Influence of Powdery Mildew on Yield and Growth of Rosette Grapevines

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ABSTRACT

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Different levels of infection by the powdery mildew fungus *Uncinula necator* were established on Rosette (*Vitis* interspecific hybrid) grapevines growing in a vineyard at Naples, NY, by deleting portions of the recommended protective spray program. Infected vines had lower pruning weights and hence lower yield. Fruit quality was reduced because of higher acidity. Wines made from infected fruit were reduced in quality. Infection also reduced the winterhardiness of canes.

Implementation of an integrated pest management program for a specific disease and crop depends on the accumulation of knowledge about the pathogen and its development. The impact of disease incidence on yield and crop quality must be quantified and the data incorporated into a model that assesses the impact of the pathogen and its control on economic loss. Data on perennials are particularly difficult to assess because consideration must be given to the effects of one season's disease development on future disease. In addition, the effects of disease on the current season's yield and on long-term yield potential must be considered. Furthermore, the impact of disease on fruit quality may reduce value as well as total yield.

To develop information on the economic impact of powdery mildew (PM) caused by *Uncinula necator* (Schw.) Burr. on vineyards in New York, we studied the relationship between disease development and quantity and quality of Rosette (*Vitis* interspecific hybrid) grapevines in a commercial vineyard during the period 1979–1981.

MATERIALS AND METHODS

Rosette was chosen because it combines PM susceptibility with winterhardiness (8), which ensured survival of infected vines for sufficient time to assess the impact of PM on productivity.

The experiment was conducted in a 4.2-ha commercial vineyard of 20-yr-old self-rooted Rosette vines located in Naples, NY. The row-by-vine spacing was 2.7 × 2.4 m and the experimental design was a Latin square with six treatments and six replicate blocks. Individual plots consisted of three vineyard rows separated by one buffer row. Within each plot, five individual vines near the middle of the midplot row were tagged and monitored for the duration of the experiment.

Variable disease infection levels were established by using six different PM preventive spray programs for three consecutive years. New York Cooperative Extension recommends that spraying of Rosette should begin 2 wk before grape bloom and continue at 10- to 14-day intervals throughout the season (2). The variable spray programs included 1) full-season sprays applied at about 2-wk intervals from just before bloom until about 1 mo before harvest, 2) three early-season sprays applied at 2-wk intervals from the beginning of the spray period, 3) three midseason sprays applied at 2-wk intervals during the middle of the spray period, 4) three late-season sprays applied at 2-wk intervals at the end of the spray period, 5) an extended-season spray program consisting of every second application of treatment 1, and 6) no spray application (Table 1). During the first year and for the first five sprays of the second year, benomyl (Benlate 50W) at 0.56 kg a.i./ha was used for control of PM. Because of the development of benomyl-resistant strains of *U. necator* in various New York vineyards (7), we substituted triadimefon (Bayleton 50W) at 0.07 kg a.i./ha in subsequent sprays.

Each leaf and cluster on four shoots per sample vine was rated for PM once per week using the Barratt-Horsfall system and the data were converted to percent area infected using Elanco conversion tables (11). The exterior foliage canopy surface area for each count vine was also rated by the Barratt-Horsfall system to give a single-value estimate of total infection for the vine.

Cane prunings were weighed and vines were balance-pruned using a 15 + 10 pruning formula (15 nodes retained for

Table 1. Dates of fungicide applications for various spray treatments of Rosette grapevines at Naples, NY

Spray treatment	Fungicide application[z]						
1979	**13 June**	**25 June**	**9 July**	**23 July**	**6 Aug.**	**20 Aug.**	**3 Sept.**
Full season	X	X	X	X	X	X	X
Early season	X	X	X				
Midseason			X	X	X		
Late season					X	X	X
Extended season	X		X		X		X
None							
1980	**6 June**	**23 June**	**7 July**	**21 July**	**4 Aug.**	**15 Aug.**	**2 Sept.**
Full season	X	X	X	X	X	X	X
Early season	X	X	X				
Midseason			X	X	X		
Late season					X	X	X
Extended season		X		X			
None							
1981	**8 June**	**18 June**	**8 July**	**24 July**	**7 Aug.**	**21 Aug.**	
Full season	X	X	X	X	X	X	
Early season	X	X	X				
Midseason			X	X	X		
Late season					X	X	
Extended season		X		X			

[z] Benomyl was used at the rate of 0.56 kg a.i./ha in 1979 and in the first five sprays of 1980. Triadimefon was used at the rate of 0.07 kg a.i./ha in the last two sprays of 1980 and during the 1981 season.

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the first 0.5 kg and 10 nodes retained for each additional 0.5 kg of cane prunings). They were head-trained to the bottom wire of a three-wire vertical trellis and cane-pruned (Modified Keuka High Renewal training). Cluster number and crop weight per vine were determined at harvest. Berry samples were collected from each vine and percent soluble solids (by refractometer) and total acidity (by titration with NaOH) were determined on the expressed juice. Anthocyanin concentration of berry epidermal disks was determined after extraction with methanolic-HCl (10).

In 1981, after hand-harvest of the selected vines, the bulk of the experimental area was harvested mechanically. To assess the relationship between disease infection and damage to the vine canopy by harvesters, the percent trellis fill of leaves was estimated visually before and after mechanical harvest.

In 1980, wines were made using fruit from each treatment by the Department of Food Science and Technology at Geneva (5), and in 1981, impact of PM on wine quality was evaluated by adding variable weights of infected berries to uninfected lots of fruit. Wines were evaluated for sensory quality using a trained taste panel. During 1980 and 1981, the number of nodes per cane with periderm was determined after leaf fall and Merbein bunch counts (1) were made to quantify yield components.

RESULTS

Whole-canopy estimates of leaf infection at harvest showed that 68–92% of the foliage was infected by *U. necator* on unsprayed vines (Table 2). All spray schedules significantly reduced leaf infection, except for the early season coverage in 1980. Percent leaf infection after full-season spraying in 1979, 1980, and 1981 was 39, 48, and 11, respectively. The level of infection on vines receiving full-season sprays was significantly lower than for all other treatments, except vines receiving the extended schedule of four sprays in 1979. There were no obvious trends among the other treatments, except that vines receiving only the early-season sprays tended to have more leaf infection at season's end.

There was a high level of cluster infection on unsprayed vines during the early or midseason (Table 2). About 50% of the cluster area on unsprayed vines had PM, whereas less than 10% was infected on vines receiving full-season sprays.

Vegetative growth (cane pruning weights) was recorded at the end of each respective growing season (Table 3). There was a tendency for pruning weight to increase during the experiment, regardless of treatment. This probably reflects the effects of individual management attention given these vines and the effects of balance pruning, which adjusts the potential crop load to the individual vine's capacity for crop. However, the total vine size increase was inversely related to leaf infection. Compared with vines receiving season-long control, the final pruning weight was significantly reduced on vines that had received no

Table 2. Effect of time of application of protectant sprays of benomyl or triadimefon on the severity of powdery mildew at harvest in Rosette grapevines at Naples, NY

Spray treatment	Percent area infected[z]: Upper leaf (adaxial surface)	Vine canopy	Clusters
1979			
Full season	13 d	39 d	1 c
Early season	43 b	50 c	3 c
Midseason	30 c	47 c	4 c
Late season	56 b	66 b	42 b
Extended season	21 cd	12 d	2 c
None	77 a	77 a	57 a
1980			
Full season	30 c	48 c	7 d
Early season	60 ab	77 ab	14 c
Midseason	51 b	69 b	15 c
Late season	44 bc	71 b	43 b
Extended season	50 b	73 ab	12 cd
None	77 a	92 a	64 a
1981			
Full season	12 e	11 e	1 d
Early season	37 b	42 b	12 c
Midseason	21 d	20 d	5 d
Late season	24 d	38 c	18 b
Extended season	31 c	38 c	13 bc
None	51 a	68 a	42 a

[z]Mean separation within columns and years by Duncan's multiple range test ($P = 0.05$).

Table 3. Cane pruning weight, number of nodes retained per vine, and harvest data of Rosette grapevines on various fungicide schedules for control of powdery mildew during 1979–1981 at Naples, NY

Spray treatment	Pruning wt (kg)	Nodes/vine (no.)	Crop/vine (kg)	Clusters/vine (no.)	Cluster wt (g)	Soluble solids (%)	Soluble solids (kg/vine)	Total acid (g/100 ml)	Anthocyanin ($\mu g/cm^2$)
1979									
Full season	0.71 a[z]	...	8.5 a	98.2 a	86.6 ab	17.7 ab	1.9 a	6.9 a	20.6 a
Early season	0.60 ab	...	5.8 c	64.3 b	90.2 ab	16.6 ab	1.0 d	7.0 a	20.9 a
Midseason	0.65 ab	...	6.1 bc	69.7 b	87.5 ab	18.2 a	1.1 bc	7.0 a	11.0 ab
Late season	0.51 b	...	5.7 c	77.0 b	74.0 b	16.4 b	0.9 cd	7.0 a	21.7 a
Extended season	0.76 a	...	7.3 ab	76.9 b	94.9 a	18.1 ab	1.3 b	6.9 a	21.0 a
None	0.31 c	...	5.8 c	75.1 b	77.2 b	14.6 c	0.8 d	7.5 a	14.5 b
1980									
Full season	1.08 a	20.8 a	7.2 a	94.6 a	76.1 a	19.2 ab	1.4 a	6.1 b	32.7 ab
Early season	0.73 c	18.4 ab	6.1 a	84.4 a	72.3 ab	16.3 c	1.0 b	7.0 ab	22.5 b
Midseason	0.77 bc	19.1 ab	6.3 a	84.8 a	74.2 ab	17.7 bc	1.1 ab	6.3 b	22.8 b
Late season	0.68 c	15.8 bc	4.5 ab	73.2 ab	61.4 b	19.5 a	0.9 b	7.1 ab	22.6 ab
Extended season	0.97 ab	20.9 a	7.0 a	92.6 a	75.6 a	17.7 bc	1.2 ab	6.5 b	21.9 b
None	0.47 d	11.7 d	2.3 b	54.9 b	41.9 c	20.2 a	0.5 c	7.9 a	33.8 a
1981									
Full season	1.15 a	28.9 a	5.1 a	63.8 a	79.9 a	17.2 a	0.9 a	9.1 bc	52.8 b
Early season	1.02 ab	21.5 c	3.3 b	42.1 b	78.4 a	16.6 a	0.6 c	9.5 abc	59.8 b
Midseason	0.97 ab	22.5 bc	4.0 ab	49.6 b	80.6 a	17.6 a	0.7 b	9.1 bc	73.2 b
Late season	0.82 bc	20.9 cd	3.6 b	46.9 b	76.8 a	16.9 a	0.6 c	8.9 c	67.4 b
Extended season	1.02 ab	26.7 ab	4.0 ab	51.4 ab	77.8 a	16.4 a	0.7 b	10.0 ab	82.2 ab
None	0.68 c	16.8 d	1.8 c	25.8 c	69.8 a	17.1 a	0.3 d	10.2 a	107.6 a

[z]Mean separation within columns and years by Duncan's multiple range test ($P = 0.05$).

Table 4. Cane maturity and components of yield of Rosette grapevines on various fungicide schedules for control of powdery mildew during 1980–1981 at Naples, NY

Spray treatment	Periderm internodes/ shoot[z]	Cane and spur shoots/ node	Total shoots/ leaf node	Cane and spur clusters/ shoot	Total clusters/ shoot
1980					
Full season	14.6 a	1.49 a	1.96 a	0.88 a	0.96 a
Early season	12.8 ab	1.61 a	1.94 a	0.89 a	0.94 a
Midseason	13.0 ab	1.58 a	1.93 a	0.85 a	0.95 a
Late season	13.8 ab	1.28 b	1.60 b	0.80 a	0.91 a
Extended season	11.6 ab	1.61 a	1.94 a	0.87 a	0.96 a
None	9.7 b	1.26 b	1.56 b	0.61 b	0.76 b
1981					
Full season	22.0 a	0.68 a	0.83 a	1.27 a	1.10 a
Early season	21.9 a	0.53 b	0.73 ab	1.10 ab	0.99 ab
Midseason	25.6 a	0.61 ab	0.78 ab	1.24 a	1.08 a
Late season	23.6 a	0.58 b	0.74 ab	1.23 a	1.10 a
Extended season	20.7 a	0.53 b	0.72 ab	1.26 a	1.01 a
None	20.1 a	0.42 c	0.61 b	0.87 b	0.73 b

[z]Mean separation within years and columns by Duncan's multiple range test ($P = 0.05$).

Table 5. Effect of mechanical harvesting on loss of leaf area of Rosette grapevines on various fungicide schedules for control of powdery mildew during 1981

Spray treatment	Percent trellis fill: Before 5 Oct.[z]	Percent trellis fill: After 9 Oct.	Percent loss in leaf area
Full season	90.7 a	83.7 a	7.8
Early season	81.4 a	75.0 a	7.9
Midseason	85.6 a	76.3 a	10.8
Late season	83.1 a	75.9 a	13.8
Extended season	84.9 a	83.7 a	13.8
None	69.4 b	40.1 b	42.3

[z]Mean separation within columns by Duncan's multiple range test ($P = 0.05$).

sprays or received sprays only during the last third of the growing season.

Node number on balance-pruned vines was determined by the weight of cane prunings; therefore, node number had the same relationship to PM as did pruning weight. Clusters per vine and crop per vine were determined by nodes retained per vine and generally showed the same relationship to infection that pruning weight did (Table 3). In the final year, unsprayed vines yielded only 35% of the crop compared with vines receiving a full-season spray program. The crop in 1981 generally was reduced, regardless of treatment, because of winter injury. Cluster weight in 1979 and 1980 was reduced as a result of disease. The reduction in cluster weight in 1980 was related to the amount of fruit infection. In 1981, the same trend was evident, but no significant differences were observed.

There were differences in percent soluble solids of the juice in 1979 and 1980 but not in 1981. There was little correlation between soluble solids and infection. Total acid was related to spray treatment, and unsprayed vines had highest acid levels. Generally, anthocyanin concentration was higher on fruit from more severely infected vines. Soluble solids per vine, the product of percent soluble solids and crop weight, were reduced by infection and were primarily related to crop per vine (Table 3).

In the winter of 1980–1981, cane maturity (number of internodes on canes with periderm) was significantly reduced on unsprayed vines (Table 4). Vines receiving full-season sprays had the most periderm-covered internodes and other treatments had intermediate values. Cane maturity was greater after the 1981 growing season, and there were no significant differences among the spray programs.

During the 1980 growing season, after a mild winter in which there was little cold injury observed in New York vineyards, buds on canes and spurs produced 1.5 shoots per node on vines receiving full-season sprays in 1979 (Table 4). Unsprayed vines and vines sprayed only during the final third of the growing season produced significantly fewer shoots per cane and spur node. A similar relationship was observed on total production of shoots per node when shoots developing from base buds (9) were also included in the counts. Cold injury in the winter of 1980–1981 was extensive in New York, and the percentage of shoots produced on spurs and canes or from all buds was greatly reduced. On vines receiving full-season sprays, 70% of the nodes produced shoots, but only 40% of the nodes survived on unsprayed vines (Table 4). The number of shoots per cane and spur node was also reduced on vines receiving sprays only during the first or last third of the growing season. The fruitfulness of buds that grew was also affected by spray program. The number of clusters per shoot was lower on unsprayed vines, regardless of whether only leaf buds or leaf and base bud shoots were counted (Table 4).

Vines with PM had a greater loss in leaf area caused by mechanical harvest than did uninfected vines (Table 5). There was an estimated 42% loss in leaf area during harvest on vines receiving no protectant sprays, whereas vines receiving full-season spray coverage suffered an 8% loss.

A significant number of tasters noted off-flavors in wines made from grapes of vines that did not receive the full-season protection. No off-flavors were noted in the wines made from grapes receiving full-season sprays in 1979, whereas both hydrogen sulfide and mildewlike off-aromas were detected in wines made from fruit of the other treatments. There was a significant, negative, linear relationship between percent infected berries included in the must and wine quality. Using a preference scale of 1 (poor) to 10 (excellent), the relationship between percent infected berries and wine score was $y = 5.6 - \log$ (percent berries with PM). Wines from lots of fruit with 3% or more infected berries received significantly reduced quality scores.

DISCUSSION

Assessing the impact of disease on a perennial crop is complicated by the fact that both long- and short-term effects may be found (3) and should be distinguished. We found that long-term effects of PM infection include reduction in vine size and hence long-term yield potential, reduction in bud fruitfulness, and increased hazard of winter cold damage as a result of lowered vine reserves or poorly matured canes and buds.

In a previous paper (4), we showed that PM reduced photosynthesis of infected leaves of susceptible but not tolerant grape cultivars. To distinguish between the immediate versus long-term effects of this reduction in photosynthesis, we used balance pruning. Balance pruning uses an estimate of total growth during one season, the weight of cane prunings, to predict the amount of crop the vine should carry the next season. One measure of proper cropping is the time of fruit maturation. Vines with similar crop stress should have similar percent soluble solids at harvest. Using this criterion, balance pruning was relatively successful because in the final year of the study, when both vine size and crop level varied widely, no significant differences in percent soluble solids in the fruit were detected.

At the end of the experimental period, there was a 40% reduction in vine size of unsprayed vines compared with sprayed vines. This was associated with a 65% reduction in crop on the unsprayed vines. In addition to a loss of vine capacity, bud fruitfulness was adversely affected by PM.

Another major long-term effect of PM infection was the reduction in winter-hardiness. Even in a year when winter cold stress was not great, bud survival was reduced on infected vines, but after the cold winter of 1980–1981, fewer than one-half of the buds grew on unsprayed vines. This may lead to major economic losses when cold-tender cultivars are grown in New York.

Most vineyards in New York are harvested by machines using horizontal impactors (12). There is always some loss in leaf area as a result of mechanical harvesting, but on diseased vines, this loss was greatly increased. With early-ripening grape cultivars, which may be harvested as many as 7 wk before expected leaf fall, this damage may result in considerable loss of postharvest photosynthesis and reduce the vine's ability to mature ripe, fruitful, winter-hardy canes.

The primary deleterious short-term effects were on fruit development per se. Accumulation of soluble solids is a function of effective leaf area and crop size, but the reduction in acid concentration during maturation takes place in the fruit itself. Berries infected with the PM fungus had higher acid levels than uninfected fruits, indicating they were not developing normally. The increase in anthocyanin concentration in infected berries could be a result of altered physiology but more likely is a reflection of the decrease in vine size. Exposure to direct radiation will usually increase the rate of anthocyanin formation in grapes (13), and berries on small vines will receive more direct radiation than berries on large vines.

Fruit infection with *U. necator* lowered wine quality, both as a result of increased acid concentration and as a direct result of the fungus itself producing off-flavors (6). Generally, wineries in New York specify that the fruit they buy not contain more than 3% (by weight) PM-infected berries. These data support that standard, but we do not have data for infection levels between 3 and 10%.

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