elsinoe ampelina*) progress on grapevine leaves (cv. Vidal blanc) expressed as percent leaf area diseased. The leaf removal treatments were LR17-1S, LR17-2S, LR27-1S, LR27-2S, and NOLR, which correspond to leaves removed on one side of the rows at stage 17, leaves removed on both sides of the rows at stage 17, leaves removed on one side of the rows at stage 27, leaves removed on both sides of the rows at stage 27, and no leaf removal (control), respectively. The values are means calculated for 15 observations (three replicates × five vines per replicate).

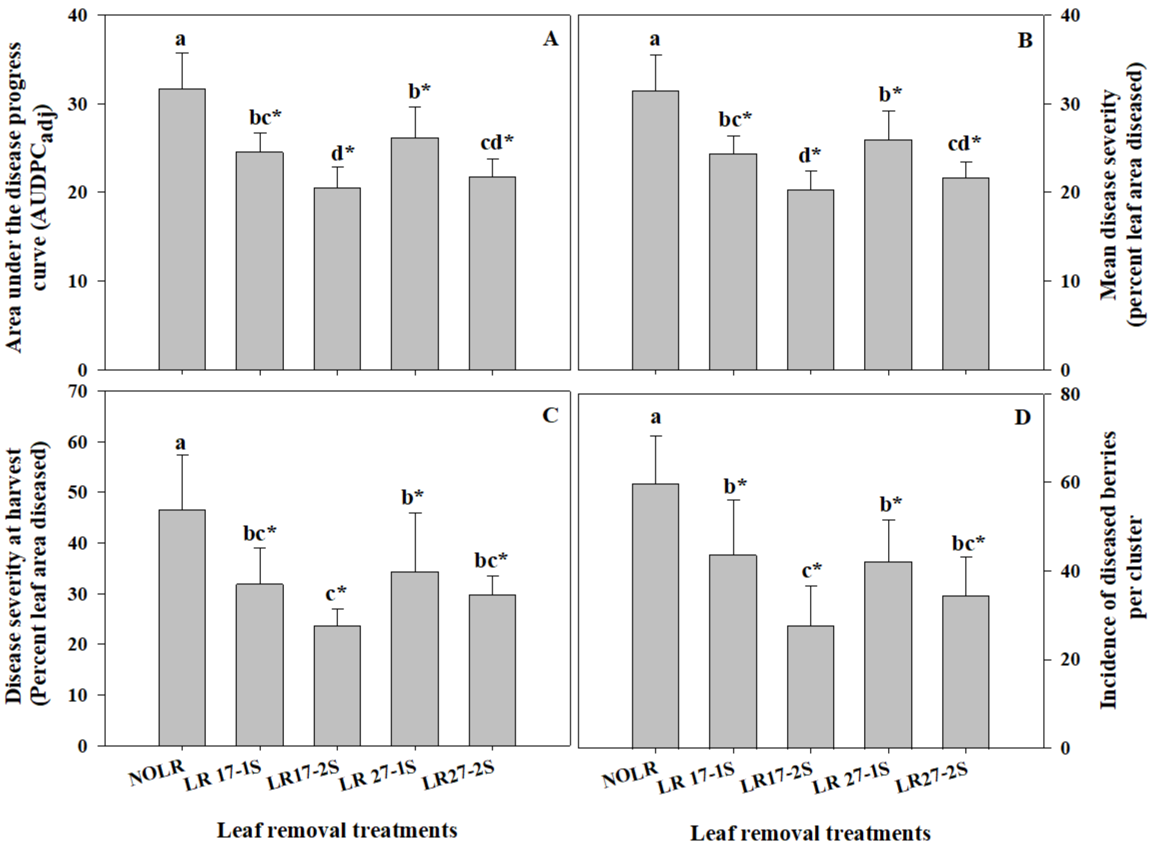

Figure 18. Influence of leaf removal in the cluster zone on the area under the disease progress curve (A), mean disease severity (B), disease severity at harvest (C), and disease incidence on cluster at harvest (D). The leaf removal treatments were LR17-1S, LR17-2S, LR27-1S, LR27-2S, and NOLR, which correspond to leaves removed on one side of the rows at stage 17, leaves removed on both sides of the rows at stage 17, leaves removed on one side of the rows at stage 27, leaves removed on both sides of the rows at stage 27, and no leaf removal (control), respectively. The values are means calculated for 15 observations (three replicate plots × five vines). Bars with the same letter are not significantly different based on Tukey's test at a 0.05 level of significant. Stars accompanying mean separated letters indicate a significant difference at the 0.05 level of confidence from the control (NORL) in which leaves were not removed.

Influence of leaf removal on anthracnose management. At both sites, the first symptoms of anthracnose appeared towards the end of May (Day 146). Thereafter, the disease progressed rapidly and stabilized with a severity level on leaves varying between 5% and 35% of the leaf surface infected (Fig. 19A-B). All anthracnose management programs including leaf removal in the cluster zone reduced anthracnose development compared to the standard program without leaf removal (Fig. 19A-B). The temporal development of grape anthracnose was similar for all treatments however, fewer differences in disease severity between management programs were observed at site 1 than at site 2 (Fig. 19A-B). The area under the disease progress curve (AUDPC) adjusted for the number of sampling days was 15.18, 9.31, 8.20, and 7.145 for the standard program (STD), standard program with leaf removal (STDLR), risk-based program with leaf removal (RISK), and a microclimate risk-based program with leaf removal (MRISK), respectively (Fig. 20A). Regardless of the management program, the AUDPC in plots with leaf removal was significantly lower than in the standard program but there was no significant difference in AUDPC in plots with leaf removal (Fig. 20A). Similarly, the overall mean leaf anthracnose severity, severity at harvest, and anthracnose incidence on cluster at harvest were significantly lower in plots with leaf removal than in the standard program, but the differences between the treatments were not significant (Fig. 20B-D). Mean leaf anthracnose severity was 14.99%, 9.18%, 8.10%, and 7.08% leaf area diseased; severity at harvest was 12.86%, 7.60%, 7.20%, and 6.33% leaf area diseased; and incidence of anthracnose on cluster at harvest was 10.73%, 5.38%, 4.68%, and 4.12% berries infected, for the standard program (STD), the standard program with leaf removal (STDLR), the risk-based program with leaf removal (RISK), and the microclimate risk-based program with leaf removal (MRISK), respectively (Figure 11B-D). On average, the spray coverage in the cluster zone was 22.25% in plots without leaf removal, which was significantly lower than in plots that had leaf removal, with 81.1%, 81.6%, and 83.7% spray coverage in plots managed based on the standard program with leaf removal (STDLR), a risk-based program with leaf removal (RISK), and a microclimate risk-based program with leaf removal (MRISK), respectively (Table 3). More fungicide applications were made in the plots managed based on standard programs, specifically 13 applications, compared to plots managed based on weather-related risk of anthracnose, which had 9 and 10 applications at site 1 and site 2 for the risk-based program (RISK), respectively, and 5 and 7 applications at site 1 and site 2, respectively, when microclimate within the cluster zone was considered (MRISK).

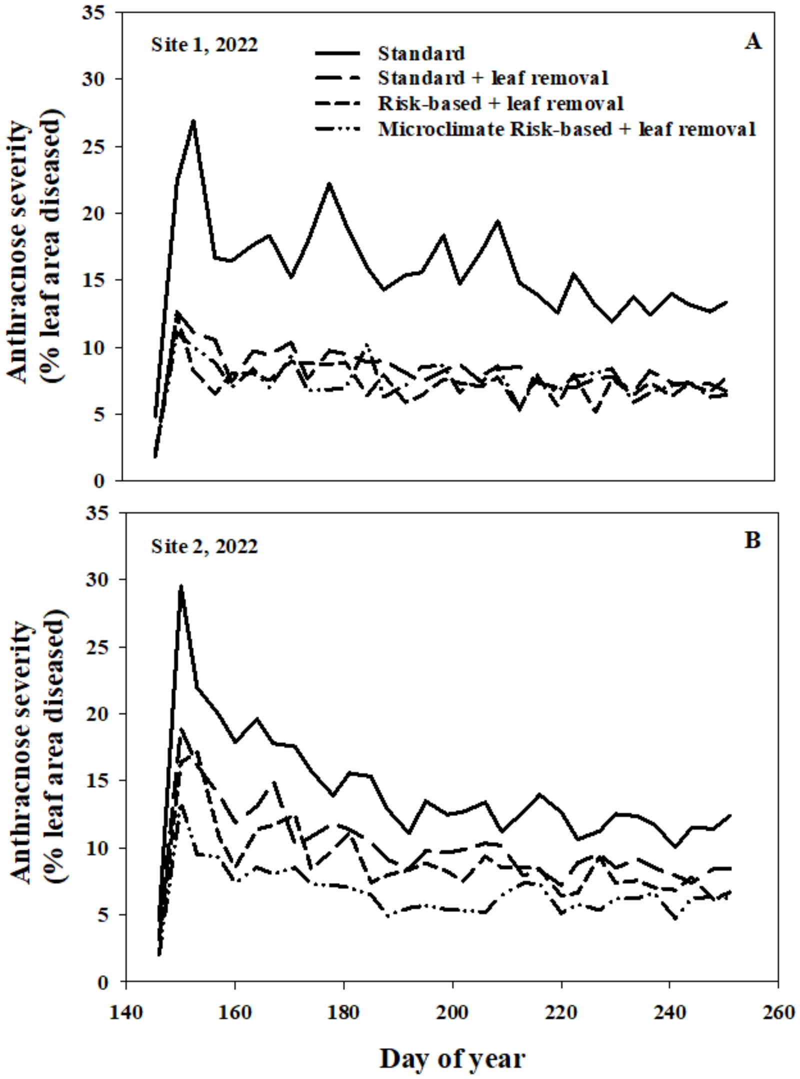

Figure 19. Anthracnose (caused by *Elsinoe ampelina*) progress on grapevine leaves (cv. Vidal blanc), expressed as percent leaf area diseased. Each disease progress curve is from plots where anthracnose was managed using a standard program (STD), a standard program with leaf removal (STDLR), a risk-based program with leaf removal (RISK), and a microclimate risk-based program with leaf removal (MRISK). The values are means calculated for 15 observations (three replicate plots × five vines).

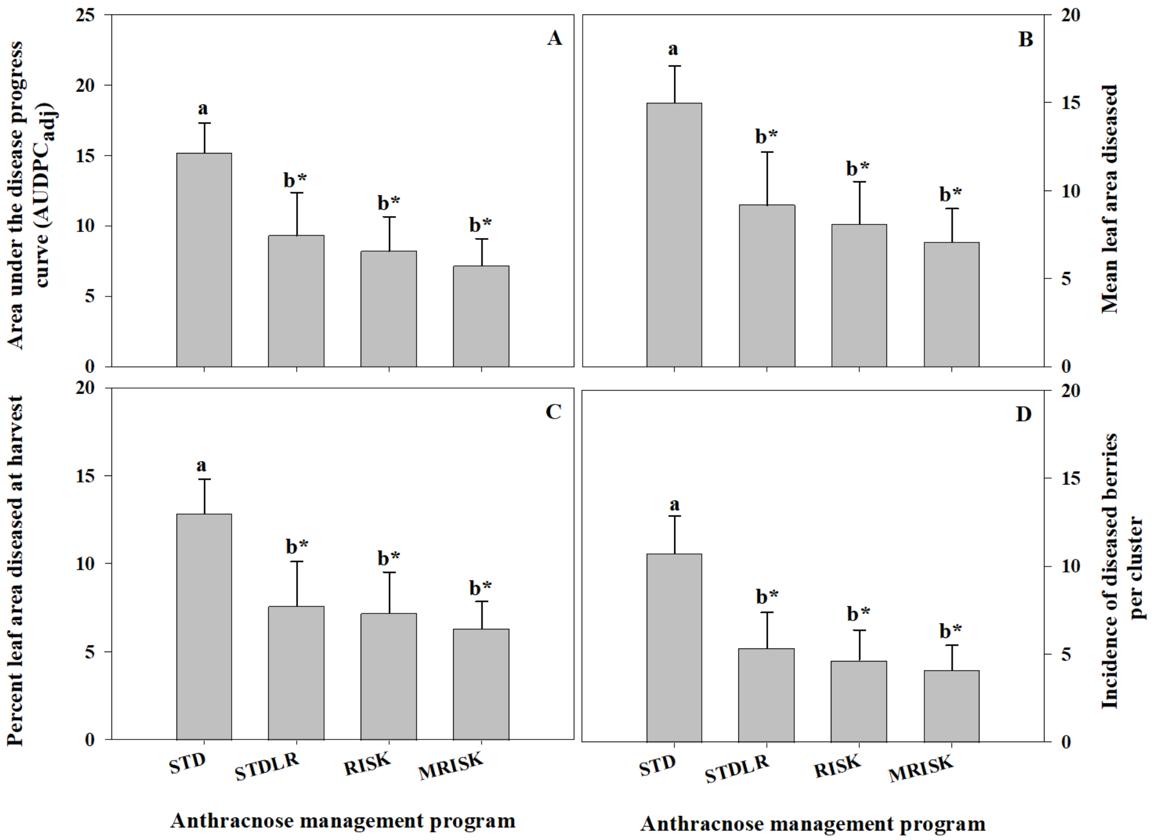

Figure 20. Influence of anthracnose management programs on the area under the disease progress curve (A), mean disease severity (B), disease severity at harvest (C), and disease incidence on cluster at harvest (D). The values are means calculated for 15 observations (three replicate plots × five vines). Each observation is from plots where anthracnose was managed following a standard program (STD), a standard program with leaf removal (STDLR), a risk-based program with leaf removal (RISK) and a microclimate risk-based program with leaf removal (MRISK). Bars with the same letter are not significantly different based on Tukey's test at a 0.05 level of confidence. Stars accompanying mean separated letters indicate a significant difference at the 0.05 level of confidence, with the control corresponding to the standard program (STD).

Table 5. Spray coverage and number of fungicide applications for different anthracnose management programs with and without leaf removal in the cluster zone.

Site	Site 1		Site 2	
Management program[y]	Spray coverage[z]	Number of fungicide applications	Spray coverage	Number of fungicide applications
STD	25.07 (5.72)	13	19.43 (9.90)	13
STDLR	79.97 (1.16)	13	82.05 (9.93)	13
RISK	83.23 (6.91)	9	79.97 (12.26)	10
MRISK	87.67 (3.02)	5	79.73 (5.67)	7

y Anthracnose management programs were as follows: a standard program (STD), a standard program with leaf removal (STDLR), a risk-based program with leaf removal (RISK), and a microclimate risk-based program with leaf removal (MRISK).
z Spray coverage was assessed as percent area covered using water sensitive cards. Values are means calculated for 15 observations (5 cards per replicate × 3 replicates)

Objective 3. Survey of the Quebec grape industry to evaluate the current canopy management practices including timing, level of exposure and the grower's expected benefit.

Overall 62 grape growers from 11 growing regions of Quebec. Overall, 82% of growers were in business since more than 6 years, answered the questionnaire. Typically (87%) of vineyards were small with 1 to 6 ha in production, however 13% of vineyards are larger than 10 ha. Most vineries (56%) are produce from 2000 to 30000L of wine annually and some larger wineries (13%) are producing >30 000L. The most commonly grown cultivars are winter hardy, followed by moderately hardy, and vinifera. The training system vary according to the rusticity of the cultivars with the most commonly used Cordon Royat (53%) on winter hardy cultivars, gobelet (43%) on moderately hardy cultivars, and Guyot (48%) on *viniferea*
Canopy management (CM) involves pruning, shoot thinning, sucker removal, shoot positioning, leaf and lateral removal, hedging and any other practice that manipulates shoots and leaves. Fruit zone management (FZM) involves de-leaf removal around the cluster. Hence growers were asked in each of these practices were applied and on which proportion of their vineyard. Based on the survey, 55%, 80%, 15%, 74%, 69%, and 31% are doing shoot thinning, shoot positioning, vendange en vert, hedging, lateral removal, and leaf removal around the cluster, respectively. These canopy management practices are done manually in 91%, 98%, 97%, 44%, 46%, 84% for shoot thinning, shoot positioning, vendange en vert, hedging, lateral removal, and leaf removal around the cluster, respectively.

Objective 4. Determine the economics of canopy management practices for disease management and fruit quality using cost/benefit analysis.

Considering that the number of sprays, the application rate, and the product used varies according to the susceptibility of the grape cultivars, the season, and the yield objectives of the grower, it is virtually impossible to make a cost-benefit analysis that applies to all situations. Therefore, we present here the results for anthracnose management since we have collected data on fungicide reduction in plots with and without leaf removal.

In the plots without leaf removal a total of 11 fungicide applications were made at a total cost of $1543/ha (product and labor). In the plots with leaf removal but without consideration of microclimate change due to leaf removal, the total cost (product and labor) was $ 2018/ha and $ 1738/ha, for manual and mechanical leaf removal, respectively. In the plots with leaf removal and consideration of the microclimate the total cost (product and labor) was $1748/ha and $1468/ha, for manual and mechanical leaf removal, respectively. Therefore, if we consider only the benefits of leaf removal on anthracnose management, leaf removal is profitable. On the other hand, leaf removal provides other benefits on the management of more than one disease and on the quality of the grape. However, leaf removal also has its share of disadvantages including sunburn and the demand for skilled labor.

Table 6. Cost benefit analysis for of leaf removal in the cluster zone for anthracnose management.

Trait	**No leaf removal**	**Cost**	**Leaf removal**	**Cost**	**Leaf removal (microclimate)**	**Cost**
1	Lime Sulphur	40.00 $	Lime Sulphur	40.00 $	Lime Sulphur	40.00 $
2	Copper	60.00 $	Copper	60.00 $	Copper	60.00 $
3	Inspire	113.00 $	Inspire	113.00 $	Inspire	113.00 $
4	Nova	90.00 $	Nova	90.00 $	Nova	90.00 $
5	Boscalide	72.00 $	Boscalide	72.00 $	Boscalide	72.00 $
6	Inspire	113.00 $	Inspire	113.00 $	Inspire	113.00 $
7	Nova	90.00 $	Nova	90.00 $		
8	Boscalide	72.00 $	Copper	60.00 $		
9	Inspire	113.00 $				
10	Copper	60.00 $				
11	Copper	60.00 $				
	Total	**883.00 $**		638.00 $		488.00 $
	Labor (Hrs)	44	Labor (Hrs)	32	Labor (Hrs)	24

	Labor cost (15$/hr)	**660.00 $**	Labor cost (15$/hr)	**480.00 $**	Labor cost (15$/hr)	**360.00 $**
		1 543.00 $		**1 118.00$**		**848.00 $**
	Manual Leaf removal	- $	Manual	900.00 $		900.00 $
	Total cost	**1 543.00 $**		**2 018.00 $**		**1 748.00 $**
	Mechanical Leaf removal		Mechanica l	620.00 $		620.00 $
	Total cost	**1 543.00 $**		**1 738.00 $**		**1468.00$**

Fruit zone management (FZM) involves de-leafing around the cluster. The effect FZM on light penetration and temperature in the fruiting zone and the resulting impact on grape color, flavor and aroma characteristics was documented by Price et al. (1995). However, the effect of FZM on flavour, aroma and pigment profiles vary with the climate of the production region and the exposure levels to both temperature and light (Spayd et al., 2002, Arnold and Bledsoe, 1990). These practices are considered as good practices and may will limit the development of grape diseases such as Botrytis bunch rot (*Botrytis cinerea*), downy mildew (*Plasmopara viticola*), and powdery mildew (*Erisyphe necator*). The impact of these practices is through promoting microclimate less favorable to disease development (increase aeration and reduced tissue wetness) and by a better fungicide penetration into the canopy (Huglin et Schneider 1998). However, timing is crucial (Smith et al. 1988). Moreover, impacts of FZM on diseases occurrence can be modulate by climatic conditions of the growing regions. There is a cost to FZM, it is thus essential to document their value as a component of integrated disease management as well as of fungicide resistance management. The objective of this part was to determine the economics of canopy management practices for disease management and fruit quality using cost/benefit analysis.

Based on the results of the four years project as well as the time required for fruit zone management during experiments conducted, the costs of FZM practice was calculated including labor and machinery (cost of purchase and use).

Several types of machinery are available in eastern Canada (Tab. 1) to do FZM and may be selected according to vineyard specificities and preferences. Mainly two types of equipment exist, either by blower or by suction. The equipment purchases costs vary according to the machinery acquired and are presented in Table 2. Using mechanization for carrying out leaf around cluster saves significant time in terms of labor and operating costs. Costs vary depending on the equipment. For example, the number of foliage faces worked by a tool (number of cutting heads) directly influences the number of passages required between the rows of vines. Two cutting surfaces allow, for example, to make a single pass per row when a head requires two.

The results of this project demonstrated several advantages of leaf removal, mainly to reduce risk conditions for grape varieties susceptible to disease (grey mould, powdery mildew, etc.) and to improve the exposure of the bunches to the sun and, therefore the quality of the juices.

Leaf removal may be done mechanically or manually. The advantages and disadvantages are presented in Table 3 and can be summarized as follows. The mechanization of operations allows a gain in productivity, a saving in labor time, and a better ratio between precision and the time invested. At the same time, manual defoliation reduces the injuries inflicted on the vine and allows greater precision of the operation. Mechanical FZM has some disadvantages, either that the equipment can cause damage to the vine, it requires regular calibration, the cost of the machinery is high, and the use of the equipment requires skills to operate machinery. On the other hand, manual leaf removal is more labor-intensive and time-consuming, which can generate substantial costs annually.

Thus, the use or not of machinery to carry out the control of foliage around the fruit zone is a choice of the producer according, among other things, to the surface of the vineyard, the availability of labor and the characteristics of the grape varieties present in the vineyard. (presence of sensitive grape varieties or not).

Table 1. List of machinery available in Eastern Canada to do leaf removal.

Designer	Type	Origin	Local distributor
Protechni	1-head blower (forced air)	France	ProduceTech
Collard	Two-head blower (2 half-rows)	France	Lakeview Vineyard Equipment
Ostraticky	Suction with propellers and knives	Czechoslovakia	Agri-Flex
Orizzonti	TRD 500 defoliator	Italy	ProduceTech
Clemens	Suction	Germany	Lakeview Vineyard Equipment, ADJM
BMV	BMV, Suction with rollers	Italy	ProduceTech

Source : CRAAQ

Table 2. Costs of using different defoliators by forced air (blower)

Machinerie	Type	Coût (achat)	Coût d'utilisation/heure	Coût d'utilisation/hectare
Protechni, 1-head blower (half row)	forced air (blower)	39 000,00 $	172,00 $	574,00 $
Collard, Two-head blower (2 half-rows)	forced air (blower)	50 000,00 $	204,00 $	340,00 $
Ostraticky, Suction with propellers and knives	Suction	8500,00 $	120,00 $	400,00 $
Orrizonti, TRD 500 defoliator	suction	22 000,00 $	163,00 $	544,00 $
BMV, Suction with rollers	Suction with rollers	24 000,00 $	165,00 $	550,00 $

Source : CRAAQ

Table 3. Comparison between mechanized and manual leaf removal

Benefits	Disadvantages
Mechanical	
Productivity gains	Losses related to injuries inflicted on clusters if machinery is miscalibrated and used at the wrong time
Savings in working time: 4 to 5 times faster by machine than by hand (4 to 6 h/ha vs 25 h/ha: AGDEX 231/821)	Need to have the machine calibrated by an expert (we are dependent on a salesperson/expert)
Better precision/time control to complete the operation	High cost associated with the purchase of machinery (additional charge)
Lower hourly rate for specialized labor (about $25/h)	Task complexity, higher skill requirements (driver)
Reduced use of pesticides	
Manual	
Gentle gestures and control of the quantity of leaves removed	Greater need for labor (increase in wages)
Decreased mechanical damage inflicted on sprues	Higher labor time (about 24 h/ha)
Greater precision of the operation	Higher salary (more hours worked to leaf removal)
Reduced use of pesticides	

Source : CRAAQ