Development, Evaluation, and Implementation of Low Input Systems for Eastern Vineyards

Incorporating the renewal of the project
"Use of Electronic Technology to Deliver Information and Direct Research: The Grape Paradigm"

Final Report
to
The National Research and Extension Program on Low-Input Sustainable Agriculture

Submitted by

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LNE 88-10

Project Summary

This final report consists of three major sections. The first major section contains research reports submitted by the various cooperators covering the results of research completed in 1988. In the second section, copies of journal publications, newsletters, and extension bulletins which cover the significant results and applications of those results are provided. The third and final section consists of an annotated list of scientific and grower meetings at which the results of the project were presented and/or growers were trained in the application of the results to their vineyards.

Our overall goal was to develop low-input systems for eastern viticulture through research on those problems which limited production. Specifically, we sought to lower the costs and maintain the efficacy of weed, insect, and disease control; reduce costs of grapevine culture through mechanization, and to better use existing knowledge through the use of a computer-based expert system. Significant progress was made in all of the areas.

Objective 1. Dormant treatments to eradicate overwintering plant pathogens have demonstrated the feasibility of reducing seasonal fungicide use through this method of sanitation. Discovery of less expensive materials for use in dormant treatments, or discovery of other means of sanitation will allow will make this approach competitive in cost with conventional methods of disease control.

Objective 2. A non-pesticidal means to control the major insect pest of grapes in the eastern U.S. has been developed, registered, and deployed.

Objective 3. Improved knowledge of the effects of mechanical pruning, thining, and harvesting on yields of grapevines have allowed yields to increase with the adoption of this technology.

Objective 4. High resolution weather forecasts now allow the observations at a single ground station to be adjusted for slope, aspect, and other features of remote sites as small as 1 km^2. This has been an important advance in the use of satellite data for disease forecasting systems.

Objective 5. The Grape Expert System (GRAPES) was developed and distributed to over 30 grape growers and advisors in New York and Pennsylvania. The system currently provides growers with the most current recommendations on insect and disease management, and cultural practices for northeastern vineyards.

Report of Research Completed in 1988

The Use of Electronic Technology to Deliver Information and Direct Research: The Grape Paradigm

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20 January 1989

Investigator:
M. J. Saunders
Department of Entomology
Pennsylvania State University

Objective: To further develop the grape expert system (GRAPES), and deliver the system to grape grow in PA and NY.

The knowledge-bases for insect and disease control have been prototyped and coded into GRAPE Functionally, a user can investigate discrete problems solving involving individual pests. Additionally, th user can evaluate multiple problem simultaneously. Further revisions to the knowledge base will take plac pending consultation with Geneva researchers.

A total of 16 growers used GRAPES for the duration of the 88 growing season to evaluate its utili a decision-support tool. These growers were contacted by phone every 2 weeks and surveyed with a questionnaire twice. This continuous feedback resulted in several major program updates which were immediately distributed to the field. A meeting in planned this winter in which these growers will discuss merits and failings of GRAPES with system developers.

Objective: Perform large-plot evaluations of pheromones to disrupt mating of the grape berrry moth as a non-pesticidal means of control.

Two grower cooperators' vineyards (20 acres each) and a vineyard at the ErieCounty Field Resea Laboratory (15 acres) were treated with the GBM pheromone emitters. Adjacent, equivalently sized viney were managed using traditional pesticide applications. Although the data is not fully analyzed, the followi observations are relevant:
The ECFRL vineyard, which traditionally has very low GBM pressure, suffered no damage in either treat

Both cooperators vineyards sustained heavy damage in conventionally treated and pheromone trea plots (as high as 48% damaged berries). This damage was confined the the 8-10 rows bordering Vitis festooned woodlands. This "edge effect" is well known for many of the native pests of grape, and seriou impairs control efforts in years when GBM pressure is high. The pheromone treatment may have preclude mating within the vineyard, but mated females from the woodlands likely flew into the border rows and inflicted the observed damage. In 1989, treatments will include placing pheromone emitters into the wooc well as within the vineyard to attempt to create a buffer zone around the border rows.

Investigator:
James Travis
Department of Plant Pathology
Pennsylvania State University

Objective: To determine the practicality of developing a low input disease management strategy based u the disease potential specific to the northeastern grape growing areas.

Two Arax weather stations were installed along the shore of Lake Erie in Erie County, PA. The stations were located on the lake plain, and on the crest of the Allegheny escarpment south of the lake sho Due to the timing of the 88 project, these monitoring stations were not in place until October. Work has b to link the weather output of the Arax stations to the weather input routines currently implemented in GRA

During the 1988 growing season in Erie County, a protectant spray program was required to cont powdery mildew. Black rot infection periods were few and fungicides for control of black rot were not necessary. Plots that received no fungicides for black rot did not have significantly high levels of black ro than sprayed plots. It is clear from these data that sprays for various diseases can be omitted when environmental factors do not favor disease development. Fungicides were not needed for control of black in 1988. In 1989, we plan to use the weather data collected by ARAX to determine the need for fungicide applications for control of the various grape diseases.

Investigator:
Carl W. Haeseler
Department of Horticulture
Pennsylvania State University

Objectives:

A. Assess effects of mechanical pruning on growth, production, product quality, and cost of production.
B. To determine effects of vineyard reconfiguration.
C. To increase production per unit of land and reduce total vineyard size.

Trickle irrigation: Equipment to set up this experiment did not arrive until the fall of 1988. Therefore, the initial data will be accumulated and assimilated in the 1989 growing season.

Mechanical pruning experiment: consists of data for the past two years.

Treatments:
M = Manually pruned every year
H = Hedge pruned by machine every year
H/H = Hedge pruned, followed up by hand pruning every year
HA = Hedge pruned in alternate years
MA = Manually pruned in alternate years
HHA = Hedge pruned, followed up by hand pruning in alternate years

In the alternate years, those vines so designated were not pruned.

The data reflect that production was significantly increased by all treatments with respect to vines pruned manually every year. The yearly data are supported, also, by the fact that vines with the highest yi produced more clusters per vine than vines pruned manually every year. Fruit from vines pruned manuall each year produced optimum quality fruit whereas, vines pruned by machine only, regardless of the yearly pattern produced unmarketable fruit. Vines hedged and followed up by hand pruning every year appeared be the better alternative to manual pruning every year. Labor cost savings, based on $5.00 per hour, amo to $30.00 per acre on vines that were hedged and followed up by hand every year compared to vines man pruned every year. In addition, production averaged 2.4 tons per acre more in vines hedged and manuall pruned every year than vines manually pruned every year. Based on the past year's payment for grapes, gain of $480.00 per acre was realized as a result of hedging and hand pruning combined every year over t control vines which were manually pruned every year.

Vines treated in other ways, particularly those vines that were not pruned in alternate years, were completely unacceptable due to unacceptable fruit quality. Mineral nutritional concentrations, potassium i particular, were adversely effected by hedging only every year or alternate years. Vines hedged and manu pruned in alternate years also were adversely effected. Thus, an additional cost in fertilization would have be added to the total losses involved in those treatments.

CONCORD SPACING EXPERIMENTS:

Procedures: "Concord" grapevines were planted at three different densities - Normal: 605 vines per acre, times Normal: 806 vines per acre and 2 times Normal: 1210 vines per acre. All vines were trained to the Geneva Double Curtain system of training.

Results: Initial two years of data (Table 3) revealed that the extra cost of plants needed for the closest spac was nearly paid for in two years, which was due to the increase in production per unit of land area. Thus, those vines planted closest in the row returned an average of $1120 per acre, whereas vines spaced the no distance returned an average of $860 per acre, based on the past year's payment of $200 per ton. Thus, th single factor of close spacing in the early years of a vineyard trained to the GDC system appears to be retu a grower's investment sooner than when vines are planted at the normal spacing. A planting configuratior been developed whereby a grower can remove every other plant so as to have a normally spaced vineyard, the need should arise. Disease and insect control has not been a problematical in the closely planted situati date.

Table 1. Response of mature "Concord" grapevines to differential manual and machine pruning techniques.

Treatment	Yield Tons/acre	Yield Clusters/vine	Cluster Wt (lb)	Berry Wt (g)	Soluble Solids (%)
M	5.4	99.0	0.182	3.22	16.0
H	7.0	188.0	0.119	2.66	13.4
HT	7.4	140.0	0.181	3.18	14.8
HA	9.6	262.0	0.123	2.71	13.2
MA	7.6	220.0	0.143	3.26	14.4
HTA	6.4	185.0	0.135	3.10	14.4

Table 2. Effect of differential hand and mechanical pruning techniques on the mineral nutritional status of "Concord" grapevines.

Treatment	N	P	K	Ca	Mg
M	0.99	0.18	1.11	1.04	0.44
H	0.97	0.24	0.64	1.27	1.08
HT	0.98	0.16	1.08	1.01	0.34
HA	1.00	0.19	0.77	1.33	0.91
MA	1.00	0.14	1.44	1.17	0.55
HTA	0.98	0.15	0.92	1.16	0.60

Table 3. Effect of vine spacing on performance of "Concord" grapevines in the two initial production years after planting.

Treatment (vines/acre)	Yield (tons/acre)	Clusters (no./vine)	Cluster weight (lb)	Soluble solids (%)	Juice pH	Total acidity (g/100g)	Pruning weight (lb/vine)
1.0 N	4.3	42	0.340	18.4	3.36	1.26	3.0
1.5 N	5.0	38	0.329	18.1	3.38	1.26	2.4
2.0 N	5.6	31	0.298	18.3	3.35	1.24	1.7

Investigators:
David M. Gadoury and Roger C. Pearson
Department of Plant Pathology
Cornell University

Objective: Field evaluation of dormant eradicant sprays in commercial vineyards for control of powdery mildew and other diseases.

Lime sulfur was applied just before bud break as an over-the-trellis spray at 36 gal/acre in 300 gal/acre of water to large (1-3 acre) plots of Chardonnay vines in Hector and Dresden, Seyval vines in Dresden, and Concord vines in Westfield. Adjacent plots of the same cultivars received no dormant treatment. Seasonal sprays were applied to some vines in each plot, while others remained unsprayed during the growing season. In all cases, the dormant spray delayed mildew development on leaves and fruit by 2-4 weeks. On the cultivars Concord and Seyval, the single dormant spray controlled powdery mildew as well or better than several seasonal fungicide applications. The dormant spray did not provide acceptable commercial control when used as the only spray on Chardonnay, but did significantly improve mildew control in Dresden when combined with seasonal sprays. In Hector, the dormant lime sulfur spray also reduced the incidence of black rot on Chardonnay. Dormant eradicant sprays may be an effective, low cost method to augment or replace seasonal fungicide sprays for control of powdery mildew and other diseases.

In laboratory tests, a fluorescent vital stain was used to identify fungicides that killed cleistothecia of the powdery mildew fungus. Lime sulfur, copper sulfate, bordeaux mixture, and Karathane were selected for vineyard evaluation. Sprays were applied to replicated 120-vine plots of the cultivar Rosette using 300 gal/acre of water. Each of these compounds significantly reduced foliar and fruit infection by the powdery mildew fungus. The percentage of the cluster surface infected on treated vines ranged from 0.01 to 0.16%, while control vines bore fruit with 4.6% of the cluster surface infected. Due to unusually dry weather, black rot, downy mildew, and Phomopsis cane and leaf spot did not occur on unsprayed vines, thus none of the compounds could be rated for efficacy against these diseases. Copper sulfate was selected for further study due to its low cost and efficacy. In laboratory tests conducted in April and May, copper sulfate killed approximately 90% of treated cleistothecia exposed to the compound for only 5 minutes. Newly matured cleistothecia collected in August and September were less sensitive to copper sulfate and survived exposures of several hours. In order to conduct large scale commercial tests, an application for a Special Local Need (24-C) Label has been submitted to the New York Department of Environmental Conservation for use of copper sulfate as a spring dormant treatment to control powdery mildew.

Objective: Determine effects of initial inoculum levels on disease development

The actual number of viable cleistothecia on bark of vines of the cultivars Rosette, Concord, Chardonnay, and Seyval was determined before and after a dormant eradicant treatment of lime sulfur. Disease development at the various levels of inoculum was then compared. On Concord vines, powdery mildew had infected 0.03 leaves/shoot on 7 July at an inoculum level of 85 cleistothecia/kg bark, while 2.90 leaves/shoot were infected by the same date in an adjacent vineyard with 2,844 cleistothecia/kg bark. No significant fruit infection occurred on unsprayed vines in the vineyard with the lower inoculum level, but over 30% of the cluster surface was infected on unsprayed vines in the vineyard with the higher inoculum level. Repeating and expanding this study may eventually allow the development of threshold levels of inoculum for various cultivars below which control measures for powdery mildew can be significantly delayed or omitted with minimal risk.

Objective: Suppression of powdery mildew by eradication of primary infections

Various steps in the germination and infection process of ascospores were investigated. Ascospores germinated in free water, and at relative humidities as low as 54%. Although water is necessary for ascospore discharge, it is not required for germination and infection, nor was it harmful (as is often reported for conidia, the secondary spores of the pathogen). Infection of grape leaves occurred from 50-77 F. No infection occurred at 41 F or above 77 F. Ascospores will be released from cleistothecia during rain, and will infect if temperatures remain in the range of 50-77 F, even if the foliage and fruit dry before infection occurs.

Rules were formulated to schedule combined applications of Bayleton and Ridomil based upon exposure of vines to infection when ascospores were released from cleistothecia. Presently, sprays are timed according to host growth. This results in the first spray being applied long after the host has been infected. We applied the first spray to vines of the cultivars Chancellor, Delaware, Aurore, Niagara, and Rougeon within 6 days after the first 0.10 inches of rain after bud break (this amount of rain is needed to release spores). Subsequent sprays were applied after 21 days had elapsed since the last spray and rainfall was recorded (we assumed 21 days of fungicidal protection after an application). This schedule also provided simultaneous control of black rot and downy mildew. During the dry 1988 season, vines treated on this schedule received four fungicide sprays compared to six sprays applied on the standard program. Disease control was equal with both schedules. Because 1988 was unusually dry and did not favor development of downy mildew and black rot, the rules we used to time fungicide sprays should be evaluated under conditions more favorable to development of these diseases before they can be recommended. The rules, however, have already demonstrated that substantial savings in disease control costs can be made by tailoring applications to the biology of the three major grape pathogens during dry weather.

Publication of results (1988 only)

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Investigator:
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Objective: Generate and deliver weather forecasts at a high resolution (1km).

With few exceptions, plant diseases are never forecast, at least in the sense of predicting disease in advance (Seem and Russo, 1983). What are called disease "forecasts" are usually limited to evaluation of current weather conditions and a determination of how favorable or unfavorable those conditions have been for disease development. On the other hand, if weather forecasts are used as predictors of disease then a certain level of precision is lost because disease development is so much a function of local weather conditions; weather forecasts cannot predict accurately very localized conditions.

We report a method of true disease forecasting based on 24- and 48-hr weather predictions for areas as small as one km^2. The method, called model output enhancement or MOE, performs additional analyses of standard output from numerical (computer) weather forecasts by combining the forecasts with elevation data from a geophysical data base (Kelley et al, 1988). The approach is based on the knowledge that topography and other surface features exert a strong influence on mesoscale weather systems, and hence, can be used indirectly to predict smaller-scale, short-term conditions close to the farm level. The technique involves a three-step process: 1) interpolation of numerical model output (at the 700-850 mb or about 1500 m level) to approximately 1 km^2 resolution; 2) extrapolation of the interpolated data to the surface using theoretical and observed temperature lapse rates; and 3) "enhancement" or adjustment of the extrapolated surface values with digital terrain data. Thus individual forecasts can be provided for each point in the geophysical data base, in this case, 1 km^2. The forecast parameters include 2-hr estimates of temperature, relative humidity, rainfall, and leaf wetting. These parameters can be adapted easily to standard prediction rules for plant diseases such as potato late blight, grape downy mildew or apple scab. A scenario for the forecast of potato late blight has been proposed (Russo et al, 1988).

In 1988 we developed a program to forecast weather parameters (temperature, relative humidity, leaf wetting duration and rainfall) and downy mildew disease development. We utilized a 1987 subset of numerical weather forecasts from the U.S. National Weather Service for the period April through July. The data were processed by the MOE algorithm modified to predict the level of grape downy mildew infection using combined criteria for Smith wetting periods and infection periods (Seem and Pearson, unpublished). Results (weather parameters) were compared to the predictions based on hygrothermograph and leaf wetness recorders at six locations in New York State. Temperature forecasts up to 48 hr in advance are within 2 C of the actual temperature. Relative humidity, calculated as hours above 90%, is predicted with similar accuracy. The moisture parameters, rainfall and duration of leaf wetting, have been more troublesome to predict, but revisions to the MOE algorithm have resulted in steadily improving predictions.

Results from the MOE plant disease forecast can be presented either as numeric forecasts (weather and disease) for individual 1 km2 locations or as high-resolution regional maps. The maps can be displayed as two-dimensional greyscale, as color-class maps, and as color-class maps overlaid on perspective plots of terrain. For an area the size of New York State, such a map contains over 300,000 pixels and permits easy interpretation weather or plant disease expected within the next 48 hours. It is possible to deliver this information to advisors (and growers) in a timely and cost-effective manner.

True plant disease forecasting using the MOE technique only provides guidance information for growers. It is important that the MOE forecast be validated or confirmed by local weather and disease monitoring. Having a 24- or 48-hour lead for making disease management decisions can be a major aid to producers, but it must be viewed as complementary to, and not a replacement of, the current methods of plant disease "forecasting."

References

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Russo, J. M., Kelley, J. G. W., and Royer, M. H. 1987. High resolution weather forecast data as input into a plant disease model. 18th Conference on Agriculture & Forest Meteorology, West Lafayette, IN, 15-18 September.

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Publication and Presentations

Seem, R. C., Russo, J. M., Kelley, J. G. W., and Royer, M. H. 1988. Progress towards true forecasting of plant disease. Ann. Mtg. Am. Phytopathol. Soc., San Diego, CA, 14 November.

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Investigators:
T. J. Dennehy and J. P. Nyrop
Department of Entomology
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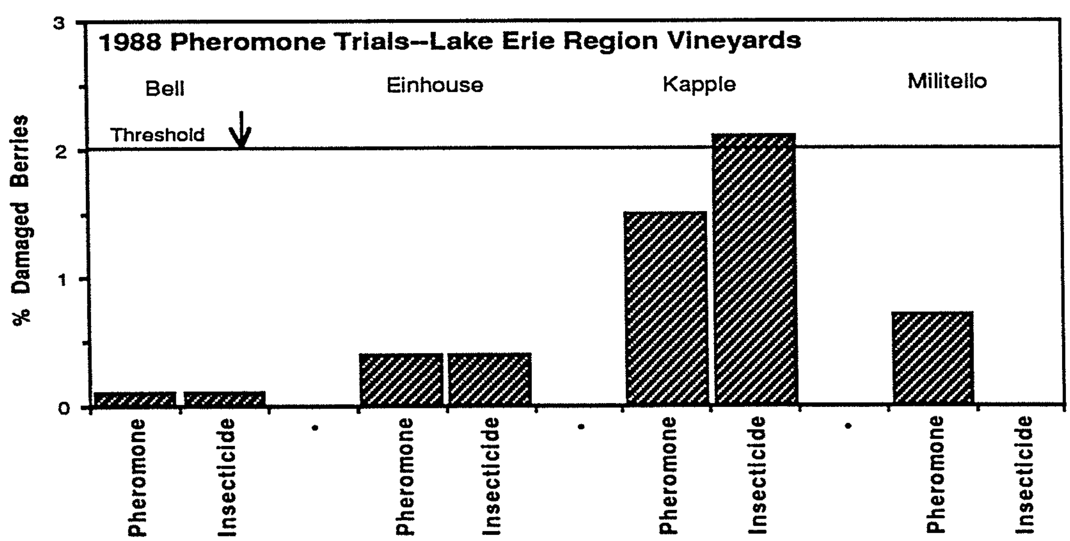
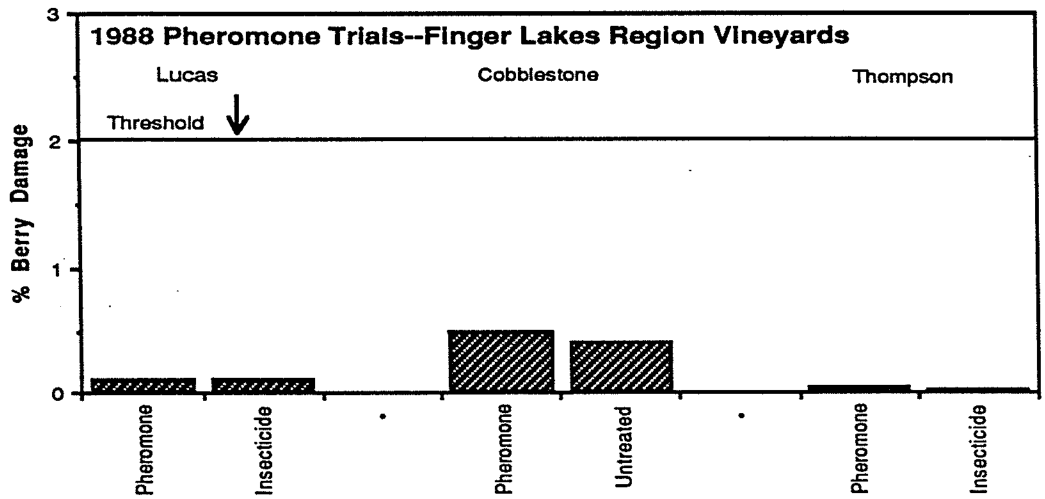
Objective: Perform large-plot evaluations of pheromones to disrupt mating of the grape berrry moth as a non-pesticidal means of control.

The Shin-Etsu pheromone tie was evaluated in approximately 100 acres of New York vineyard in 1988. Four vineyard sites were located in the Lake Erie Region and three in the Finger Lakes Region. In all but one case, comparisons were made between control of grape berry moth obtained within vineyard areas treated by grape growers with 2 to 3 conventional insecticide sprays and control obtained from treatments of 200 Shin-Etsu pheromone ties per acre. At one location, the Cobblestone Organic Vineyards, the grower applied no conventional insecticides to any vines.

Lake Erie Region Trials. At all four Lake Erie Region vineyards the pheromone treated plots produced successful control of grape berry moth: damage was well below the 2% industry-stipulated threshold. At two locations, the Bell and Einhouse vineyards, pheromone treatments and insecticide treatments produced essentially identical results. At the Kapple vineyard the pheromone treatment produced better control than the two insecticide treatments made by the grower. Though insecticides produced better control than the pheromone at the Militello vineyard, damage in the pheromone plots was very low and less than half of the threshold level.



Finger Lakes Region Trials. Pheromone-treated vineyards in the Finger Lakes Region all had levels of grape berry moth damage that were well below the 2% threshold. Control in pheromone and insecticide-treated blocks was comparable at the Lucas and Thompson vineyards. Though low berry moth damage was observed in the pheromone blocks at the Cobblestone Organic Vineyard location, the comparison block which was not treated with any pesticides had relatively low damage also. This result of low damage in the untreated area at Cobblestone was due to differences in berry moth damage from area to area within the vineyard.



How do these pheromone trial results size up with that which growers normally get from insecti treatments? The following figure shows results of random surveys of grape berry moth damage in 198: in vineyards that growers had treated with conventional insecticides. The figure shows that it is not unc for insecticide-treated vineyards to have greater than 2% damaged berries. Indeed, the pheromone prod appears to be giving control of grape berry moth on a par with the conventional insecticides, parathion a carbaryl.

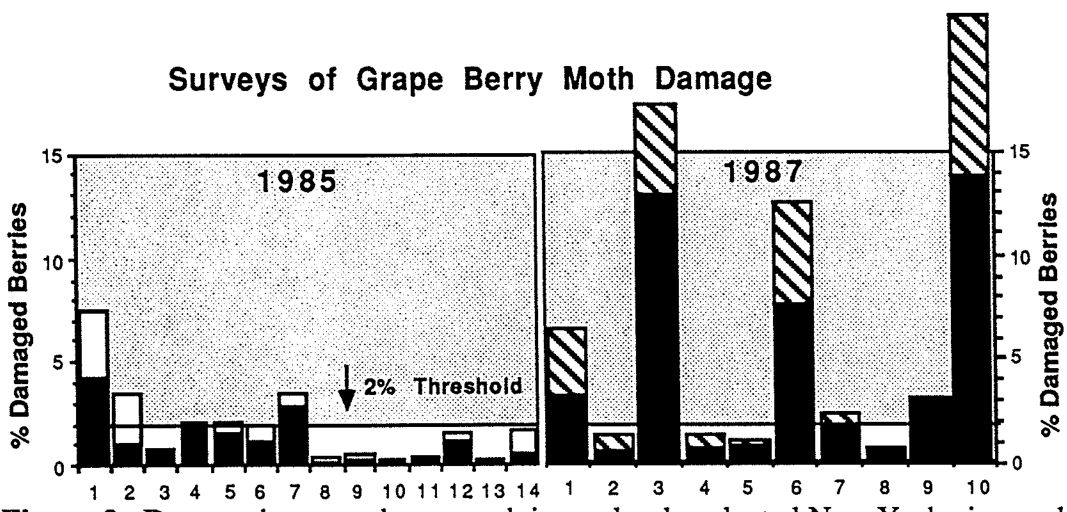


Figure 2. Damage by grape berry moth in randomly selected New York vineyards in 1985 and 1987. histogram bar representing each vineyard depicts damage at the vineyard edge (larger value) and damage the vineyard interior (lower value).

Report of Research Completed in 1989

Development, Evaluation, and Implementation of Low Input Systems for Eastern Vineyards

Investigators:
David M. Gadoury and Roger C. Pearson
Department of Plant Pathology
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Objective

Refine the technique of using dormant eradicant sprays, thereby making it an effective, practical method to replace or augment seasonal fungicide sprays.

A. Determine gallons of water/acre needed for effective eradication, compare airblast (low volume) and hydraulic (high volume) application equipment, and determine the potential for injury to vines caused by copper sulfate when used as a dormant eradicant spray.

B. Determine efficacy of dormant season applications of copper sulfate against powdery mildew, black rot, downy mildew, Phomopsis cane and leaf spot, and angular leaf scorch under conditions of severe disease.

C. Develop guidelines for use of dormant treatments on highly susceptible, moderately susceptible, and moderately resistant cultivars.

Presented at the 1988 annual meeting of the New York Wine and Grape Foundation

INVESTIGATION OF HOST AND ENVIRONMENTAL FACTORS THAT INFLUENCE THE AVAILABILITY OF PRIMARY INOCULUM (CLEISTOTHECIA) OF GRAPE POWDERY MILDEW AND PROSPECTS FOR IMPROVING CONTROL

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Introduction

Prior to this research project, the grape powdery mildew pathogen, *Uncinula necator*, was assumed to survive winter in New York only in infected buds, despite the regular production of sexual overwintering structures called cleistothecia. *U. necator* had been conclusively shown to overwinter in infected buds in Europe and California. Cleistothecia had been investigated by various researchers in the United States and Europe since the late 1800s, but no study had reproduced the disease from cleistothecia. Therefore, dormant infected buds were assumed to be the only significant source of inoculum, and cleistothecia were widely reported to be nonfunctional, degenerate structures of little consequence in the epidemiology of the disease.

Buds infected by *U. necator* give rise to heavily mildewed shoots called flag shoots, which are dwarfed and white with a coating of powdery mildew. Despite their conspicuous appearance, in 1985 there was no direct evidence for *U. necator* surviving in infected buds in New York. Our research project was therefore initiated to investigate the role of cleistothecia in the epidemiology of grape powdery mildew.

Vineyard Surveys (1983-1988)

Vineyards in the Long Island, the Finger Lakes, and the Lake Erie growing regions were systematically surveyed for flag shoots in early spring for six years. Although over 100,000 vines were examined, none were found to bear flag shoots. These results ruled out infected buds as a consistent and significant source of primary inoculum for grape powdery mildew in New York.

Initiation and Development of Cleistothecia (1986 and 1987)

We investigated host and environmental factors that cause cleistothecia to be initiated and grow, in the belief that understanding these processes would provide information on their role as overwintering inoculum. We found that mildew populations are composed of two mating types, and that cleistothecia formed only when the two mating types were paired on the same leaf. Thereafter, the rate of growth was determined by temperature and host resistance. The incidence and severity of disease determined when cleistothecia were initiated and, consequently, whether or not they matured before the leaves were killed by frost in autumn. Cleistothecia will form regularly in New York vineyards, but these results indicate that we may be able to prevent their maturation by delaying their initiation through disease suppression in early spring and summer.

Dispersal and Survival of Cleistothecia (1986 and 1987)

We found that cleistothecia formed a thread-like network, called anchorage hyphae, that fastened them to the mildew colony as they grew. The final event in development was the abscission of the anchorage hyphae, allowing the cleistothecium to be swept away by rain. Rain dispersed cleistothecia to the bark of the vine and to the surface of the soil in vineyards, but only those cleistothecia on the bark survived winter. Cleistothecia that remained behind on leaves, canes, and berry clusters were morphologically mature, but physiologically immature, and died during winter. Earlier researchers had invariably inoculated grapevines with the dead cleistothecia that were still attached to mildew colonies. This explained the failure of previous studies to demonstrate that cleistothecia were a source of inoculum. When we harvested overwintered cleistothecia from bark and inoculated vines with spores from these cleistothecia, we easily reproduced the disease. These studies proved that cleistothecia on the bark of the vine were the principal source of primary inoculum for grape powdery mildew in New York.

Discharge of Spores from Cleistothecia (1986 and 1987)

Lab studies showed that cleistothecia discharged spores, called ascospores, only when wet, and that the percentage of spores released was reduced at low temperatures. In fact, at 40 F, spore release was nearly completely suppressed. A spore trap was operated in a vineyard during the 1986 and 1987 growing seasons. Ascospores were trapped only during or immediately following rain in excess of 0.10 inches when temperatures were above 40 F. Furthermore, the period of spore release began at bud break and was completed shortly after bloom. These studies identified the season of primary inoculum release and the environmental conditions that promoted release and dispersal of the primary inoculum. Our results also showed that significant infection occurs in commercial vineyards prior to the initiation of the fungicide spray program, which generally is initiated shortly before bloom.

Germination of Ascospores and Infection of *Vitis* (1988)

We found that ascospores of *U. necator*, unlike the secondary spores produced on mildew colonies, germinate equally well in water and on dry surfaces at temperatures between 50 and 75 F. No infection occurred below 50 F or above 75 F. Therefore, ascospores can be expected to cause infection following rain in the amount of 0.10 inches that falls between bud break and bloom, when temperatures are between 50 and 75 F. These criteria can be used to time fungicide applications for control of powdery mildew. A program of four post-infection sprays timed according to these criteria in 1988 controlled powdery mildew as well as a program of six conventionally timed protectant sprays.

Eradication of Cleistothecia to Control Powdery Mildew (1986-1988)

Over-the-trellis sprays of lime sulfur at 36 gallons per acre in 300 gallons of water delayed epidemics of powdery mildew for two-three weeks on highly susceptible *Vitis vinifera* cultivars, and for three-four weeks on more resistant *Vitis* interspecific hybrid cultivars and on *Vitis labrusca* cultivars. These treatments also provided nearly complete control of angular leaf scorch and partial control of Phomopsis cane and leaf spot and black rot. Angular leaf scorch, but not powdery mildew, was affected when the rate of lime sulfur was reduced to 12 gallons per acre. A 24-C (Special Local Need) label has been obtained for lime sulfur as a dormant treatment to control powdery mildew in New York. The cost of material for this treatment makes it impractical except in rare circumstances. Copper sulfate was more effective than lime sulfur as an eradicant of cleistothecia in lab studies, and was as effective as lime sulfur in delaying powdery mildew in vineyard trials in 1988. An application for a 24-C label for copper sulfate has been submitted based upon this work. Copper sulfate may serve as a low cost alternative to lime sulfur, but further studies are needed to address questions of phytotoxicity, and efficacy against other diseases.

Vineyard trials in 1988 showed that dormant treatments can provide seasonal control of powdery mildew on V. labru*sca* Concord, and that the dormant treatment was superior to late season sprays on the cultivar Seyval. On V. *vinifera* Chardonnay, the dormant treatment increased the apparent efficacy of an intensive program of 11 seasonal fungicide sprays. Further work will develop guidelines for use of dormant eradicant treatments on cultivars that differ in susceptibility to powdery mildew. The use of dormant treatments is consistent with several goals in disease management: (i) they reduce disease control costs by reducing or eliminating the need for seasonal sprays, (ii) they appear to have some activity against diseases other than powdery mildew, and (iii) they reduce the pathogen population size and the number of cycles of exposure to fungicides, an important part of the management of fungicide resistance.

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eradication of primary inoculum, the use of inoculum measurements and weather, and the integration of control measures for powdery mildew and other grape diseases

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Dormant eradicant treatments of copper sulfate and lime sulfur

In general, dormant treatments provided mediocre control of powdery mildew in 1989, irrespective of choice of material, gallonage per acre, rate of active ingredient, or method of application. The exception was a trial conducted on Rosette in Geneva, where an over-the-trellis spray of lime sulfur at 12 gal/acre in 300 gal/acre of water applied when shoots were 1 inch long provided season-long control of powdery mildew on fruit. Foliage infection was delayed by lime sulfur, but was not suppressed to the same degree as fruit infection, an event that has occurred in past studies and is probably related to increasing resistance to infection as fruit matures. The substantial disease control afforded by this delayed eradicant treatment in a year of unusually high rainfall, taken together with the poor performance of other treatments applied before bud break, indicates that significant improvements in efficacy of lime sulfur, and perhaps copper sulfate, treatments may be possible if they are applied after bud break.

No consistent reduction in incidence or severity of black rot or downy mildew was seen in dormant treaments. However, on the cultivar Concord, both lime sulfur and copper sulfate significantly reduced sporulation of *Phomopsis viticola* and the severity of leaf, rachis, and internode infection.

Relationships between overwintering inoculum levels and disease

The correlation between disease incidence, severity, and the number of cleistothecia of *Uncinula necator* that are subsequently dispersed to bark is poor. It appears that disease severity determines the potential number of cleistothecia formed in a vineyard, but not the number that are dispersed to the bark. Other factors are involved in dispersal and deposition of cleistothecia on bark. We have devised a simple paper funnel trap that can be used to catch and quantify cleistothecia of the grape powdery mildew pathogen as it is dispersed by rain in late summer and early fall. The catches of cleistothecia in these funnel traps are highly correlated with the number of cleistothecia found on bark, and the technique of trapping cleistothecia during dispersal appears to offer a rapid and accurate way to estimate inoculum dose in a vineyard. Extensive studies will be needed before we can relate the density of *U. necator* populations on bark to the subsequent threat of disease. A proposal to conduct these investigations has been submitted to the New York State IPM Program.

Ascospores of *Guignardia bidwellii* were released from overwintered mummified berries beginning shortly after bud break, increased to a peak approximately 3 weeks later, and was completed shortly after bloom. Ascospore release by *U. necator* followed a similar pattern. It would appear that growth stages of grape may be used as indicators of the beginning and termination of primary inoculum release by these two pathogens.

Early season protection of grapevines

We treated Chardonnay grapevines with Dikar™ (4 lb/acre) + Karathane™ (1 lb/acre) every 10 days beginning at one-inch of shoot growth and continuing until the supply of powdery mildew and black rot ascospores was exhausted. The goal was to determine if highly effective, early season control would allow an early termination of the spray program. Sprays were applied on 23 May, and on 2, 12, and 22 June. On 12 July, 20 days after the last fungicide application, only 0.15 leaves per shoot bore powdery mildew colonies, and on three of 150 fruit clusters examined, a single berry was infected (0.007% fruit surface infected). Twelve days later on 24 July, there were 9.0 infected leaves per shoot and average fruit surface infected had increased to 1.6 per cent. These are relatively small numbers, but represent a 60-fold increase in leaf infection and a 228-fold increase in fruit infection. Fruit surface infection continued to increase rapidly in the absence of fungicidal protection to 23.9 per cent by 17 August, even though the experiment was terminated by the application of Nova™ (5 oz/acre) on 2 August. The results indicate that early season termination of fungicidal protection on Chardonnay can potentially result in high levels of leaf and fruit infection. Eventually, it may be possible to establish threshold levels of disease for various times of the growing season, below which spraying can be safely terminated. However, in the absence of these thresholds, it is important to maintain disease at trace levels until fruit acquire some resistance to infection (ca 5.0 brix). The rapidity with which the disease increased on fruit, and the incomplete success of a highly effective fungicide (Nova™) to halt this increase illustrate the importance of effective disease control on highly susceptible cultivars.

Simultaneous control of black rot and powdery mildew with post-infection fungicide sprays

Two acres of Aurore in a commercial vineyard in Dresden, New York, were divided into three one-acre plots. One plot was treated with Nova™ in a post-infection program. Weather instruments to record rainfall (onset, duration, intensity, and amount), temperature, relative humidity, and leaf wetness were installed in the vineyard. The first post-infection spray of the season was applied when the following conditions were satisfied: (i) inoculum of *U. necator* or *G. bidwellii* was available for discharge, and (ii) temperature and rainfall criteria were met for infection by either pathogen. Fungicides were applied within six days of rainfall if the requirements for infection by *U. necator* were met, or within three days of rainfall if requirements for infection by *G. bidwellii* were met. Fungicides were applied following subsequent infection periods only if 14 days or more had elapsed since the last fungicide application. Fungicide applications were terminated when assessments indicated that the supply of primary inoculum was exhausted. In the remaining one-acre plots, the vineyard manager applied protectant sprays of Nova™ at 14 day intervals. One plot was protected for as long as primary inoculum of *U. necator* and *G. bidwellii* was detected, and the remaining plot received a full season protectant spray program.

Although the spring of 1989 was one of the wettest recorded, only two post-infection fungicide treatments and three protectant treatments were needed to provide control of powdery mildew and black rot during the period of primary inoculum release. Black rot and powdery mildew primary infection periods were recorded in Dresden on 23, 26, 30, and 31 May; and on 3-4, 6, 9, 12-13, 14, 15, 17, 20-21, and 27-28 June. Protectant sprays of Nova™ were applied on 22 May, 5 June, 19 June, 5 July, and 24 July. The last two protectant sprays were not applied to one plot due to exhaustion of the supply of primary inoculum of *U. necator* and *G. bidwellii*. The first post-infection treatment was applied on 25 May, which acted against the infection period of 23 May and provided protection from infection periods from 26 May to 9 June. The second post-infection treatment was applied on 14 June, following the infection period of 12-13 June. Protection from the second application extended through the remaining primary infection periods, and through the periods of primary inoculum release for *U. necator* and *G. bidwellii*. Rainfall, leaf wetness, and temperature conditions were also suitable for secondary infection by *G. bidwellii* on 4-5, 7, 19-20, 22, and 28 July and on 2 August.

Early season powdery mildew and black rot were effectively controlled by all three schedules. At the time of harvest, there was no significant ($P = 0.05$) difference in the incidence or severity of powdery mildew on vines under any treatment. Early termination of the fungicide spray program in the post-infection and primary season protectant treatments led to an increased incidence of black rot when compared to the full season protectant treatment. However, the small proportion of the cluster surface infected had no significant effect upon yield, and thus was economically inconsequential. Costs per acre for the post-infection treatments were less than one-half that of the protectant program.

There was an unexpected increase of downy mildew on vines treated with Nova™, which has no activity against this disease. Defoliation on Nova™-treated vines reached 40 per cent by late September. No measurable defoliation had yet occurred on nearby Aurore vines that had been treated with other fungicides that controlled downy mildew. By 23 October, defoliation had reached 99 per cent on Nova™-treated vines, vs 90 per cent on the nearby vines treated with other fungicides. The magnitude of the effects of this late-season defoliation are unknown. No reduction in periderm formation was observed on Nova™-treated vines. These vines will be monitored in 1990, to determine if there were significant deleterious effects due to early defoliation. In years, such as 1989, that are especially favorable for the development of downy mildew, inclusion of a material that has activity against *P. viticola* will be necessary in post-infection applications directed against black rot and powdery mildew on cultivars that are susceptible to downy mildew.

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Eradication of primary inoculum, the use of inoculum measurements and weather, and the integration of control measures for powdery mildew and other grape diseases.

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Eradicant treatments of copper sulfate

Copper sulfate was applied to eradicate overwintering cleistothecia of *Uncinula necator* at two sites: a Concord vineyard in Westfield, and a Seyval vineyard in Dresden. At the Westfield site, copper sulfate was applied in 300 gallons of water per acre at the rate of 24 lb of $CuSO_4$ per acre. Treatments were applied at bud break or when the shoots were 1 inch long. Similar treatments were applied at Dresden, but gallonage per acre was varied from 100 to 300 GPA, and the rate of $CuSO_4$ was either 12 or 24 lb/acre.

Severe phytotoxicity was observed on Concord vines treated when the shoots were 1" in length. At 4" of shoot growth (on untreated vines) shoot length was decreased 12% by an application of copper sulfate at 1" of shoot growth, and the fresh weight of leaves on these shoots was reduced by 56%. Injury was confined to those leaves present at the time of application. No significant damage to flower clusters was observed, and within 4 weeks there was no longer any difference in leaf weight, shoot lenght, or cluster numbers between treated and untreated vines. No phytotoxicity was observed on Concord vines treated with copper sulfate at bud break, nor was significant damage observed on Seyval vines.

Irrespective of the amount of copper sulfate used per acre (12 or 24 lb), the gallonage of water in which it was applied (100 or 300 GPA), or the timing of the application (bud break or 1" shoots), these treatments provided mediocre control of powdery mildew or no control at all. Copper sulfate does not appear to be a suitable material for the eradication of cleistothecia on the bark of grapevines as it is presently applied. Although some mild suppression of disease has been seen in plots where disease on control vines was slight, under high inoculum loads, the material provides no detectable benefit. Lime sulfur, although more expensive, is far more effective than copper sulfate as an eradicant treatment. Although it was not available for use in 1990 due to the expiration of the 24-C label, Miller Chemical Co. has recently received a federal registration for the use of this material on grapevines. The maximum rate of application is 36 gallons of lime sulfur per acre. Best results have been obtained in high volume applications of 300 gallons of water per acre. No phytotoxicity has been observed when applications were delayed until after bud break.

Simultaneous control of multiple grape diseases

The overall goal of experiments conducted in 1990 was to simultaneously control the major grape diseases with a reduced number of fungicide applications. This was achieved by using simple rules to identify combined black rot and powdery mildew infection periods. Black rot infection periods were identified by Spott's criteria. Powdery mildew infection periods were identified by rainfall in excess of 0.10 inches and temperatures above 4 C. Downy mildew infection was forecasted by a model developed in France called EPI. Control of the major grape diseases was evaluated at five commercial vineyards from the Finger Lakes and western New York.

Electronic weather stations, which incorporated a microprocessor to use the powdery mildew, black rot, and downy mildew forecasting systems, were donated for the trials by Neogen Corporation. These units (Envirocasters) were installed in four vineyards of the *Vitis* interspecific hybrid cultivar Aurore shortly after bud break. Commercial cooperators were Taylor Vineyards in Dresden, Lakeview Vineyards in Dundee, Lakemont Vineyards in Watkins Glen, and Knapp Vineyards in Romulus. A vineyard of *Vitis labrusca* 'Concord' in Westfield operated by DeGolier Vineyards also cooperated.

At the commercial Aurore vineyards, the objective was to control black rot and powdery mildew with post-infection sprays of Nova, and to simultaneously manage downy mildew by either tank mixing Nova with a protectant such as mancozeb in each application, or by withholding the protectant until EPI forecasted downy mildew. A calendar protectant program was applied at each location for comparison purposes, and unsprayed control vines were available at Dresden and Watkins Glen. Disease incidence and severity, ascospore maturity of *Uncinula necator* and *Guignardia bidwellii*, and host phenology, were recorded at 1-3 week intervals. Post-infection treatments either ran for the entire season (Full season) or were terminated when the supply of ascospores for *G. bidwellii* was exhausted (Primary season).

At Taylor Vineyards, Full-season post-infection (5 sprays) programs provided control of powdery mildew, downy mildew, and black rot that was equivalent to a 7-spray protectant program. EPI did not recommend control for downy mildew in 1990 until after the last spray had been applied in the post-infection primary-season treatment, and no significant downy mildew infection was observed on this treatment. However, lack of disease on control vines in this vineyard indicate that no downy mildew should have been expected on any treatment. Powdery mildew did increase on leaves and fruit after sprays were stopped on 20 June in the post-infection primary-season treatment. However, the low severity of infection indicated that there was no significant effect on yield.

At Lakeview Vineyards in Dundee, the post-infection primary-season treatment provided excellent control of powdery mildew and black rot with only 4 sprays, but allowed a level of downy mildew infection that could possibly cause early defoliation of vines. A single application of captan on 24 July recommended by EPI prevented this infection in the full-season treatments. Five post-infection sprays were applied in the full season treatment, and 6 sprays were applied in the protectant treatment.

At Watkins Glen, early termination of the spray program was associated with severe powdery mildew infection of fruit and foliage. This was avoided in full season protectant and post-infection treatments. An examination of disease progress and gradients indicated that powdery mildew moved from a nearby abandoned vineyard to the commercial site once the protectant activity of the final Nova spray had declined below effective levels. Adequate control of black rot and downy mildew was maintained despite the nearby abandoned vineyard. Although 10% of the clusters became infected by *G. bidwellii* in the post-infection primary season treatment, severity was so low that it is doubtful that yield was affected.

At Romulus, excellent control of powdery mildew and black rot was obtained in all treatments. Six protectant sprays were applied, while 5 and 3 sprays were applied in the full-season and primary-season post-infection treatments, respectively. Timing of downy mildew suppression by EPI resulted in high levels of foliar, but not fruit infection, and could potentially lead to early defoliation of post-infection treatments.

On the cultivar Concord at Westfield, downy mildew was of less concern than Cane and Leaf Spot and Fruit Rot caused by *Phomopsis viticola*. EPI was not used therefore, and mancozeb was added to all sprays to suppress *Phomopsis*. Three post-infection sprays provided excellent control of all three diseases in the primary season treatment, as compared to 5 sprays in the full season treatment, and 7 sprays in the protectant treatment.

In 1990, as in previous years, the major portion of the primary inoculum for black rot and powdery mildew was released before bloom. The practice of intensive disease control centered upon the primary season appears to be effective when large outside sources of inoculum are not present, and when downy mildew pressure is low. Significant defoliation from downy mildew can be expected if spraying is terminated early in vineyards with a history of downy mildew. This defoliation is likely to be of greater consequence on cultivars with a later harvest date than Aurore, e.g. Riesling. Presently, the *primary season* post-infection program appears to involve excessive risk of late-season defoliation on cultivars that are susceptible to downy mildew and powdery mildew. However, the *full season* post-infection program applied to susceptible cultivars can and does provide excellent control of powdery mildew and black rot with a reduced number of applications.

Results on the cultivar Concord indicate that a reduced spray program consisting of only the primary season post-infection sprays may provide adequate control of powdery mildew, black rot, and Phomopsis, and should be further evaluated in western New York.

The integration of downy mildew forecasting into a post-infection fungicide program for powdery mildew and black rot is still an unsolved problem. The French model, EPI, does not, as presently formulated, appear to be a sufficiently accurate predictor of downy mildew in New York to allow its use by growers. No other model allows sufficient lead time to allow predictions to be useful. At present, the most effective and lowest-risk tactic is to include a material such as captan or mancozeb in the post-infection sprays for powdery mildew and black rot. This is not a very sophisticated approach, but it works and allows the savings to be made in the post-infection program without accepting risk of crop loss to downy mildew. One solution that will be explored in 1991 will be to suppress model predictions of downy mildew before a calendar date or growth stage that is known to coincide (based on historical data) with the earliest reported date of downy mildew in a region. This would eliminate false early-season forecasts.

Subsequent reductions in fungicide use may require a shift in emphasis to post-infection control of downy mildew after bloom, with inclusion of materials for powdery mildew determined by disease assessments. The failure of black rot to increase to damaging levels when primary infection is prevented, in three years of trials on susceptible cultivars, indicates that spraying may be discontinued for this disease once the supply of *Guignardia* ascospores has been exhausted. This may allow a shift away from the sterol biosynthesis inhibiting fungicides, such as Bayleton and Nova, to less expensive sulfur compounds in late season sprays to control powdery mildew on many cultivars.

It should be emphasized that the post-infection programs described above are intended for use in well managed vineyards, and should not be used in the year following a failed control program for black rot. Recent studies suggest that the mummified berrries that are retained in the vines may release ascospores well into August of the year following the epidemic. When black rot has been controlled in the previous year, these ascospores have not caused detectable infections in late sunmmer. Until the significance of this late-season ascospore release is determined, it would be prudent for growers to use the more intensive protectant spray program for one year to "clean up" the vineyard, before switching to a post-infection program.

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Dormant Sprays: Theory and Practice

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Introduction

As early as 1898, there are reports of grape growers obtaining partial control of powdery mildew by stripping the exfoliating bark of grapevines, and by painting the dormant vines with various fungicidal compounds. The efficacy of these treatments was assumed to be due to a direct action upon the survival of *Uncinula necator* on the vine. In spite of this early practice, for many years mycelium in dormant infected buds was thought to be the only significant source of primary inoculum for grape powdery mildew.

In 1985, we reported that cleistothecia of *Uncinula necator*, and not mycelium in dormant infected buds, are the principal source of primary inoculum for grape powdery mildew in New York. Cleistothecia may have escaped notice as a source of inoculum because they are dispersed to the bark of the vine by rain as they mature and overwinter in bark crevices. Although numerous cleistothecia remain on leaves, canes, and berry clusters, they are physiologically immature and die during winter.

Having identified cleistothecia on the bark of the vine as the source of primary inoculum in New York, our objectives were to identify compounds potentially useful as eradicant fungicides, to determine the effects of eradicating a portion of the overwintering pathogen population on the subsequent development of mildew epidemics, and to explore the feasibility of using dormant eradicant treatments to aid in the control of grape powdery mildew.

The theory underlying the use of eradicant treatments is not complex. Just as money increases in a savings account as interest is added to principal, so does disease increase in a vineyard when infected vines serve as a source of further infection. The initial amount of disease or the initial amount of inoculum, is analogous to the initial amount of money in the bank. The rate of increase of the disease is analogous to the rate of interest. The time that a pathogen requires to produce a single generation is analogous to the interval of compounding for interest. Decrease the amount of overwintering inoculum (initial investment), and you will delay the time that it takes to reach a certain level of disease (amount of money in the bank). In other words, eradicating part of the overwintering inoculum will delay an epidemic.

There are two important differences between the increase of money and disease. First, there is an upper limit to an epidemic. When disease reaches 100%, the crop is destroyed. Second, the rate of disease increase can be slowed by maturation of the host. This happens in grapevines when sugar accumulation in the fruit results in increased resistance to powdery mildew. In the case of powdery mildew, if we can delay the epidemic for a long time, then the host may become resistant before the epidemic reaches a damaging stage.

Selection of materials and field trials

A number of compounds were screened in the laboratory. Cleistothecia on filter paper disks were wet with the test compounds for 5 minutes, dried, and then incubated for 2 weeks at 20 C. Ascospore viability was then assessed in crush mounts of treated and untreated cleistothecia using the fluorescent vital stain fluoroscein diacetate.

Lime sulfur, copper sulfate, fixed copper compounds, and dinocap all reduced ascospore viability. Interestingly, Bayleton, which is highly effective as a seasonal treatment, was not effective in reducing ascospore viability.

In field trials conducted during 1986 and 1988, we applied lime sulfur at the rate of 36 gallons per acre in 300 gallons of water to vines of the highly susceptible cultivar Rosette. In 1987, we lowered the rate of application to 12 gallons per acre. Vines in these trials received no other fungicide treatments during the growing season. At the higher rate of application in 1986 and 1988, the dormant eradicant treatment delayed powdery mildew epidemics on the foliage, but eventually the leaves of treated vines became nearly as severely diseased as the untreated vines. However, at the lower rate of application used in 1987, there was little effect on disease development.

On Rosette fruit, reduced levels of disease on vines treated with 36 gal/acre of lime sulfur were apparent through harvest, possibly because delaying disease development allowed soluble sugars to increase in the fruit prior to widespread infection. Once soluble sugars reach about 5-8% in August, berries of even mildew susceptible cultivars are nearly immune to powdery mildew.

In a commercial vineyard of the cultivar Seyval we obtained excellent control of fruit infection in 1988 with only a dormant eradicant spray. In fact, we controlled powdery mildew better with a single dormant spray than with a protectant spray program without the dormant treatment. Similar results were obtained in 1988 in a commercial vineyard of the more resistant cultivar Concord. Disease control on vines receiving only a dormant eradicant spray was as good as vines receiving several seasonal fungicide sprays.

Eradicating a significant part of the pathogen population and delaying the development of powdery mildew may also affect formation of cleistothecia. Delaying disease development results in a delay of ascocarp formation and ascocarp dispersal. If this delay extends into late August or early September, the cleistothecia will not have sufficient time to mature before the leaves are killed by frost. Immature cleistothecia do not survive winter.

Copper sulfate and lime sulfur as eradicant treatments

In 1988, we evaluated a number of compounds as eradicants of cleistothecia in a vineyard of the cultivar Rosette. We were interested in identifying a compound to replace lime sulfur which, although effective, costs about 90 dollars per acre at our rate of application. The treatments were applied as over-the-trellis sprays using 300 gallons of water per acre.

All of the alternative compounds examined in 1988 were equally effective in reducing fruit infection, and the material cost was substantially lower than that of lime sulfur. However, 1988 was a drought year, and disease levels were quite low, even on untreated vines. Nonetheless, these results were encouraging in that they indicated that copper sulfate might be an inexpensive and effective alternative to lime sulfur.

Treatment of dormant vines with either lime sulfur at a reduced rate, or copper sulfate provided no significant reduction of powdery mildew in 1989. However, when treatments of lime sulfur were delayed until one inch of shoot growth, they were very effective in reducing fruit infection on Rosette vines. This indicated that the effects that we were seeing in previous years might have been due both to eradication of overwintering cleistothecia, and some limited protectant activity of these high-volume sprays.

Because the 24-C label for lime sulfur expired in 1989, we were unable to repeat this trial using lime sulfur in 1990. So we substituted copper sulfate at the rate of 24 pounds per acre in 300 gallons of water per acre. These treatments were applied to a Concord vineyard in western New York, and a Seyval vineyard in the Finger Lakes region, when shoots were approximately one inch in length.

The copper sulfate treatments caused severe stunting of Concord shoots. By the time shoots were 4" long on control vines, leaf weight on treated vines had been reduced by 56%. However, injury was confined to those leaves present at the time of application, and four weeks later, there was no longer any difference in leaf weight, shoot length, or cluster number between treated and untreated vines. No such phytotoxicity was seen on Seyval vines.

Irrespective of the rate of application, the gallonage of water used, or the timing of the application, copper sulfate provided mediocre control of powdery mildew in 1990, or no control at all. Copper sulfate does not appear to be a suitable material for eradication of cleistothecia as it is presently applied. Although some mild suppression of disease has been obtained when disease is not severe, under favorable conditions for epidemic development, the material provides no detectable benefit.

Lime sulfur, although far more expensive than copper sulfate, is far more effective as an eradicant treatment, and it now has a federal registration for use against grape powdery mildew. Our best results have been obtained at 36 gallons of material per acre in 300 gallons of water. Efficacy of the application appears to be increased by delaying the application until after bud break. We have not seen phytotoxicity when applications are delayed, but this is something that we will investigate in greater detail in 1991

Summary

To summarize our results with eradicant treatments to date:

1. A number of compounds have been identified that show lab and field efficacy in eradicating cleistothecia of *Uncinula necator*. To date, the best of these materials is lime sulfur.

2. Depending upon weather and cultivar susceptibility, the eradicant treatments of lime sulfur can provide either partial or complete control of fruit infection.

The are several potential uses for eradicant treatments:

1. They can be used to reduce the need to focus upon powdery mildew in timing fungicide sprays, allowing for optimal timing of sprays for other diseases.

2. Eradicant treatments could reduce selection of fungicide resistant strains by reducing the number of seasonal applications of a compound at risk.

3. And finally, eradicant treatments could be used to augment control of powdery mildew in low input systems.

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Objective

A. To conduct large-scale demonstrations of the effectiveness of the grape berry moth pheromone and to compare the effectiveness of the GBM pheromone with that of conventional toxic insecticides.

B. To illustrate that secondary pests seldom cause economic damage to processing grapes.

C. To measure the improvement in biological control of grape berry moth obtained from using the pheromone rather than conventional toxic insecticides.

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REDUCING THE COST OF CONTROLLING THE GRAPE BERRY MOTH IN NEW YORK VINEYARDS

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Project Summary

We have found that only a portion of vineyards presently receiving treatments for grape berry moth (GBM) are at risk of incurring damaging levels of infestations of this pest. Our research has been aimed at pinpointing problem areas of GBM damage in New York vineyards by devising straightforward protocols for rating

vineyards as high, intermediate, or low risk of GBM damage. A simple procedure for sampling for GBM has been developed and published in an Experiment Station Bulletin (#120). Risk of GBM damage can be easily assessed during the growing season using this sampling procedure, and insecticide treatments can be adjusted to account for the actual risk of the specific vineyard site. We have accomplished these objectives by measuring and describing how, where, and when this pest of grapes develops and what vineyard characteristics are associated with damaging GBM levels. The end product of our work is methods for growers to limit insecticide treatment to only those vineyards (or areas within vineyards) where they are necessary.

The risk-rating system is as follows:

Assigning Risk Categories

High Risk Vineyards:

-History: Vineyards (or areas within vineyards) with a history of annual GBM problems, often above six percent damaged clusters in July, and above two percent damaged berries at harvest.

-*Ecology:* Vineyards (or areas within vineyards) adjacent to wooded areas or hedgerows.

-*Climate:* Vineyards with prolonged winter snow cover or in areas prone to mild winter temperatures (e.g. lake plains).

-*Economics:* Grape varieties with low economic thresholds for GBM damage (e.g. table grapes or premium wine varieties).

Low

-*History:* Vineyards seldom having GBM problems, usually below six percent damaged clusters in July, and below two percent damaged berries at harvest.

-*Ecology:* Vineyards in open settings, without wooded edges.

-*Climate:* Vineyards in locations where permanent winter snow cover is slight or rare and in areas prone to severe winter temperatures.

Intermediate Risk Vineyards

Vineyards not meeting the criteria for high- or low-risk sites, occasionally having more than six percent damaged clusters in July, and more than two percent damaged berries at harvest.

Treatment Based on Risk

High Risk Vineyards (or high-risk areas within vineyards)

Insecticide Treatment: Treat with insecticide at 10 days post-bloom and again in early August

Sampling: Sample once in late August to detect the unusual late season problem.

Intermediate Risk Vineyards

Insecticide Treatment: Treat with insecticide at 10 days post-bloom.

Sampling: Sample in the third week of July to determine the need for an August treatment. Use the six percent cluster infestation threshold.

Low Risk Vineyards

Insecticide Treatment: Do not treat at 10 days post-bloom.

Sampling: Sample in the third week of July to determine if an August insecticide treatment is warranted. Use the six percent cluster infestation threshold.

Practical Importance

There are two major reasons why this work is of practical value to New York grape growers. First, the "pesticide picture" is getting increasingly more bleak. Growers are facing new restrictions on the kinds of pesticides they may use and how and when they can use them. Our work has shown that approximately 60 percent of the vineyards in New York do not need August treatments for grape berry moth control, and many vineyards can get by with no treatments at all for insect pests. We have devised strategies and methods which allow growers to determine what vineyards do and do not need insecticide treatments. As it gets more complicated to treat New York vineyards with insecticides, growers will be able to fall back on these alternate strategies. The second value of this work is of greatest concern to juice grape growers who wish to optimize production costs. We have developed the tools which will allow growers to assess GBM damage levels and to decide if treatments are economically warranted in their vineyards.

Presented at the 1989 annual meeting of the New York Wine and Grape Foundation

reduced insecticide use in concord grapes: will it result in serious grape leafhopper problems

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Introduction

As a direct result of our development of a risk assessment strategy for management of the grape berry moth as well as our work with pheromone technology for berry moth control, grape growers in New York can substantially reduce insecticide use in vineyards while maintaining control of this pest. However, growers have expressed concern about the possibility of reductions in insecticide use resulting in increased severity of secondary pests (primarily grape leafhopper). Our observations indicate that leafhopper severity in vineyards is influenced by factors in addition to the insecticides used to control berry moth. Other factors such as natural enemies may be very important in leafhopper control (as is the case in many California vineyards). In addition, the extent to which damage by leafhoppers reduces the yield and quality of Concord grapes is not fully understood (especially in light of vines stressed by todays high crop loads). The objectives of this work are to define factors that promote high leafhopper populations, determine the effect of leafhopper damage on fruit quality, and to provide growers with a management strategy compatible with the low spray or alternative strategies for control of the grape berry moth.

Specific Objectives

1. To document the extent and severity leafhopper infestations in vineyards treated with pheromones for control of berry moth and in other vineyards in which no conventional insecticides were used.
2. To determine when, during the season, leafhoppers occur and where they occur within vineyards.
3. Measure the impact that visible injury from leafhoppers has on leaf function of Concord grapes.
4. Provide growers with management recommendations regarding when and how to control leafhoppers with low or alternative insecticide use strategies for control of grape berry moth.

Due to the timing of summer rains and other factors, the 1989 growing season was characterized as very mild for the build up of leafhopper populations. In the 73 vineyards we monitored throughout the growing season (41 without insecticide treatment), we found no leafhopper problems that warranted insecticide treatment. The information which we gathered during the past season has greatly increased our understanding of leafhopper ecology and population dynamics. However, higher population levels would have allowed us to evaluate more critically the potential of the grape leafhopper as a secondary pest problem in vineyards where no conventional insecticides were used.

Results

Objective: Document leafhopper severity in vineyards without insecticide treatment.

Side-by-side comparison: During the peak of the second generation (mid-September), leafhopper population levels were measured in 13 pairs (one vineyard with and one vineyard without insecticide treatment) of vineyards. Leafhopper populations were greater in untreated vineyards in 10 of the 13 pairs. Population levels averaged 23.1 nymphs per sample (40 leaves) in untreated vineyards and 11.2 nymphs in insecticide treated vineyards. The fact that leafhopper populations were higher in treated vineyards in three of the 13 cases suggests that other factors besides insecticide treatment are affecting population levels.

State-wide vineyard survey: In a total of 73 vineyards (41 not treated with insecticide) we found an average of 30.5 nymphs per sample in the untreated vineyards and 9.3 nymphs per sample in the treated vineyards during the peak of the second generation.

Conclusions

Although infestation levels of leafhopper as well as damage from other secondary pests were higher in the untreated or pheromone treated vineyards when compared to insecticide treated vineyards, this difference was slight in most cases and was not of economic concern. However, during years of high population levels of secondary pests, these differences may be greater and, therefore, pose potential problems that growers should be able to detect during routine inspections of vineyards.

Objective: Determine when during the season leafhoppers occur and where they occur within vineyards

Adult seasonal flight phenology and movement. A grid of yellow sticky cards was set up in two untreated vineyards that were serviced weekly throughout the growing season to detect when adults first appeared in vineyards and how fast they spread within vineyards. In both vineyards, leafhopper adults were trapped primarily in wooded areas adjacent to the vineyards throughout the season.

Flight phenology of Adults. Large numbers of adult leafhoppers were trapped beginning on May 20 (primarily in wooded areas) Numbers of adults captured steadily decreased in both vineyards and leveled off in mid-August. Trap catch remained low throughout the season, reflecting the lack of a significant second generation of leafhoppers, presumably due to climatic factors.

Within-field distribution of immature leafhoppers: The two vineyards used in the trapping studies (one Nagara block and one split block containing Diamond and Dutchess) were sampled intensively throughout the growing season for the presence of immature leafhoppers. A total of 70 vines were inspected on a weekly basis in each of the two vineyards to determine the within-field distribution of leafhopper immatures and to detect possible movement through the season.The distribution of leafhopper immatures appeared random in the Niagara block with respect to the distance from the wooded edge. Also, although the adults are active in the wooded areas during the early season, leafhopper nymphs (and therefor eggs) are found throughout the vineyard without any discernable edge effect such as we see with the grape berry moth. These data suggest that a significant proportion of leafhopper adults may remain in wooded areas depending upon the availability of wild grape hosts and that insecticide treatment on the edge of vineyards may, in some cases, prevent movement in from this reservoir. Another interesting pattern occurred in vineyard 2. This block contained two varieties and their appeared to be a distinct preference throughout the season for the more "labrusca-like" Diamond when compared to the Dutchess variety.

Seasonal phenology of immature leafhoppers: As discussed previously, there was a marked drop in the population levels for the second generation which is historically much larger than the population levels of the first generation.

Objective: Measure the impact of leafhopper injury upon leaf function of Concord vines

The reduction of leaf photosynthesis by leafhopper feeding is relatively straightforward and is essentially proportional to the amount of visible damage. The effects on leaf water loss are comparable so that the water use efficiency (i.e. the amount of photosynthesis per unit of water lost) was not affected by leafhopper feeding. The effects of leafhopper damage on vine performance is likely to be minimal in lightly cropped vines with late season damage to interior leaves. Conversely, leafhopper damage is likely to be more important in heavily cropped vines that have earlier season damage on exterior leaves. A complete analysis of effects on long-term vine performance will require detailed studies over several years.

In the past when low yields per acre were common, the productivity of grapevine leaves was not critical since the vines had more than enough leaves to support these low yields. More recently, the demands for higher and higher yields per acre and per input has meant that Concord grapevines are forced to operate at higher and higher efficiencies. A result of this high efficiency is that all leaves must operate at their optimum to support such large crops. This increases the likelihood of economic effects of loss of leaf function due to stresses such as leaf hoppers.

Objective: Provide growers with management recommendations for leafhopper management in low or no-spray management strategies

A first step in the development of a management strategy for leafhoppers involves the development of an accurate and efficient sampling procedure. In this regard, our goal is to develop a sampling procedure for estimating leafhopper densities that is easy, quick, and reliable. This requires a detailed knowledge of the within and the between field distribution of leafhoppers throughout a range of population levels.

We sampled several vineyards intensively, taking approximately 1,500 leaf samples per vineyard. With these data we have developed a good understanding of leafhopper population distribution at lower infestation levels but, due to average populations in 1989, were unable to describe distribution at higher infestation levels. With an accurate method for determining population levels and an understanding of how leafhopper damage affects vine physiology we can then tell growers how to sample for leafhopper and what population levels warrant insecticide treatment.

Reduced insecticide use in concord grapes: will it result in serious eastern grape leafhopper problems?

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Introduction

As a direct result of the development of risk assessment for management of grape berry moth, as well as work with pheromones for grape berry moth control, grape growers in New York have been offered new possibilities to reduce substantially insecticide use in vineyards while maintaining control of this pest. However, growers are concerned that reductions in insecticide use could result in increased damage by secondary pests, primarily the Eastern Grape Leafhopper. To address this concern we have undertaken in depth studies of secondary pests in vineyards.

Specific objectives

Specific objectives were: 1) to document the extent and severity of leafhopper infestations in vineyards treated with pheromones for control of grape berry moth and in other vineyards in which no conventional insecticides were used; 2) To determine when during the season leafhoppers occur and where they occur within vineyards; 3) Measure the impact that visible injury from leafhoppers has on leaf function of Concord grapes; and 4) Provide growers with management recommendations regarding when and how to control leafhoppers with low or alternative insecticide use strategies for control of grape berry moth.

Results

Objective 1: Document the severity of leafhopper infestations in vineyards without insecticide use.

Leafhopper populations were measured in several vineyards not treated with insecticides in both 1989 and 1990. In 1989, populations in general were very low, and only one of 43 sites had populations higher than the very conservative threshold of 5 nymphs (immature stages) per leaf. In 1990, however, conditions were more favorable for leafhopper development. In 25% of the sites (7 of 28)monitored in 1990, populations were above the threshold of 5 nymphs per leaf in early September. Unlike 1989, 1990 was a year quite favorable for Eastern grape leafhopper development in New York. Yet, these results showed that, despite the favorable conditions for leafhoppers, they did not cause economic damage at a majority of locations where no insecticide was used. As shown in our 1989 studies, years unfavorable to leafhopper development will require even fewer insecticide treatments.

Objective 2. Document when during the season leafhoppers occur and where they occur within vineyards

Eastern grape leafhoppers complete two generations a year, so peak periods of damage occur in July and September. Leafhoppers spend the winter in protected areas outside of vineyards, moving into the vineyard in late spring and out in late fall. To study leafhopper movement patterns and population buildup, populations of adults were monitored with a grid of sticky traps and immature leafhoppers were counted directly on leaves in the vineyards. Detailed observations were made at several sites in the Finger Lakes and Lake Erie growing areas. Adult leafhoppers were monitored with traps placed at different distances from vineyard edges. These traps showed that adults were concentrated at the wooded edge in the spring and again in the fall, suggesting seasonal movement in and out of the vineyard.

Weekly counts of immature leafhoppers in 7 vineyards showed two seasonal patterns: Early population buildup and late buildup. At two of the sites, populations built up in mid-July, and remained high throughout August and September. At two sites, populations remained low until rising during the second generation in mid September. At the remaining 3 sites, populations were low all season. Counts made on individual leaves showed that immature leafhoppers tend to be clustered in the older leaves, both early and late in the season.

These studies showed that both the timing of damage varied, and that damage was most severe in the shaded leaves. Early damage can be expected to more severely affect vine performance than late damage. Damage on shaded leaves is less important than damage on leaves exposed to the sunlight.

Objective 3. Measure the impact of that visible injury from leafhoppers has on Concord grape quality, yield, and on the function of grape foliage.

Measurements of photosynthesis. Photosynthesis (leaf function) was measured on leaves with and without leafhopper damage. As visible leafhopper injury increased, photosynthesis decreased. However, shaded leaves also had low levels of photosynthesis, comparable to unshaded leaves with leafhopper damage.

Long -term effects on yield and quality. The effect of leafhopper damage on yield and quality of concord grapes are being evaluated in a 5 year experiment started in 1990. Because this is the first year, no results are yet available.

Objective 4: Provide growers with management recommendations regarding when and how to control leafhoppers with low or alternative insecticide use strategies for grape berry moth control.

To provide sound management recommendations for controlling leafhoppers, we need to consider: What to apply to control leafhoppers, when damage warrants an application of insecticides (treatment thresholds), and how to determine whether treatment is needed (sampling techniques). Materials are available to effectively control leafhoppers with a single treatment in most cases. Our studies have shown that, even with a very conservative treatment threshold of 5 leafhoppers per leaf, the odds of having damaging populations of leafhoppers in a given vineyard are probably less than 1 in 4. It is likely that Concord vines can tolerate much higher populations without adversely effects on yield and quality. Simple sampling techniques for determining when damaging populations are present will be incorporated in an experiment station bulletin to be written this winter.

In contining this work, we will define the factors that are most important in regulating leafhopper populations (factors influencing whether it will be a 'bad' year for leafhoppers); we will determine how leafhopper damage affects yield and quality of 'Concord' grapes; and we will provide growers with a 'provisional' leafhopper management strategy that is compatible with low spray or pheromone strategies for control of the grape berry moth. In cooperation with the IPM program and Cooperative Extension, we will assess the provisional program and make adjustments as necessary over the coming two years.

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ASSESSING THE RISK OF GRAPE BERRY MOTH ATTACK IN NEW YORK VINEYARDS:

C.J. Hoffman and T.J. Dennehy

Some Practical Results of Studies Supported by the New York Wine/Grape Foundation and the Cornell IPM Program

INTRODUCTION

Research on assessing risk of grape berry moth (GBM) damage is the result of questions raised by New York State grape growers about: (1) the possibility of reducing expenditures on insecticides, (2) the possibility of treating only problem areas within vineyards, and (3) why the grape berry moth (GBM) is such a problem in some areas and not in others. Our objective is not to make decisions for growers but to provide the information and methods necessary for the grower to decide what solution for berrymoth control is best for a particular vineyard and financial situation. That is the purpose of studying risk assessment for the GBM. The following are some observations we have made that show the differences between high-risk and low-risk vineyards and a method is presented that may be used to determine what the actual levels of GBM are in particular vineyards.

GBM LIFE HISTORY

The GBM is a small moth that is native to the Eastern United States. The larvae feed only on species of *Vitis*, which includes both wild and cultivated grapes. The adults begin to emerge in mid- to late-May but, in most years, do not lay eggs in commercial grapes until the beginning of July. The eggs are laid on the grape berry, and the newly-hatched larvae bore directly into the berry, leaving only to enter another berry or to form a cocoon (pupate). The cocoon is made by folding a grape leaf or other plant material. The insects spend the winter in the pupal stage within their cocoon. There are 2-3 generations per year, the exact number depending mainly upon weather conditions.

DIFFERENCES IN GBM INFESTATIONS IN VINEYARDS

One aspect of berry moth ecology that seems to stand out is the extreme variability of population levels. Several vineyards have been monitored in the Finger Lakes, Chautauqua/Erie, Wayne County, and Long Island grape growing regions for the past 2 years. GBM infestation rates vary, not only from region to region, but also from vineyard to vineyard within regions (see Fig. 1). Each of the pairs of vineyards in this figure received similar insecticide treatments or were not treated with insecticides (like the vineyards in Branchport). Infestations in the treated vineyards ranged from .01% to 1.25% berry damage and ranged from .01% to 0.6% berry damage in untreated vineyards. These findings illustrate that the intensity of GBM problems varies widely within New York Vineyards.

There are more dramatic differences in the average intensity of GBM infestations in different regions of the Eastern United States. GBM is reported to be an uncommon pest in North Carolina, while it is a serious problem in Missouri. There are vineyards on the Niagara Peninsula in Canada that, without seven applications of insecticide, would not have a marketable crop.

Besides differences from region to region, differences were found from year to year. The same vineyards were monitored in both 1985 and 1986 and infestation levels for these are shown in Figure 2. Prolonged periods of rainfall in 1986 made it a banner year for fungal pathogens of grapes, yet only a moderate year for insect problems. The vineyards in Fredonia and Branchport depicted in Figure 2 were not treated with insecticides and GBM was not a serious problem in either vineyard during 1986 (below the 2% industry threshold). Several possible reasons for these differences are being investigated. One of the most important factors appears to be how well the berry moth survives the winter. Through the cooperation of Dr. Robert Pool, Horticultural Sciences, Geneva, we determined that the overwintering pupae can tolerate short-term exposure to temperatures down to -10F without freezing. Below this temperature they will instantly freeze and die. With this information, we have related berry moth infestations to weather patterns in different grape-growing regions.

Table 1. Effect of climatic region upon grape berry moth infestation rate.

Region	Odds of reaching GBM freezing point	Level of winter snow cover	Infestation rates
Finger Lakes	Once in 10 years	Low	Light
Western NY	Once in 20 years	Medium	Moderate
Niagara Pennin.	Extremely low (a 67-year record low)	High	Heavy

Table I shows general infestation rates (during most years), the level of permanent snow cover, and the odds of berry moth cocoons freezing during the winter in three different grape growing regions. This lethal temperature (-10 F) happens about once in 10 years in the Finger Lakes Region, once in 20 years in Fredonia, and is a 67-year record low on the Niagara Peninsula in Canada. The amount of permanent snow cover, which may act as a blanket to protect cocoons from freezing, also increases as you approach the Niagara Peninsula. This suggests that the more likely a berry moth is to be exposed to low temperatures, the higher the mortality and the lower the observed infestation rate for the region the following year.

Additional experiments are currently being conducted to determine the actual effect that snow cover and leaf litter have on the survival of the GBM. Patterns of snow cover may be of useful for predicting problem areas-areas you should watch more closely for GBM damage.

Rates of infestation can vary dramatically within a single vineyard as well. Many growers and researchers have noticed hot spots in vineyards, usually along wooded edges. What they may not know is how dramatic this "edge effect" actually is and what factors are responsible for it. Figure 3 shows a pattern of GBM damage throughout the season. The area of highest damage is adjacent to a wooded area which, we hypothesize, provides shelter for the GBM during the winter in the form of increased levels of snow-cover and leaf-litter, and provides a natural barrier for leaf-bound GBM pupae to blow into in the fall. There were also several wild grapevines in this wooded area. Figure 4 shows the high infestation rates in these wild grapes compared to those in the vineyard. Differences in infestation rates illustrate that berry moths lay far more eggs/cluster on wild grapes relative to cultivated varieties. This would contribute to, but may not be totally responsible for, the edge-effect of GBM damage within the vineyard.

CONCLUSIONS

It must be emphasized that, because of the variability in infestations, the need to treat with insecticides for GBM varies from year to year, location to location, and from vineyard to vineyard. The challenge is to accurately determine when it is worth investing money to control GBM. This can be done easily. The first step is to re-evaluate the long-standing recommendation of three insecticide treatments (post bloom, 10-days post bloom, and August) for berry moth. From insecticide trials conducted in Fredonia in 1985 and 1986, we found that, during years of average GBM development, there was little difference between three applications of carbaryl and a two-application schedule of 10-days post bloom and August. Therefore, for processing grapes, it is possible during most years and in all but the most high-risk locations, to cut out the first post-bloom application. Additionally, research has shown that the need for the late season (August) application varies from vineyard to vineyard. There are many vineyards in the Finger Lakes that do not need this late treatment in most years.

Although the berry moth is by far the most serious insect pest of grapes in New York, it is by no means the only pest. However, growers who are in their vineyard at least once a week can easily detect problems of build-up of periodic pests like steely beetle, rose chafer, and leafhoppers.

In conclusion, we suggest that growers monitor GBM damage in their vineyards during July and August of each year to assess the intensity of infestations. At present, we recommend that a GBM treatment be routinely made at 10-days post-bloom and that monitoring be done in July to determine if an early August treatment is warranted. In unusually warm seasons, monitoring in August is recommended to determine if late August treatments are needed.

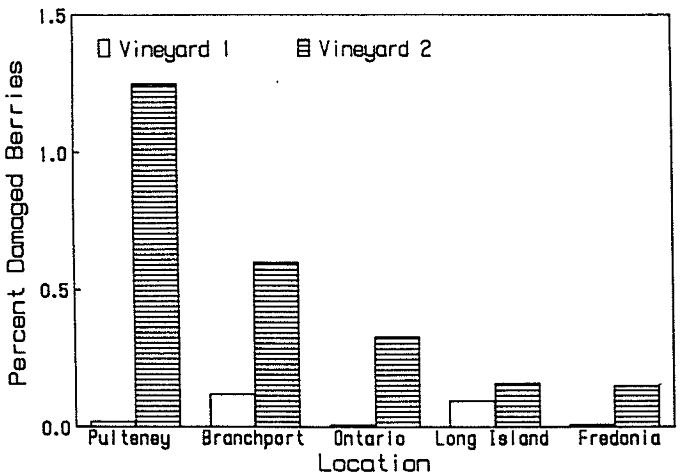


Figure 1. Grape berry moth infestation rates vary dramatically from vineyard to vineyard within each of the New York grape-growing regions (1986 data).

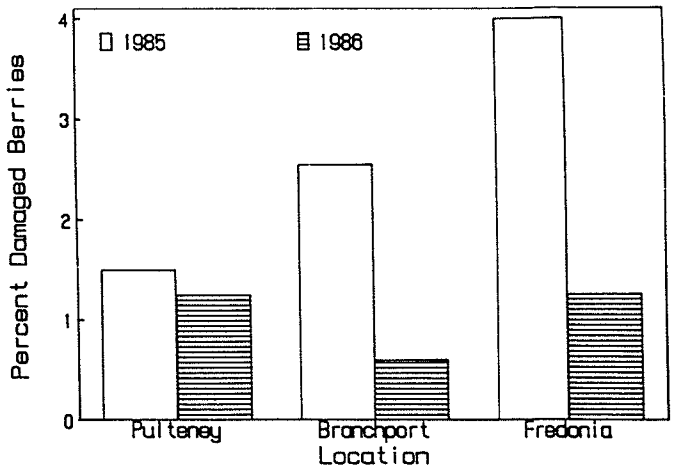


Figure 2. Grape berry moth infestation rates vary dramatically from year to year.

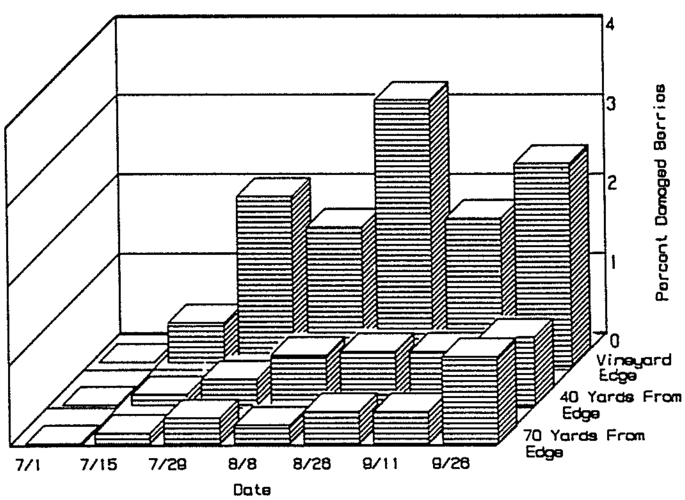


Figure 3. Grape berry moth damage at field edges is much greater than throughout the interior of vineyards.

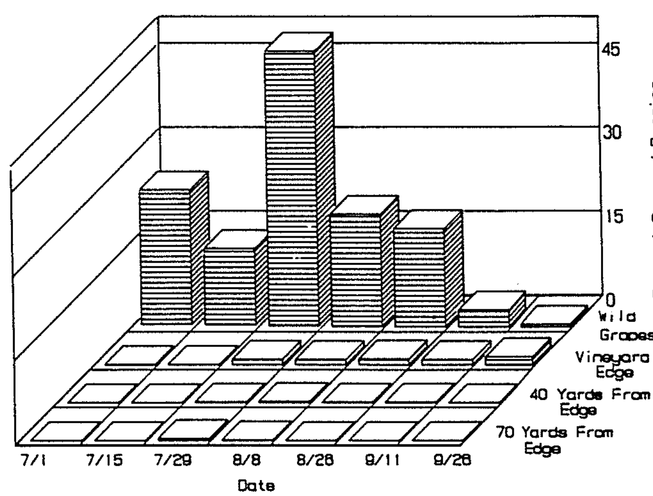
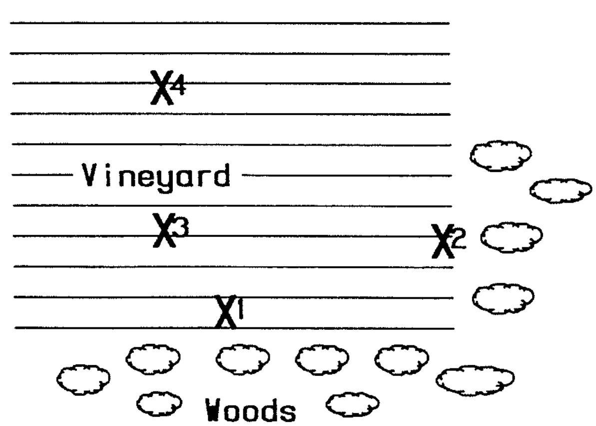


Figure 4. Wild grape vines adjacent to vineyards often are heavily infested with berry moth while adjacent vineyards have relatively little damage.

Procedure:

Select four areas in the vineyard to be sampled: Two on the vineyard edge (1 and 2) and two in the center (3 and 4). Visually inspect, at random, 10 clusters on each of five vines (a total of 50) in each of the four areas. Record the number of GBM-damaged clusters in each area. Compute separate totals for areas 1 and 2 (edge) and 3 and 4 (center) to determine the percent damaged clusters (to convert this to percent damaged berries, divide by the average number of berries per cluster). See the IPM factsheet No. 1 on Grape Berry Moth for photographs of damage.



TAKE 30 MINUTES TO MONITOR GRAPE BERRY MOTH

By sampling vineyards weekly in July, one can determine if a treatment for GBM is warranted in August. The sampling procedure doesn't require much time and will give growers an indication of the severity of berry moth attack and whether treatment is necessary. Details of the plan are as follows:

Choose four areas in a vineyard: two along a wooded edge, if there is one, and two in the center of the vineyard. Within each of these areas, visually inspect 10 clusters at random on each of five different vines and record the number of clusters infested out of 50. This makes a total of 100 clusters on the edge and 100 clusters in the center of the vineyard.

If, for example, eight of 100 clusters on the vineyard edge are infested, this is an 8 percent cluster infestation. If, in the same vineyard, three clusters are infested in the center, this is a 3 percent infestation. Data indicate that, for processing grapes, 90 percent of the time, anything below a 6 percent cluster infestation in mid- to late-July should not require an August treatment. If the infestation of the edge of the vineyard is above this threshold while the center is below, a grower may want to consider treating only on the edges.

The authors are prepared to assist growers in the sampling procedure and in interpreting the results.

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PHEROMONAL CONTROL OF THE GRAPE BERRY MOTH: AN EFFECTIVE ALTERNATIVE TO CONVENTIONAL INSECTICIDES

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INTRODUCTION AND BACKGROUND

Many factors acting together have heightened interest in alternatives to broadly-toxic pesticides used in agriculture. The public has called for reduced pesticide residues in agricultural products. Growers must deal with increasingly complex regulations governing pesticide use: regulations focusing on pesticide-related damage to the environment, especially ground water and wildlife, and exposure of farm workers. While it is recognized that the imperatives of modern agriculture and public health continue to necessitate use of conventional pesticides to prevent crop loss from pests, researchers the world over are striving to develop feasible alternatives to broadly-toxic chemicals. In most situations where environmentally-safe alternatives to conventional pesticides are available, they are implemented within the context of integrated pest management (IPM) programs. These programs foster the use of pest monitoring procedures and pest density or crop injury thresholds coupled with optimization of non-chemical methods such as biological and cultural control (e.g., sanitation and cultivation). Such is the case with pheromonal control of grape berry moth (GBM) in New York vineyards, where complementary research programs in plant pathology, viticulture, and entomology are focusing on development and integration of alternatives to pesticides.

Cornell University scientists have conducted research on pheromones of the grape berry moth for nearly 20 years. These efforts provided a foundation for the development of the Isomate-GBM®* pheromone product. This product received EPA and New York State registrations in 1990. The purpose of this bulletin is to describe the impressive results obtained with the Isomate-GBM® pheromone in large-scale field trials conducted throughout New York, and to provide instructions on how to use the pheromone product most effectively.

MATING DISRUPTION WITH PHEROMONES

Insect pheromones are naturally occurring chemicals that insects use to communicate with individuals of their own species. By releasing minute amounts (often less than one billionth of an ounce) of pheromone, very specific biological messages are conveyed from the insect releasing the chemical to the insect receiving it. Most synthetic pheromones, like that of the GBM, are essentially non-toxic (toxicity similar to many foodstuffs), and are mixtures of the very same chemicals naturally produced by the female moths. Pheromones are commonly used by insects as a very efficient method for attracting mates for reproduction. Female moths of many different species are able to attract male moths from long distances by releasing minute amounts of volatile pheromone. Male moths, using sensors on their antennae, detect the chemical released by females and fly to the females and mate. Just as aircraft use radar signals to guide them toward an airport, male moths use the chemical signal of the pheromone to direct them toward a female moth.

Disruption of sexual communication, called mating disruption, can be accomplished by releasing pheromone in fields or vineyards from artificial sources such as the Isomate-GBM® pheromone dispenser. By producing an invisible "cloud" of pheromone throughout vineyards, male moths are thought to perceive the pheromone in many directions and, therefore, become confused in their attempt to orient toward female moths. The end result of mating disruption is an environmentally safe form of insect birth control; female moths are prevented from producing the next generation of the pest. Whereas grape growers may apply pounds of insecticide (e.g., from 6 to 12 pounds of carbaryl) to vines each season to control GBM, less than 0.2 lbs of pheromone dispensed in Isomate-GBM® pheromone ties has been shown to provide season-long control of this pest.

*Isomate-GBM is a trademark of Pacific Biocontrol Corporation. Environmental Protection Agency registration number 50675-9

THE ISOMATE-GBM® PHEROMONE TIE

The Isomate-GBM® pheromone tie looks much like an oversized "twist-tie" of the sort that is used to close garbage bags. It is eight inches long, less than 1/8 inch wide, and contains a wire embedded within the polyethylene plastic (Photo 1.). Liquid pheromone is contained within a closed channel that runs along the wire for the entire length of the tie. Slow release of the pheromone is achieved over the course of approximately 100 days as the pheromone moves through the plastic walls of the channel and is released into vineyards. Mating disruption is achieved with the Isomate-GBM® pheromone product (Photo 2.) by placing 200 to 400 pheromone dispensers (called "ties") within an acre of vineyard. Ties are placed within vineyards during the second week of May by twisting them onto the upper trellis wire of vines (ca. 3 to 5 feet from the ground). Rates of 200 to 400 ties per acre have resulted in excellent control of GBM. Based on conventional vine spacings employed in New York, one person can dispense pheromone ties for about two acres of vineyard in one hour, at the treatment rate of 200 ties per acre.

Photo 1.

Photo 2.

EXPERIMENTAL METHODS FOR EVALUATING THE ISOMATE-GBM® PHEROMONE

Experimental plots and pheromone treatment rates

During 1988 and 1989, studies were conducted in the Lake Erie and Finger Lakes regions. Most vineyards in 1988 and all vineyards in 1989 had at least one vineyard edge that fit the criteria for high GBM risk (i.e., that had a wooded edge, and/or areas of prolonged winter snow cover). Our intention was to evaluate the pheromone at vineyards with "high risk" areas in order to test it under severe GBM pressure. A total of approximately 100 acres of vineyard were employed in tests each year. Additionally, small trials were conducted by A. Wise (Cornell Cooperative Extension) on Long Island.

The objective of our trials was to evaluate the control of grape berry moth in large plots treated with the Isomate-GBM® pheromone and contrast it with control of GBM observed in adjacent vineyards treated by growers with their normal insecticide programs. Conventional programs employed by growers usually comprised two or three treatments of either parathion or carbaryl. Exceptions were Trials 6 and 17 (Figs. 1 and 2) which received no insecticide in the check plots. The size of pheromone-treated plots varied from three to seven acres. Most pheromone plots were treated with Isomate-GBM® dispensers at rates of 200 ties per acre (approximately 1 every 3 vines) throughout the vineyard interior. For sampling GBM, edges of vineyards were defined as either the first three vines in rows running perpendicular to wooded areas, or the first 2 rows of vines arranged parallel to the edge. The first six vines (or two post lengths) from vineyard edges were treated at a rate of 400 ties/acre. This higher rate of pheromone used along vineyard edges was used to compensate for the fact that berry moth damage, if it is a problem at all, is usually greatest along edges, especially when vineyards are bordered by woods or hedgerows. Trials 8 and 9 were treated throughout with rates of 400 ties per acre.

Grape berry moth damage in pheromone-treated plots and adjacent commercial plots

The most meaningful measure of the effectiveness of GBM mating disruption is provided by direct counts of the percentage of berries in treated versus untreated vineyards that are damaged by this pest. Pairs of pheromone-treated and insecticide-treated (control plots comprised of the grower's normal insecticide regime) plots were sub-divided each into three to five sub-plots. Within each of the sub-plots, four sampling sites were identified: two within the interior of the vineyard and two along the edge. At each sampling site five vines were selected randomly and the fruit on 10 clusters on each of the five vines was examined for GBM damage. Evaluations of damage began in mid-July and continued at three-week intervals until harvest.

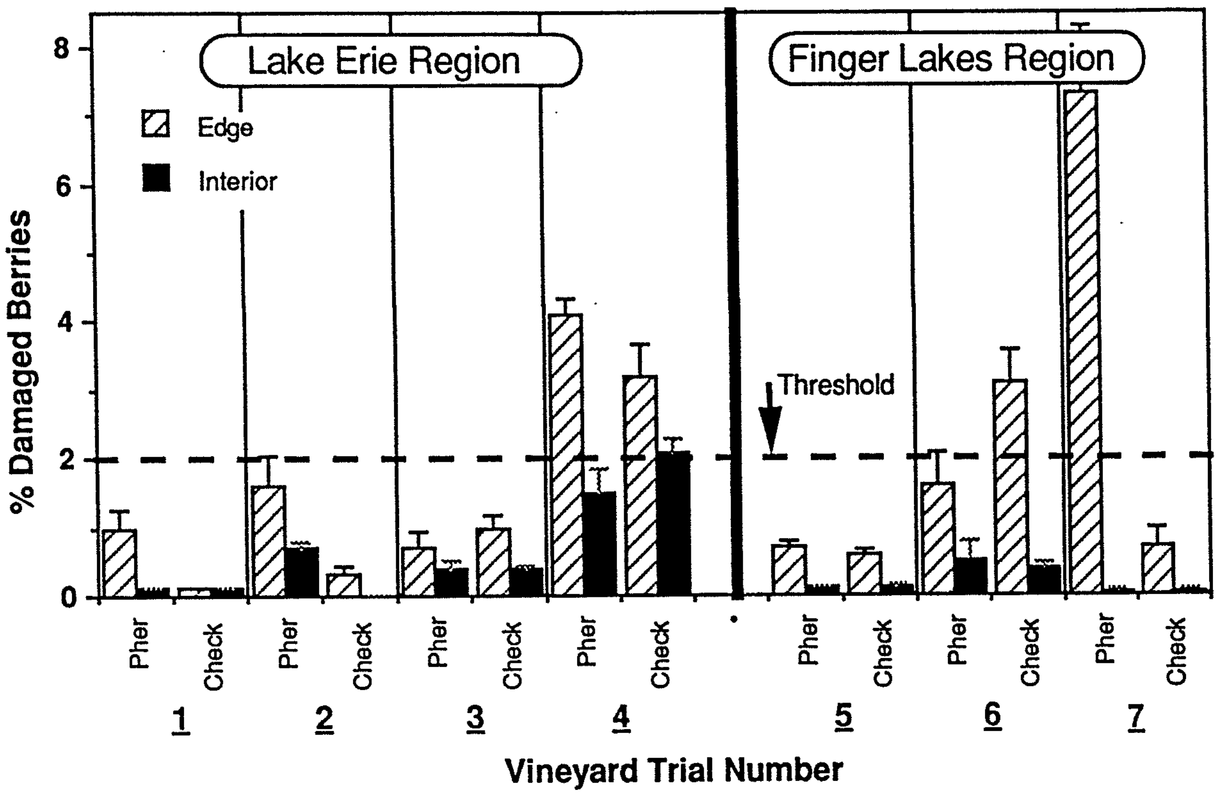

Figure 1.—1988 Evaluations. Damage by grape berry moth at harvest in four vineyards in the Lake Erie region and three vineyards in the Finger Lakes region of New York treated with Isomate-GBM® pheromone compared with adjacent check plots treated by the growers with conventional insecticides. The arrow denotes the threshold for grape berry moth damage (2% damaged berries). Vertical bars denote ±1 standard error of the mean.

Emission rates of the Isomate-GBM® dispenser

Season-long disruption of mating requires that specific amounts of the volatilized pheromone be present within vineyards from approximately mid-May through August or early September. Measurements were conducted of the rate of release of pheromone from Isomate-GBM® ties in order to characterize how they release pheromone throughout the season and, therein, to determine if modifications were necessary in the design of the pheromone dispenser. On May 16, 1986, 50 pheromone ties were placed at the height of the top trellis wire of the vineyard at the New York State Agricultural Experiment Station's Vineyard Research Laboratory, Fredonia, New York. Weight of each of the 50 ties was recorded weekly through September 9, 1986. On June 8, 1988, 500 Isomate-GBM® dispensers were placed on the top trellis wire of a vineyard located at the New York State Agricultural Experiment Station, Geneva, New York. At weekly intervals during the summer, biweekly intervals during the fall, and monthly intervals during the winter and spring, groups of 20 pheromone ties were sampled from this collection of ties. Weight of each of the 20 ties was determined on each sampling date.

Observations of Secondary Pests in Pheromone Plots

Since pheromones do not kill pests like conventional insecticides, an important issue is whether pest species that in past years have been inadvertently suppressed by insecticide treatments for berry moth will become much more serious problems when pheromones are used. Specifically, growers are most concerned about damage from Eastern grape leafhopper (*Erythroneura comes*). Our five years of field trials showed that the use of pheromones would not result in predictable or consistent problems from leafhoppers. Multi-year field studies were begun in 1989 to derive improved estimates of the degree to which leafhoppers and other secondary pests are problems in vineyards treated with pheromone (or vineyards treated with no insecticides). Estimates of the severity of leafhoppers and other secondary pests were made in 26 pairs of pheromone-treated and adjacent insecticide-treated vineyards. Throughout the season, secondary pest damage was rated every two weeks for three categories: grape leafhopper, Japanese beetle, and other pests. Damage ratings were: 0=none, 1=low, 2=moderate, 3=severe. We estimated that most growers would not be concerned with populations assigned ratings of none or low. However, we assumed that most growers would be inclined to spray secondary pest populations we rated as moderate or severe. In addition to the comparisons of pheromone- and insecticide-treated vineyards, a state-wide survey was conducted in which 73 vineyards, 41 not treated with conventional insecticides, were monitored for leafhopper densities.

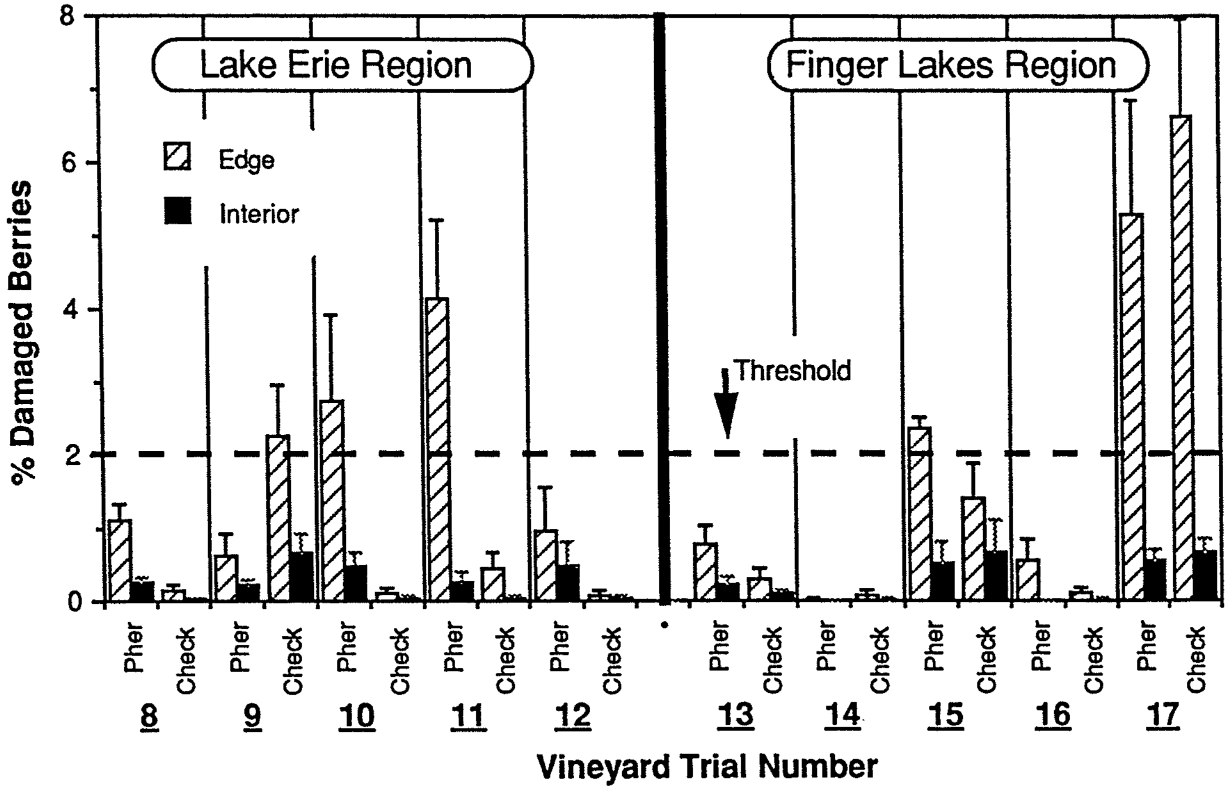

Figure 2.—1989 Evaluations. Damage by grape berry moth at harvest in five vineyards in the Lake Erie region and five vineyards in the Finger Lakes region of New York treated with Isomate-GBM® pheromone compared with adjacent check plots treated by the growers with conventional insecticides. The arrow denotes the threshold for grape berry moth damage (2% damaged berries). Vertical bars denote ±1 standard error of the mean.

RESULTS OF VINEYARD TRIALS: 1988 AND 1989

Grape berry moth damage within the interior of pheromone treatments

Damage by grape berry moth in the interior area of vineyards was below the threshold of two per cent damaged berries at harvest time in 17 of the 18 plots treated with pheromone in 1988 and 1989 (Figs. 1 and 2). Thus, the pheromone provided excellent results in interior areas, even in vineyards with high-risk edge areas. However, it is important to note that overall damage within the interior of the pheromone-treated plots was somewhat higher than in insecticide-treated plots, though still below threshold and very acceptable.

One insecticide-treated plot (Fig 1: Trial 4) had damage at harvest time in the interior of the vineyard that slightly exceeded the threshold of two per cent damaged berries. Results of trials conducted at this same location in the following year, 1989, are not included in Figure 2 because monitoring of this trial in July 1989, showed that *both* the insecticide and pheromone treated areas of the vineyard had unacceptably high GBM damage. Therefore, in August 1989, this vineyard was sprayed with insecticide, and the pheromone trial was terminated at this location. The Trial 4 location represented the most extreme high-risk situation for GBM. The pheromone- and insecticide-treated plots at this location each were less than three acres in size and nearly surrounded by wooded areas containing wild grape. Though the pheromone performed satisfactorily at this location in 1988 (Fig. 1), it is important to reiterate that it failed here in 1989. The narrow configuration of this vineyard conferred a vineyard-edge effect to the entire plot, due to close proximity of wooded areas. Though all of the vineyards tested in 1989 had at least one edge with high risk of GBM damage, unacceptable damage occurred in the interior of only this one vineyard. We conclude that small, extreme high-risk locations, like the Trial 4 site, are not appropriate for GBM mating disruption because female moths that mate outside the vineyard have the potential to cause unacceptable damage. Having noted this extreme situation, our data demonstrate clearly that mating disruption will give very satisfactory results in the interior areas of vineyards of 5 acre size, or larger, even when a high-risk edge is present.

Grape berry moth damage at the edge of vineyards treated with pheromone

Grape berry moth damage was below the harvest-time threshold of two per cent damaged berries at the edges of 11 of

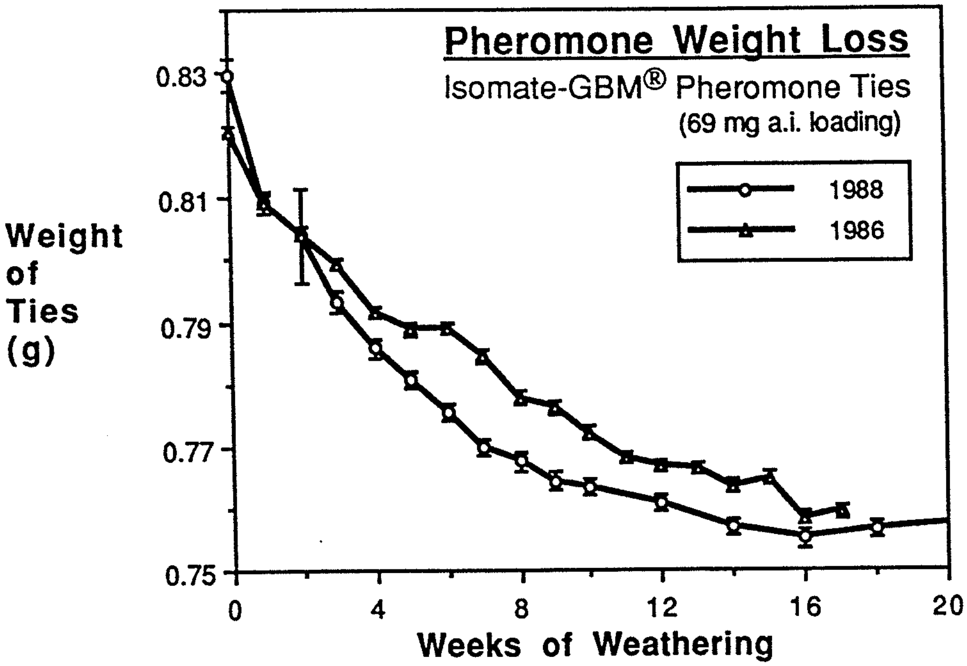

Figure 3.—Loss of pheromone from the Isomate-GBM® dispenser afterfieldweathering during the 1986 and 1988 growing seasons. Ties contained 69 mg of pheromone.

18 vineyards treated with pheromone in 1988 and 1989 (Figs. 1 and 2). Nine of the 17 vineyard trials depicted in Figures 1 and 2 had below-threshold levels of damage in both the insecticide treatment and the pheromone treatment. However, in six of these cases where both treatments gave satisfactory control of GBM, damage was appreciably lower along the edge of the insecticide treatment than in the pheromone treatment. In the edge areas of two of the 17 trials (Fig 1: Trial 4; Fig. 2: Trial 17) both the pheromone and insecticide treatments failed, with berry damage ranging from three to seven per cent. As previously noted, one trial conducted in 1989 was terminated (sprayed-out) mid-season when monitoring detected failure of both the pheromone and insecticide treatments. This location, when combined with those depicted in Figures 1 and 2, made a total of 18 pairwise comparisons of grower insecticide treatments and pheromone treatments conducted in 1988 and 1989.

In two cases, the edges of pheromone treatments had acceptable control (below 2% damage) while the edges of grower-treated plot had greater than two per cent damage (Fig. 1: Trial 6; Fig. 2: Trial 9). In four of the 17 trials depicted in Figs. 1 and 2, GBM damage along the perimeter of the pheromone-treated plots was above the two per cent threshold, but was well below threshold along the edges of the insecticide-treated plots (Fig. 1: Trial 7; Fig. 2: Trial 10, Trial 11, and Trial 15). In three of these cases, the difference in edge damage of pheromone- versus insecticide-treated plots was considerable. Importantly, in the three cases where edge damage was comparatively high in pheromone treatments, the vineyards fit the description of *very* high-risk sites for GBM damage. Such locations (Trial 7, Trial 10, Trial 11) had wooded edges very close to the vineyard edges and were areas where snow accumulated for prolonged periods during winter, facilitating high survivorship of GBM.

In summary, over the course of two years of evaluation of approximately 100 acres of pheromone test per year, unacceptable levels of damage were observed along the vineyard edges of 6 of 18 pheromone trials. In each instance where the pheromone gave unacceptable results, damage was confined to the vineyard edge that was adjacent to a wooded area or other typical high-GBM-risk area. From these findings we conclude that when high-risk areas are treated with pheromone, the two or three rows of perimeter vines along the wooded edge should be sprayed with conventional insecticides using established protocols for high risk vineyards.

Emission rates of the Isomate-GBM® dispenser

Based on measurements of weight loss in 1986 and 1988, the Isomate-GBM® dispenser provided sustained release of pheromone for somewhat greater than 15 weeks, under New York vineyard conditions (Fig. 3). For ties placed in vineyards by our recommended date of May 15, the Isomate-GBM® dispenser (with a 69 mg a.i. loading) should provide sustained release of pheromone until early September. Since pheromone released before mid-May is wasted, we suggest that growers avoid putting Isomate-GBM® dispensers in vineyards before approximately the second week of May.

Observations of Secondary Pests in Pheromone Plots

Grape leafhopper and other secondary pests were of relatively minor importance in almost all vineyards we monitored in 1989, whether treated with pheromone, conventional insecticides, or no insecticides. In the 26 pairs of pheromone treatments and adjacent insecticide treatments, leafhopper populations were higher in the pheromone plots than in the insecticide plots. However, very little visible damage was present in the pheromone plots in 1989. It was obvious that 1989 was not a year of severe leafhopper populations, or of other secondary pests. Contrasts of pheromone-treated plots with insecticide-treated plots are continuing and will provide better estimates of how often leafhoppers will generally need to be treated when pheromones are used. Based on our current experience, we expect that for many vineyards, if no conventional insecticides are used routinely, possibly one or two years out of 10 will result in secondary pest infestations that call for a single insecticide treatment in a season.

CONCLUSIONS AND SUMMARY

Based on six years of field testing, including the large-scale trials described herein, we conclude that the Isomate-GBM® pheromone product has proven potential as a viable alternative to insecticides applied for control of grape berry moth in New York vineyards. If widely utilized, it offers the potential to reduce organophosphate and carbamate insecticide use in New York vineyards by an estimated 50 per cent or more. The product consistently has given excellent control of GBM at locations of low and intermediate risk of GBM damage, an estimated 70 per cent of New York vineyards. With few exceptions, the pheromone product has also given very good control of GBM at high GBM-risk locations. For growers wishing to use the pheromone at high-risk locations, it will be necessary for the two or three rows of vines adjacent to wooded edges to be sprayed with conventional insecticides according to protocols established by the GBM risk assessment program. Mating disruption should not be attempted in small (less than 5 acres), extreme high-risk vineyards such as those surrounded by wooded areas on more than one side.

Pheromone dispensers should be placed in vineyards during the second week of May and before May 15. We recommend using a rate of 200 dispensers per acre of vines (1 per 3 vines) and suggest that twice this rate (2 per 3 vines) be used along the perimeter of the vineyard. In our tests we normally doubled up on the pheromone treatment for the first six vines, or two post lengths from the wooded edge. In an hour, one person can apply pheromone ties on about two acres, at the treatment rate of 200 ties per acre. Dispensers should be placed on the top trellis wire, about four to five feet above the ground.

The results described herein illustrate that both mating disruption with pheromones and conventional insecticides fail in certain years under what are define as extreme high-risk conditions. Because of year-to-year and site-to-site variability in GBM damage, it is important for growers to sample for GBM damage in their vineyards at least once per year. This will detect the cases where, due to unusually high pest pressure, pheromone or insecticide treatments have failed to provide the needed suppression of GBM. A sampling procedure for grape berry moth is presented in detail in New York's Food & Life Sciences Bulletin 120, New York State Agricultural Experiment Station, Geneva. Individuals desiring more information on the life history of GBM and photographs of damage should consult Cornell Grape IPM Insect Identification Sheet No. 1. Information of grape leafhopper can be obtained from Cornell Grape IPM Insect Identification Sheet No. 4.

Clearly, pheromones are not without their drawbacks. Because they are not broadly toxic like conventional insecticides, they require that greater attention be given by the grower to monitoring for the secondary pests that usually are suppressed by broadly-toxic insecticides. Fortunately, in New York grape, the principal secondary pests, leafhoppers and Japanese beetle, are relatively easily monitored, and are very effectively controlled by a single application of insecticide, when necessary. Though we will continue to rely upon broadly-toxic conventional insecticides to 'clean-up' secondary pests and severe GBM problems, utilization of mating disruption for control of the grape berry moth could bring New York grape growers a long way toward fulfilling the call for reduced reliance on toxic chemicals in grape.

ACKNOWLEDGMENTS

This research was made possible by funding provided by the New York State Wine and Grape Foundation and the New York Production Grape Research Fund. Special recognition is given to Dr. W. L. Roelofs, who pioneered the basic research on the grape berry moth pheromone, and to Dr. E. F. Taschenberg who through vision and tenacity promoted and conducted pheromone research in New York vineyards over the past 20 years. We thank H. Crowe, C. Cummings, and R. Dunst of the Geneva Station's Vineyard Research Laboratory and A. Wise of Cornell Cooperative Extension for help in conducting experiments. C. Hoffman and T. Martinson assisted in conducting field trials and studies of secondary pests. Thoughtful review of this manuscript was provided by M. Goffinet. We are indebted to the many New York grape growers who provided vineyards for our studies. The Isomate-GBM® pheromone was provided by Pacific Biocontrol Corporation, Davis, California.

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Objective

Develop an optimal vineyard design and management plan for low input systems.

A. Assess the impact of mechanical and minimal hand pruning systems on vine growth, yield, cold hardiness, and fruit, juice and wine quality.

B. Develop low-input methods (mechanical, non-chemical) methods of thinning to prevent over-cropping and to maintain fruit quality on minimally hand pruned or mechanically pruned vines.

C. Develop no-till systems for vineyard floor management.

Presented at the 1988 annual meeting of the New York Wine and Grape Foundation

INCREASING VINEYARD PRODUCTION EFFICIENCY VIA MECHANIZATION

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New York State Agricultural Experiment Station
Cornell University, Geneva and Fredonia, New York

Research to improve the competitiveness of our industry in 1988 centered around developing systems which maintain or increase productivity while decreasing labor input. The important contributions of Don Crowe, Harriet Hubbard, and Gordon DeGolier must be acknowledged as well as the cooperation of Steve Baran, Marty Martin, Mrs. Al Nixon, and the Taylor Wine Co. who allowed us to conduct research on their farms. Tom Davenport and Len Salva also made valuable personal contributions by aiding harvest data collection. Without such cooperation we could not do the research. Within the context of mechanization several areas are under investigation, but they all address aspects of pruning and crop control. Result highlights will be given in an order that reflects the degree to which the concepts modify the traditional approach to vine culture.

Viticultural Evaluation of Mechanical Shoot Positioners

In this work we supplement the efforts of Dr. Gunkel and his co-workers. They have made important improvements in the machine shoot positioner and used it to apply positioning treatments. Vineyard Laboratory staff measured treatment response. Properly shoot positioned vines produce canes with high quality, productive buds suitable for retention in traditional pruning. Shoot positioning also creates 180 training allowing efficient machine or hand pruning. Thus, summer positioning can greatly increase efficiency of winter pruning.

In 1988, we started a demonstration experiment to test the improved positioner. Data on breakage, crop production, and layers of leaves (a measure of season long effectiveness of positioning) indicate that results comparable to hand positioning were obtained. Data in 1989 will reflect impact of 1988 shoot positioning and will be required to fully evaluate the machine.

Our grape industry is very interested in this work. The primary manufacturer of positioners is developing a "Cornell Kit" which will allow growers to modify their equipment to meet the specifications developed by Dr. Gunkel. The combination of machine shoot positioning and pruning allows growers to greatly reduce hand pruning labor vines that are essentially traditionally pruned.

Hedge Pruning to Control Node Number

We are attempting to reduce node number by shaping the vines with hedgers. Second year response with **non-divided** canopies indicates the difficulty. Close side trimming does not greatly reduce nodes, shoots, or crop per acre. On the other hand, good return yields were obtained. Brix was reduced in comparison with balance pruning. With GDC there are two goals, reducing node number and maintaining canopy separateness. We have two experiments, one in the third year and one in the first year. Attempts to reduce node number by hedging are not effective, but using hedging as a way to maintain canopy separateness is promising. It is not logical to establish GDC for hedging, but it may have a place on established GDC vineyards.

Hedge Pruning in Combination with Node or Fruit Thinning for French-American Varieties

Experiments test the concept of machine hedging vertically trained vines (3 trimming heights) and controlling crop by hand node or cluster thinning or by machine berry thinning. Varieties include Cayuga White, Seyval, Aurore, Vidal, and De Chaunac. We now see that there are three basic factors to consider: (1) base bud fruitfulness, (2) potential crop/node, and (3) intrinsic vine size potential. With moderate base bud fertility, fruitfulness and vigor, hedging alone is suitable (Cayuga White, Aurore). With high fruitfulness, a combination of mowing and some form of crop reduction benefits quality but not necessarily quantity (Vidal, grafted Seyval). Low vigor, highly fruitful vines require supplementary crop control to maintain productivity and quality (De Chaunac, own-rooted Seyval). Quality of machine thinned fruit is maintained or increased for all but Cayuga White where increased botrytis was obtained.

Minimal Pruning Concord Grapevines in Combination with Machine Thinning

The effects of 1988 drought stress had a profound impact on these vines. The benefit of crop control via conventional balance pruning or machine thinning on foliage quality was remarkable. This primarily was due to longer shoots with fewer basal leaves on crop controlled vines. The large crop potential combined with poor foliage quality resulted in delayed maturity on non-thinned vines. We were able to predict the large crop from estimates of berries/vine after set. Machine thinning will be useful when it is known that normal crop will exceed capacity. Recovery of crop stressed vines in 1989 will be of great interest to those contemplating conversion to minimal pruning. These experiments also re-enforce the importance of ozone foliage injury in New York.

Taking Advantage of Mechanization by Optimizing Vine Spacing

Development of a highly mechanized production system has opened the way for re-examination of basic vineyard layout. Over-the-row equipment has been adapted to perform all vineyard operations. Closer row spacing was established by layering in new rows. First mature vine yields in 1988 were 14.9 tons/acre of 14.7 percent soluble solids fruit on vines completely managed by machine. The high yields may not be attainable over the long run, but show that the system has potential. We have established commercial size plots to obtain long-term, realistic data.

Industry Impact of Research Results was Insured in Two Ways
First, a grower seminar and field day was held under Wine/Grape Foundation sponsorship at the Geneva experiment station. Over 200 growers attended. Secondly equipment was obtained to make and edit videotape summaries of research. All operations have been documented and an introductory videotape has been produced. A complete video for grape growers will be completed during 1989.

VINEYARD MANAGEMENT TECHNIQUES

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Sponsored work was primarily in three areas of research: vineyard floor management, Niagara grape production, and identification of a method to replace Alar™. The work was primarily conducted at the Vineyard Laboratory in Fredonia, New York.

Pruning Methods for Niagara and Catawba Grapevines
These experiments test concepts developed for Concord on these two native American varieties. Niagara has assumed an increasingly important place in the future of New York viticulture. It is in great demand for both wine and fresh juice. First year (1987) response to hedging was alarming in that high yield was combined with low brix and pruning weight on hedged vines. In addition, 1988 spring growth was sparse. However, return yield was good (7.1 tons/acre of 13.0% SS fruit). Especially noteworthy was the effect of cluster thinning the hedged vines which produced the same crop as balance pruned vines but had higher fruit maturity (15.0 vs 14.2% SS). Niagara appears to be a candidate for hedge or minimal pruning so long as crop is controlled by machine.

The potential loss of Alar registration is of concern to many growers. The compound has been used to ensure regular berry set in our climate where variable weather during bloom can lead reduced set and yield. We are testing the impact of an alternate growth control method to influence flower set, summer pruning. It offers a nonchemical approach to the problem. In 1988 we confirmed that summer topping during bloom will increase set. Yield was increased only when flower number was limiting (as with balance pruned vines). Increased set, but not yield was obtained on hedged vines because flower number was not limiting. Machine hedgers contact only a small proportion of shoot tips, but enough to obtain a response. We established an experiment to test the interaction between node number and response to Alar and summer pruning. First year response indicates that the effect of either technique diminishes as node number/vine is increased. It appears that summer pruning will be most useful for Concord table grape producers who have an absolute requirement for large, compact clusters.

Vineyard Floor Management Tests were Finalized in 1988

These tests explore alternatives to soil cultivation to control competition from non-grape plant growth. Because grapevines are grown of hillsides, soil erosion is a constant threat. Three alternatives have been found to cultivation: establishment of permanent between-the-row sod, weed control with glyphosate in place of cultivation (no-till viticulture), and application of heavy mulch to smother weeds. The first two methods offer greatly reduced erosion, but only the second minimizes competition. The drought year showed that sod was detrimental and mulch beneficial to maintain vine water supply. Many growers have adopted the techniques which will help us maintain our valuable soil resource. Mulching, as a spot treatment, offers growers a non-chemical fertilizer method to increase vine size.

Presented at the 1989 annual meeting of the New York Wine and Grape Foundation

vineyard mechanization and yield assurance

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Mechanical pruning American varieties

The 1989 growing season has been critical in developing our understanding of how vines respond to minimal and hedge pruning. The drought conditions of 1988 resulted in considerable vine stress. Foliage was damaged because of drought induced potassium deficiency, ozone injury, delayed harvest, and poor ripening conditions. The fact that 1989 also proved to be a drought year during the second half of the growing season compounded the impact of 1988 growing conditions.

The results were both encouraging, discouraging, and suggestive of solutions. The primary observation is that minimal pruned vines produce full crops while balance pruned vines produce less than full crops. Minimal pruned vines "sense" crop size by conditions around the bloom and set period. Up to that time, vines under stress will compensate by reducing berry set and hence crop size. However, when, as has happened for the last two seasons, stress is not "felt" until after set, then the vine cannot compensate and an overcrop situation develops. Under these conditions vine and root growth, fruit maturity and vine winter reserves suffer. Several overcropped and stressed vines will have greatly reduced yield the following year and may even die. Balance pruned vines, which crop at about 80 per cent of non-stressed minimal pruned vines, are better able to resist the drought impact because their crop size is more appropriate for a stressed vine.

The good news is that all minimal pruned vines did not experience severe overcrop as a result of the 1988 and 1989 drought conditions, and the stress was crop, not pruning related. Thinning, which can be mechanized, proved as good a method as did balance pruning to avoid overcropping symptoms on drought stressed vines. Minimal pruned vines growing on better vineyard sites had sufficient moisture to prevent any substantial second year effects. The other good news is that vines which suffered greatly from 1988 conditions were able to increase vine size in 1989 in spite of continued drought stress. Their mature node number suggests a reasonable 1990 crop potential.

The message which we derive from this is that minimal pruning or any other cultural system designed to maximize productivity requires that the entire viticulture be optimized. Vines producing at their maximum have no surplus leaf area. If leaf function is reduced by poor nutrition; damage to the foliage from air pollution, disease, or insects; inadequate soil moisture or poor root/soil conditions, then an overcrop situation will be created and fruit quality and future yield potential impaired. The traditional solution has been to crop vines well below their potential. An alternate solution is to provide the vine with the resources it requires: good protection from pests, freedom from weed competition, a sound fertilizer program, optimal display of canopies, and an adequate water supply. The last factor can be taken care of by planting vines on sites with an abundant supply, or by irrigating vineyards which are not capable of storing sufficient water to cover dry periods in the season. Another solution which can often be of benefit is between-the-row mulch.

Mechanical thinning American varieties

The 1989 data show that stress can be avoided by either reducing node number (traditional pruning) or reducing berry number (mechanical thinning). Minimal pruned vines thinned in 1988 showed few carry-over stress symptoms in 1989 and had good mature node and cluster counts. They did not produce high crops in 1989, because the experimental design required inappropriate thinning in 1989. More importantly, the data suggested ways to assess the need for thinning and suggested possible solutions for marginal sites. Mature node counts appear to be a way to assess capacity of minimal pruned vines. Node counts not only showed how minimally pruned vines respond to machine thinning, but they allowed us to understand part of the problem. Because minimal pruning is done on a vineyard, rather than a vine basis, vine to vine variation is not reduced. On excellent sites the result is lots of variation, but few problems. On marginal sites the variation results in some vines being stressed beyond their ability to compensate. There are two potential solutions. The first is to remove non-crop related stresses. The second is to remove crop related stresses by variable machine thinning.

Mechanical thinning and pruning French-American varieties

The 1988 and 1989 seasons were as dry for hybrid vineyards as they were for American variety vineyards, and similar results were obtained. With varieties which do not easily overcrop, some form of machine pruning and thinning produced acceptable results. Sites which did not experience as much water stress produced good results over a wider range of treatments, and factors which tend to increase vine capacity helped to reduce the negative impact of water stress. Grafting vines to resistant rootstocks had a major impact on reducing water stress. In general, vigorous varieties, such as Cayuga White and Aurore performed better when machine pruned than when balance pruned. This is probably related to early and better trellis fill and light interception. Weaker growing varieties or those which have a great tendency to overcrop did less well with the less precise pruning. Seyvals at Fredonia were a problem because vine size became very small. Fruit damage from botrytis and birds was reduced by machine pruning and/or machine thinning. Wine quality was more related to maturity than to production system. Results have progressed to the point where early experiments are being terminated and emphasis is being shifted to larger scale, in field testing at commercial sites.

Use of Ponnax, Alar or shoot topping to ensure full set

Two continuing experiments were conducted to more fully explore how the two alternatives to Alar™, Ponnax™ and mechanical topping, may fit into commercial production schemes. Ponnax™ is a growth regulator which was commercially tested for the first time under an experimental use permit. Our formal experiment was done at the vineyard laboratory and was designed to complement the trials which were conducted under the supervision of the chemical company which manufactures it. As is often the case with set stimulators, the results indicated a numeric, but not a statistically significant, increase in yield due to treatment with Alar, Ponnax, or shoot topping. Order of yield was topping>Ponnax>Alar>check. Topping did produce a statistically significant increase in berries/cluster.

A longer running experiment is specifically designed to test the long term effect of topping on yield. Previous work has shown that topping will result in good increases in set, but it is associated with an apparent reduction in vine size. The long term study will test if this apparent loss in vine size is an artifact of the topping, or represents a true loss in vine production capacity. Second year data wereencouraging, as the decrease in vine size was not accompanied by a loss in apparent capacity. Both Alar and Topped vines produced about 1 ton/acre more crop than did the control vines.

Close spaced vineyards

As presently applied, minimal pruning enhances the competitive position of our industry by decreasing cost of production and labor and by achieving maximal yield from the presently configured vineyards. Many years of research and commercial experience in New York and elsewhere have shown that ultimate productivity is fixed by the percentage of available light which is intercepted by the canopy. Decreasing canopy spacing from 9-10 feet to 4-5 feet decreases the amount of light which reaches the ground and so is not intercepted by grape leaves. It also increases total vineyard productivity. This was the reason for developing GDC training which produces an aerial simulation of 4-5 foot canopy spacing. GDC, however, is only suitable for the most productive sites and increases both the cost of vineyard establishment and the annual labor and production costs. With minimal pruned vines and over-the-row equipment, yield benefits similar to those obtained with GDC should be realizable.

Preliminary experiments have shown that present commercial vineyards can be converted to 4.5 foot rows by the use of layers, and that yield increases are realized with either conventional or minimal pruning of these vines.

During 1988 and 1989, we have been converting 5 acres of vines to close spacing to more fully test the concepts. We will plant a companion experiment at the vineyard laboratory this year.

Presented at the 1990 annual meeting of the New York Wine and Grape Foundation

Vineyard mechanization

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Mechanical shoot positioning

Improvements were made on the Cornell modified commercial Slawson Mead brush type shoot positioner described in the 1987 Progress Report. Basically the Cornell modification included the addition of two hydraulically powered counter-rotating brushes mounted above the regular brushes and special stiff rubber-mounted finger-wheels backing up and reinforcing the regular brushes. These improvement included a more substantial mounting for the added top counter-rotating brushes, a mechanical cordon guide, a larger hydraulic pump, and a sensitive "joy-stick" type of controller. For 1989, a new hydraulic tank configuration for added cooling was incorporated into the design. Additional brushes of varying stiffness were purchased for both the standard six (6) side brushes and the two (2) top counter-rotating brushes. Various degrees of aggressiveness of the positioning brushes were obtained by changing brush rotational speed, stiffness and number of brushes, adding the finger- wheels, and adjusting the brush clearances.

Beginning in 1988, a comprehensive set of long term (3+ years) mechanical shoot positioning experiments consisting of a combination of hand positioning and mechanical shoot positioning operations using the Cornell modified Slawson Mead brush positioner was initiated to determine both the effectiveness and feasibility of continuous mechanical shoot positioning in a commercial vineyard. These experiments were conducted in Steve Baron's Vineyard, Rt. #20, Westfield, N.Y.

Various combinations of shoot positioning treatments including hand, brush, brush with rubber fingers and were compared at three different times. The tests included 11 treatments with 18 replicate vines per treatment. Table 1 shows the various combinations of equipment used.

Results

The effectiveness of each treatment was measured by:

1) Pruning weights
2) Broken shoots
3) Broken clusters
4) Total clusters
5) Layers of shoots above cordon
6) Nodes in renewal zone
7) Tendril attachment
8) Tons per acre yield

Table 1 —Shoot positioning treatments 1988-1990.

TREATMENT NUMBER	T1 FIRST TREATMENT	T2 SECOND TREATMENT	T3 THIRD TREATMENT
1	HAND	HAND	HAND
2	HAND	BF1	BF1
3	HAND	BF2	BF2
4	B1	HAND	HAND
5	B1	BF1	BF1
6	B1	BF2	BF2
7	B2	HAND	HAND
8	B2	BF1	BF1
9	B2	BF2	BF2
10	—	GROWER	—
11	—	BF2	—

HAND = Vineyard Lab Hand Positioning
B1 = One Pass Pre-Bloom Brush - Light Top Aggressiveness
B2 = One Pass Pre-Bloom Brush - Heavy Top Aggressiveness
BF1 = One Pass Post-Bloom Brush w/Fingers
BF2 = Two Passes Post-Bloom Brush w/Fingers
GROWER = Hand Positioned by Grower (at T2)

T1 = June 9, T2 = June 21, T3 = July 7 (Bloom = June 17) - 1988
T1 = June 12 T2 = June 27 T3 = July 19 (Bloom = June 23) - 1989
T1 = June 12 T2 = June 26 T3 = July 9 (Bloom = June 15) - 1990

The data were analyzed for all 11 treatments, and also for a 3 x 3 factorial design of hand, light and heavy machine treatments at Time 1 and Times 2 & 3. While space does not permit a comprehensive listing of results, all of us on the project are encouraged. Some combinations of machine positioning were comparable to hand positioning. 1990 data is just now being evaluated and when complete a comprehensive report will be prepared.

Finally as a practical measure of our success, several vineyard owners who visited our plots and saw our Cornell modified Slawson Mead brush positioner in action, plan either to, or already have modified their own machines using our design. We have made our experimental design drawings available to anyone who wants a copy. Also Slawson Mead offers and have sold several "Cornell Kits" for their commercial brush positioner.

Prior to 1989, all of our research on shoot positioning had been on the Hudson River Umbrella (HRU) type trellis. That year we did design, construct and initially field test a shoot positioner for the Geneva Double Curtain (GDC) trellis. Basically our approach was to construct an auxiliary bank of brushes to operate under the inside curtain of shoots with the standard bank of brushes operating on the outside. For our preliminary tests these inside brushes were attached to an arm on our modified Slawson Mead brush positioner. However, to be commercially acceptable, the positioner must be mounted on an "over-the-row" harvester frame and position the shoots on both sides of the GDC.

For 1990, we had planned to construct and test a complete shoot positioner for the GDC consisting of the left and right bank of brushes from the Cornell Modified Slawson Mead Positioner, and two under-trellis rotating brush assemblies. These were to be attached to an over-the-row self-propelled harvester frame with necessary controls. In preparation for this work, we obtained from Mr. Ray Orton, Ripley, New York the loan of his Chysholm-Ryder over-the-row, self-propelled harvester frame. Our only expense was approximately $1000 spent for transporting this unit from Ripley to Ithaca, New York. Additional drafting help was hired to do the detailed design drawings for the GDC positioner. On 20 March 1990, when I was informed that our Mechanical Grape Shoot Positioning Project had been approved for funding up to $7000, by the New York Wine & Grape Foundation for the period April 1, 1990 to March 31, 1991, I immediately stopped work on this project since the money allocated would barely cover the completion of our HRU shoot positioning research project. Needless to say our Agricultural and Biological Engineering "Team" was disappointed.

Robotic pruning

The ultimate goal of this research is to develop a robotic grape pruner for non-american variety grapes that will select for position and size woods randomly distributed along the cordon and then make mass pruning cuts. A shorter range goal is to develop a non-selective mechanical pruner that will "block prune" above and to the sides of the vine. To accomplish both the short range and long range goals, location of the grape vine cordon is essential. To locate the cordon we combined digital imaging with a computer and then developed computer software to extract the top edge of the cordon from the images.

A commercial GMF™ robot was purchased and installed in our Agricultural and Biological Engineering Laboratory. A movable trellis was designed to facilitate passing the grapevine by the stationary robot. A vision system with two cameras was used to find the position of the cordon and also determine if a post was present. The image captured by each camera was analyzed independently to determine the two dimensional position of the cordon.

The system was operated at 0.4 km/h (.25 mph) and successfully tracked three different vines with a maximum deviation of 65 mm (2.6 in) and an average deviation of 5 mm (.2 in). The largest contributing factor to the deviations during the operation is the natural variation of the cordon position before the robot is able to process a new set of images and reposition. In our first study the cycle time between robot moves was approximately two seconds, but with our newly developed software it has now been reduced to less than one second.

An economic study was conducted to determine the relative costs of pruning using three levels of automation. The levels of automation in order of least to most costly are machine selective pruning, machine block pruning with manual follow-up, and manual pruning.

For 1990 we continued our laboratory tests needed to incorporate the third dimension (velocity) into our robotic control program. Basically this is an "intelligent" computer software sub-program that first determines the pruner's down-the-row speed and then uses this information to command the robot's required horizontal and vertical speed. This has been completed. We have also completed the basic design of the robotic pruner module and have it partially constructed. Some hydraulic components have been purchased in preparation for assembly. We are presently designing a trolley frame to support the pruning module needed for running the laboratory tests.

Vineyard mechanization and yield assurance

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Mechanical pruning American varieties

Specific experiments testing the concepts of mechanical, hedge pruning and minimal pruning have been underway since 1987. The 1990 season provided data which completes the current testing phase. During the 1989 season, minimal pruned vines growing on soils with low or uneven water holding capacity often showed signs of stress due to the effect of water shortages in 1988 and 1989. The 1989 crop of minimal pruned vines was, in some cases, less than that of balance pruned vines which usually limit yield. Unlike the previous two growing seasons, the growing season of 1990 in western New York had ample rainfall to supply the needs of the vines. This growing season revealed that both balance pruned and minimal pruned vines suffered crop loss due to the water stress imposed in previous years. With minimal pruned vines, the impact was more immediate and was expressed in the year following stress, but the 1990 season revealed that balance pruned vines suffered similar yield reduction, although the impact was delayed for a full year. In contrast during 1990 minimal and hedged pruned vines produced full crops and large vines. Table 1 shows that hedged pruned Geneva Double Curtain trained vines out yielded conventionally pruned vines for the fourth year in a row.

Table 1. Components of yield of GDC trained and conventionally or hedge pruned Concord grapevines during 1990, the fourth consecutive year of such treatment.

Pruning Method	Shoots/ Vine	Clusters/ Vine	Soluble Solids	Tons/ Acre
80 buds 360	106	165	16.4	7.1
80 buds 180	103	170	16.3	6.6
inside outside 180	182	199	16.5	7.5
inside 180	203	322	15.8	9.6
Inside 360	239	293	16.1	10.0
None	280	378	16.2	11.5

Figure 1 summarizes data for a pruning experiment at the Vineyard Laboratory. It shows that a combination of vertical and horizontal hedging can reduce crop level of Concord vines to a value near that of hand, balance pruning. However, it also shows that minimal pruned vines had higher yields and produced marketable fruit in every year, even the drought

In summary, these and data from previous years show that minimal pruning will produce highest crop/acre. All grapevines are subject to water stress induced yield or quality reductions. With minimal pruned vines stress impact was evident in the following year, but with balance pruned vines the stress was delayed. Hedging can to some extent reduce crop ensuring higher fruit maturity in stress years; however, this gain is associated with reduced yield.

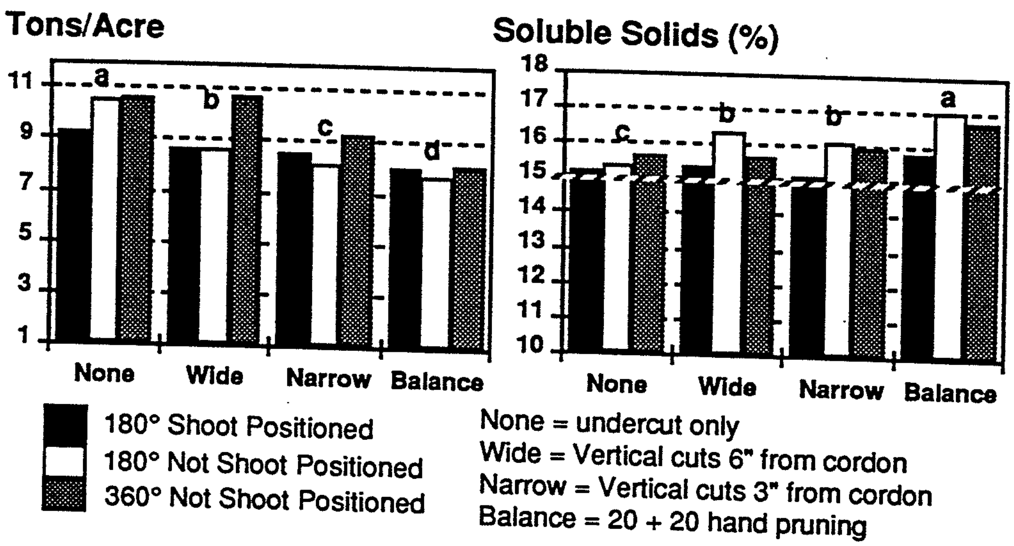

Figure 1. Four year average yield and fruit maturity of hand, hedge or minimally pruned Concord grapevines growing at the Vineyard Laboratory.

Mechanical thinning and pruning American varieties

The 1990 season completed our long term tests of combined minimal pruning and mechanical thinning for Concord grapevines. This experiment confirms the facts outlined above. Minimal pruned vines will achieve appropriate cropping level by self-regulation so long as any stress is applied before berry set. In 1988 drought stress occurred following berry set resulting in reduced yields in 1989 for minimal pruned vines and reduced yields in 1990 for balance pruned vines. Machine thinning did not harm vines, and aided return yield to the extent that crop was

Table 2. Effect of time and aggressiveness of machine thinning on crop reduction, yield and quality of minimal pruned Concord grapevines.

		Berry Wt. at Thinning Date		No. Berries Removed/ Vine		Equivalent Ripe Tons/ Acre Removed		Tons/Acre at Harvest		Potential Ton/Acre (thin + hvsted)		Fruit Soluble Solids	
Date	7/9/90	2.62	b	589	c	0.96	b	7.3	a	8.3	a	15.2	b
of	7/16/90	2.69	a	817	b	1.44	a	6.2	b	7.6	a	15.7	a
Thinning	7/23/90	2.54	c	1,044	a	1.61	a	6.1	b	7.7	a	15.3	ab
	7/30/90	2.70	a	983	ab	1.70	a	5.7	b	7.5	a	15.5	ab
Machine	0	1.17	a	809	c	0.14	c	7.6	b	7.7	a	15.1	b
Thinning	100	1.18	a	165	c	0.30	c	7.1	b	7.4	a	15.3	b
Speed	200	1.18	a	4,585	b	0.81	b	7.0	b	7.8	a	15.3	b
(RPM)	300	1.20	a	2,730	a	4.46	a	3.7	a	8.2	a	16.0	a

reduced. Along with maintenance of vine size (ripe nodes/vine) fruit quality was enhanced by thinning stressed vines. Over the years it appears that thinning about one week after the berries first begin to detach is optimal. An operating speed of 200 rpm is minimal to accomplish any thinning and 300 rpm thins excessively. There appears to be a fairly straight line relationship between rpm and extent of thinning between 200 and 300 rpm. The biggest challenge is to identify which vines require thinning when the vineyard exhibits uneven growth. Preliminary experiments indicate variable thinning may be feasible.

Vineyard design for mechanized vineyards

Mechanization offers an opportunity to redesign our vineyards to more fully optimize production efficiency. Formerly wide row spacing was used to accommodate between-the-row equipment and to reduce the number of vines/ acre needing to be pruned and picked. With complete mechanization and the use of "no-till" viticulture the constraints which applied to existing vineyards may have been removed. For many years it has been known that closer canopy spacing would increase yields, but these were only feasible with GDC training. GDC training requires vigorous vines, expensive trellis and increased labor inputs.

We have tested interplanting to establish close row and canopy spacing. In preliminary experiments yield increases comparable to those of GDC were obtained with minimal pruned vines. We have established a large (*ca.* 5 acre block) planting of close spaced vines and a smaller more intensively managed block of close space vines at the Vineyard Laboratory. These will be used to test the application of modern machinery to conventional, hedge and minimal pruned grapevines. The large block was in its second growing season in 1990, while the smaller block was planted in 1990.

Use of Ponnax or shoot topping to ensure full fruit-set of berries

Growers have been seeking a replacement for Alar which was used to ensure that berry set did not limit yield of Concord grapevines. Two potential alternative have been identified, Ponnax application or mechanical topping during bloom. Ponnax is a growth regulator and is being tested under an experimental use permit in New York. Data in Figure 3 show berry set data for vines that had both light and severe pruning. Both techniques increased set in 1990. Topping has the benefit of not depending upon a chemical treatment. It has shown a great ability to enhance set, but it also reduces vine size. In 1990 it appeared that this vine size reduction did result in a crop reduction. This is the first time that that has been seen and was observed only after three seasons of topping.

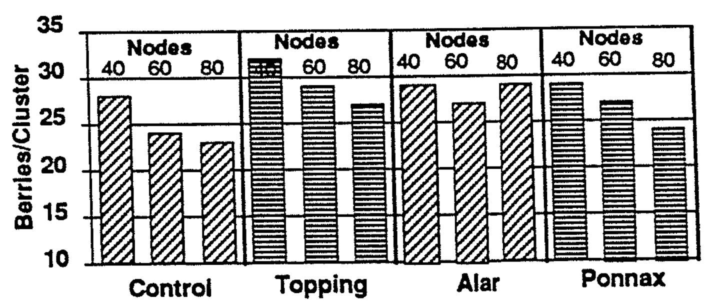

Figure 3. Effect of topping or growth regulator treatment on berry set.

Volume I Number 1

GRAPE FACTS

Managing Weeds in New York Vineyards

I. Choosing a weed management program

Robert M. Pool, Richard M. Dunst, and Andrew F. Senesac

The vineyard is an ecosystem in which many different species of higher plants grow. Viticulturists recognize three different categories of plants in the vineyard: grapevines, groundcovers, and weeds. As with most crops, weeds in vineyards are defined as plants growing where they are not wanted. In some cases, plants of a given species growing between the rows are called groundcover while the same plants growing in the vine row are considered to be weeds. To survive in the unique environment of the bare, partially shaded soil under the vines, vineyard weeds must have the ability to grow vigorously. They compete with grapevines for nutrients and water reducing vine yield and grape quality. We have attempted to find plants that will thrive in these conditions but which will not compete excessively with the vines. Such a "living mulch" would be a desirable alternative to other weed control practices. However, our search to identify plants that are vigorous enough to become established without simultaneously reducing vine size has, thus far, been unsuccessful. Hence we think of all in-the-row non-grape plants as weeds.

Excessive competition with the vine for water or nutrients is not the only reason for classifying a plant as a weed. Plants with tall stature can shade the vine, reducing photosynthesis. Weeds also intercept sprays meant for the vine and they decrease air movement within the vine and the vineyard. As a result, drying time, humidity, and disease hazard are increased. Weed parts mixed in the vine canopy become contaminates of the fruit during harvest. Weeds can serve as alternate hosts to some pests and hence can inoculate the vineyard. Finally, some plants, such as poison ivy or nettles, are directly noxious to vineyard workers.

Because groundcovers are often just weed species growing where they are wanted, and because groundcover growth is often controlled in the same way that weed growth is controlled, its management is generally considered to be part of the overall weed management program. Most New York vineyards benefit from the presence of managed plants growing between the rows. Benefits are several and include: (1) Establishing controlled competition with the vines for water and nutrients in order to prevent excessive vegetative growth and to utilize excess water during rainy periods. (2) Reducing soil compaction caused by the movement of heavy equipment through the vineyard. (3) Increasing soil organic matter through decay of ground cover. (4) Stabilizing soil by roots to decrease erosion hazard. (5) Reduced likelihood of nutrients or pesticides leaving the vineyard ecosystem.

Deciding floor management goals

Effective weed and groundcover management is only possible if the grower has a clear understanding of what is to be accomplished. The overall objectives are to have a vineyard in which sustained yield and fruit quality are maximized, cost of production is minimized, and environmental quality is maintained or improved. Decisions regarding floor management goals should thus be made on the basis of these three factors: production, cost, and environmental quality.

In-the-row goals

As stated, because of their impact on vine growth, the only in-the-row plants which are not considered weeds are grapevines. Thus, the goal is to prevent or eliminate growth of in-the-row weeds in a timely, safe, and effective manner. Grafted vines of winter-tender grape varieties require special consideration. In the colder parts of New York, the usual practice is to cover the base of grafted vines with a mound of soil to ensure survival of some scion tissue should there be an unusually severe winter. The in-the-row mound is made by moving soil from between-the-rows to in-the-rows using a grape hoe. This limits the width of cover crop which can be tolerated in the fall. To prevent scion rooting, the mound should be removed from the base of the vine at least every other year. In such vineyards, decisions about floor management must be made with the realization that soil will be moved into and out of the row on at least a biennial basis.

When chemical weed control is anticipated there is another special consideration for in-the-row weed management. Because herbicides do not always stay where they are applied, it is good practice to create a mound of soil under the vines (in-the-row). This creates a convex surface in the herbicide spray zone and ensures that, should herbicides move either by solubilization or by physical means, they will not become concentrated in the region of maximal grape root concentration. These "hills" erode with time and have to be re-established on a three- to 10-year period depending on the soil type.

Between-the-row goals

The plants growing between-the-rows can be considered a managed source of competition with the vines. Thus, the primary consideration is to establish the optimal level of competition. This is done by evaluating the amount of vegetative vine growth. Growth of small vines needs to be promoted, and the goal should be minimal competition. Very large vines not only tolerate competition, they may benefit from it. Excessively vigorous vines create shaded canopies which favor disease, reduce fruit quality, and prevent canes from becoming fully mature and winter hardy. If extremely vigorous, the vineyard may tolerate a permanent between-the-row sod ground cover.

The average vineyard benefits from some intermediate level of competition. Until the vines flower, they usually need to grow vigorously because they are creating the leaf canopy needed for maximal photosynthesis. Thus, early season competition is usually not desirable. Following the beginning of fruit ripening (veraison), further vegetative growth is rarely beneficial. Photosynthates should not be diverted from the maturing crop and are needed to establish the carbohydrate reserves in the canes, roots, and trunks which ensure winter survival and healthy growth in the subsequent year. In this way fall cover crops can be used to discourage late season vegetative growth. The grower must decide how much competition is desirable during the period between flowering and veraison (about mid-June to mid-August). If the soil is deep and well drained and the vineyard vigorous, the vines will usually not be hurt by cover crop competition during this period. When the soil does not have the depth or capacity to store water, if rainfall is lacking or if the vines are small because of previous stress, then it is best to delay the time at which cover crop competition is allowed to develop.

Once the primary goal of optimal competition in relation to vine health is determined, secondary goals should be considered. These include erosion hazard, soil quality, potential for soil compaction (which is a function of soil type, expected wetting patterns and machinery used in the vineyard), and hazard for ground water contamination. These factors will not change the desirable degree of competition, but may influence the extent to which the grower is willing to tolerate less than optimal vine growth. These considerations will also help the grower choose from among the various available weed management options.

Weed control and floor management options

Options available to control the plant growth on the vineyard floor include, mulching, mowing, shallow and deep cultivation, and a wide array of chemical control agents called herbicides. Typically, several methods will be used in an individual vineyard during the course of a year. Because the goal for in-the-row management is to have no competing weed growth, some options are only suitable for between-the-row use.

Mulching prevents weed growth by preventing light from reaching the young weeds. Mulch can consist of organic matter, such as straw or hay, or can be inorganic, as with opaque plastic or asphalt covers. Inorganic mulches are sometimes used in-the-row, but create disposal problems and make weed control along the edges of the plastic difficult. Organic mulches are not often used in-the-row because they are difficult to apply and can serve as a haven for rodents which may feed on the vine. Between-the-row organic mulches are beneficial not only because they reduce plant competition, but because they also conserve water and increase the organic content of the soil. In unirrigated vineyards, especially those on shallow soils or which have eroded portions, between-the-row organic mulches can produce dramatic results. They are highly recommended for use on trouble spots in the vineyard. However, availability and cost usually mean that mulching is not the primary weed management method. When the goal is complete weed control, mulch must be applied in a very thick layer to obtain season-long shade of the soil. This is a much heavier application than needed to obtain the other benefits of mulch.

Mowing is a very good way to regulate the amount of cover crop competition, but is not useful in-the-rows where the goal is no competition. However, even vineyards which normally tolerate moderate sod competition may lose too much vine size during especially dry seasons. In such cases, even closely mown sod may be too competitive.

Cultivation is the other non-chemical method of weed control. At one time it was the primary method, but the realization of the full impact of cultivation and the development of alternative methods has greatly reduced its use. Frequent cultivation controls both annual and perennial weeds, but has high costs. These are not only direct machine and labor costs. Cultivation, with its high energy requirement contributes to national pollution; it damages root systems and trunks. Long term cultivation degrades soil structure causing plow layers to form and it ultimately reduces percolation rates. Cultivated soil is easily eroded; this erosion can result in movement of nutrients or pesticides attached to the soil out of the vineyard and into the surrounding environment. To minimize the direct damage to the vine and its roots caused by cultivation, we recommend that only "trashy" or shallow cultivation be practiced between-the-rows. With trashy cultivation shallow (1" to 2" deep) tillage is used to eliminate a portion (80-90%) of the weed growth retaining some plants to help stabilize the soil.

The development of ***chemical weed control agents (herbicides)*** has given the grower a new array of tools with which to manage the vineyard ecosystem. As with any new technology, their safe use requires an understanding of their effects, their limitations, and the management goals. Fact Sheet 2 in this series, *Controlling Weeds in the Vineyard*, summarizes information about weeds and general information about herbicide use. Fact Sheets 3 and 4 give information about the herbicides which may be used in New York vineyards. Information about currently recommended chemical options can be found in the Cornell Cooperative Extension publication *Pest Management Recommendations for Grape*.

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Managing Weeds in New York Vineyards

Volume I Number 5

GRAPE FACTS

V. Managing Vineyard Floors Using No-tillage

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Introduction: Reasons for avoiding vineyard tillage

Productive vineyards have large vines which contain sufficient reserves to ensure that both a substantial crop of grapes and new vegetative growth can be produced. An important management practice traditionally used to enhance vine growth is the elimination of competing vegetation from the vineyard by cultivating the soil under and between the rows. In the short run, cultivation stimulates vine growth by eliminating competition, but long term yield declines have been attributed to the practice. Long term cultivation can result in damage to the soil structure and reduced organic matter, nitrogen supply, and water permeability. It also directly injures vines by pruning roots and, for vineyards planted on slopes, cultivation increases loss of top soil through erosion.

To reduce these negative effects of cultivation a modified between-the-row cultivation technique, called **trashy cultivation**, was developed. With trashy cultivation, deep disking is avoided (usually by adding spacers which restrict the depth to which disks can penetrate the soil). Instead, a shallow cultivation is used which eliminates only 70-80 per cent of the ground cover. With trashy cultivation competition from weeds is reduced, but the retained plants stabilize the soil and aid water penetration. While trashy cultivation generally reduces the negative impact of cultivation it does not completely eliminate it.

Using mown sods

The negative effects of cultivation on soil structure and erosion can be eliminated by not cultivating between-the-rows and letting a permanent or semi-permanent cover become established. These permanently growing plants effectively prevent erosion, maintain or increase soil organic matter concentration, and help maintain desirable soil structure. They also help to prevent compaction and rutting caused by heavy equipment such as the grape harvesters used in the vineyard.

The problem with this approach is that the ground cover plants compete with the vine for water and nutrients (especially nitrogen). Sites with deep or rich soils may be able to supply sufficient resources to meet the needs of both the vine and the ground cover plants, but many New York vineyard soils cannot supply adequate resources to meet the needs of both vines and cover crops plants during dry periods. The use of irrigation and supplemental nitrogen can help vines thrive on less-than-perfect sites, but most New York vineyards are not irrigated. It has been speculated that specific ground cover plants might be selected to reduce the degree of vine competition caused by the between-the-row living ground cover, but there is almost no data describing how specific plant species differ regarding competition with grapevines.

Using killed sod (no-tillage)

No-tillage has been developed as an alternative to cultivation for many crop. With no-tillage, competing plant growth is suppressed or controlled using herbicides. Eliminating plant growth with herbicides offers several potential advantages over conventional tillage, including reduced erosion and soil compaction, improved moisture status due to reduced evaporation, increased percolation rates, and reduced energy costs and equipment requirements. Soils managed with no-tillage systems for extended periods of time generally have higher soil organic matter content than tilled soils.

Vineyard no-tillage has been studied in South Africa and Europe where it was found that vines growing under no-tillage had better vine size, yield, and fruit quality than those growing under clean cultivation or sod. In these studies, no-tillage treatments utilized pre-emergence herbicides with residual activity that results in season-long weed control.

These results from areas without summer rainfall suggest that no-tillage might be a useful alternative to trashy cultivation for 'Concord' vineyards growing under the summer rainfall conditions of New York state. Because between-the-row plant covers during harvest and winter are desirable in that they reduce compaction by harvesters and supply organic matter to the soil, a non-persistent herbicide, gylphosate (Roundup®), was chosen for our New York studies. Glyphosate allows weed re-growth to occur by late summer. In order to test the utility of no-tillage for New York vineyards, two, four-year studies were conducted from 1984-1987 in Chautauqua County, New York. They compared the impact of no-tillage using non-persistent herbicides with that of traditional vineyard floor management practices. One experiment compared three herbicide treatments with two cultivation methods, permanent sod, and mulching in a typical eroded, hillside vineyard where soil depth restricts root growth. A second experiment compared three herbicide treatments with clean cultivation in a vineyard where the potential for deep (> 6m) root growth is possible.

The results were similar for both experiments and showed that a single

Table 1.—Impact of between-the-row vineyard floor management practices on growth and yield of Concord grapevines growing in a shallow, eroded soil.

	Cane Pruning Weight/Vine (lbs)			
Floor Management	1983 Grown	1987 Grown	Change 1983-87	Cumulative Tons/Acre
Mown Sod	1.6 ab	2.3 b	+0.7 b	17.7
Trashy Cultivation	1.6 ab	2.6 ab	+1.0 ab	18.7
Clean Cultivation	1.3 b	2.5 ab	+1.2 a	17.1
Mulch	1.7 a	3.0 a	+1.3 a	19.4
Bud Break Herbicide	1.4 ab	2.8 ab	+1.4 a	20.0
Bloom Herbicide	1.5 ab	2.8 ab	+1.2 a	19.2
Bud Break + Bloom Herbicide	1.3 b	2.5 ab	+1.2 a	18.7 NS

application of the non-persistent herbicide, glyphosate, would reduce competition from between-the-row weeds as effectively as either clean or trashy cultivation (Table 1). In addition, growers reported less rutting and better vineyard access for equipment during wet periods.

Chemicals available

To date we have only used gylphosate for vineyard no-tillage. (See Managing Weeds in New York Vineyards, Fact Sheets No's. 3 and 4 for information about herbicides which can be used by New York grape growers.) This herbicide has important advantages over other materials available to New York grape growers; it is systemic, non-persistent, and has low mammalian toxicity. Non-persistence ensures that plants can later become established in the row middles, providing support, organic matter, and stability to the soil. The other alternative is to use a non-systemic, non-persistent herbicide such as paraquat (Gramoxone®). However, when these materials are used, deeply rooted perennial weeds are often poorly controlled.

Timing of glyphosate application

Glyphosate will only control living plants, so late winter applications are ineffective in controlling warm season weed growth. Glyphosate may only be applied during the interval between natural leaf fall and the end of grape bloom. That establishes the window of opportunity for application; our data show that vine response to between-the-row glyphosate was similar whether it was applied soon after grape bud break or closer to the beginning of grape bloom. However, other considerations suggest that later applications are preferable. Usually there is little competition between the vine and cover crops during the early growth phase. This is because soils are usually at field water capacity following winter, and the small grapevine canopy requires little water. The presence of weeds in the row middles can provide desirable support for equipment during spring operations. If weed growth exceeds 18 inches, then mowing may be necessary prior to glyphosate application. Glyphosate application near bloom ensures that competition is minimized during the critical fruit-set and early berry growth periods. These are times in which competition for water is likely to result in substantial vine stress (Figure 1). We have obtained consistently acceptable results by using a single application of glyphosate applied about two weeks before grape bloom. That timing allows weed re-growth to occur by late season providing good footing for equipment during harvest and minimizing winter time erosion.

Ways to ensure effective application

General—Glyphosate is most effective when it is applied to actively growing weeds which are large enough that carbohydrates are being translocated to their root system. When weed height exceeds 18 inches, good coverage of low stature weeds in the canopy can be difficult to obtain. In such cases, the middles should be mowed and glyphosate application delayed for about two weeks.

Rates—Best results have been obtained when at least one quart/acre sprayed glyphosate is used. Sometimes areas of the vineyard are infested with weeds that are more difficult to control, such as burdock or curly dock. We suggest that these areas be separately treated with spot applications of higher (2-3 quart/acre sprayed) concentrations.

Carrier—The label states that glyphosate can be applied in a maximum of 40 gallons water per acre sprayed. Effectiveness is enhanced when glyphosate concentration is increased by

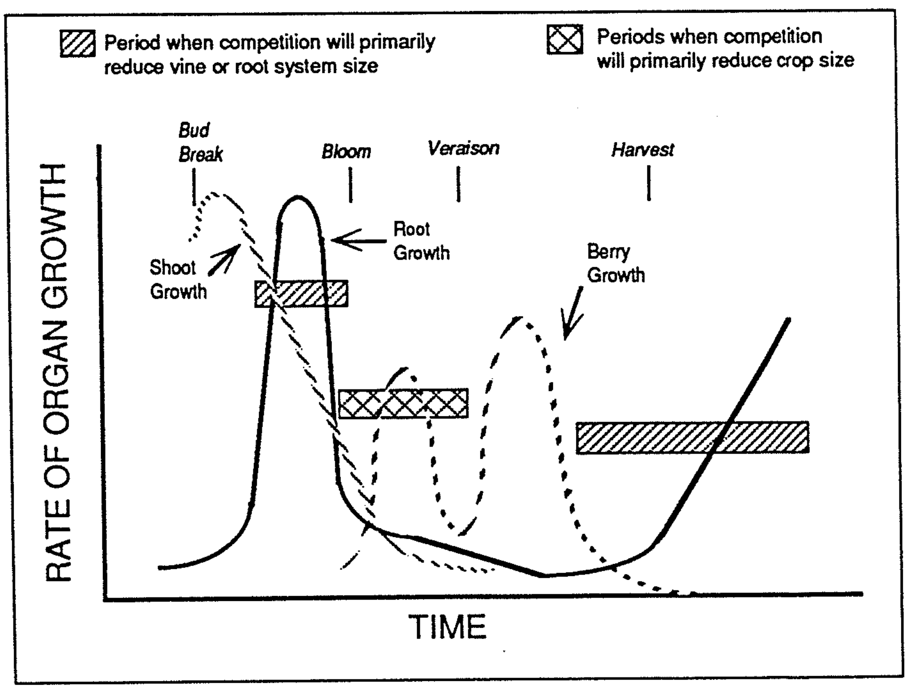


Figure 1. Seasonal change in growth rates of grapevine parts.

using less water in the spray solution. Literature from the manufacturer on low rate technology states that best results are obtained with 5-10 gallons of water per acre sprayed. With proper nozzle selection, most weed sprayers currently used in New York vineyards are capable of reliably delivering 10 gallons/acre. Accurate sprayer calibration is very important for low volume applications. Table 2 lists one method of calibrating vineyard sprayers.

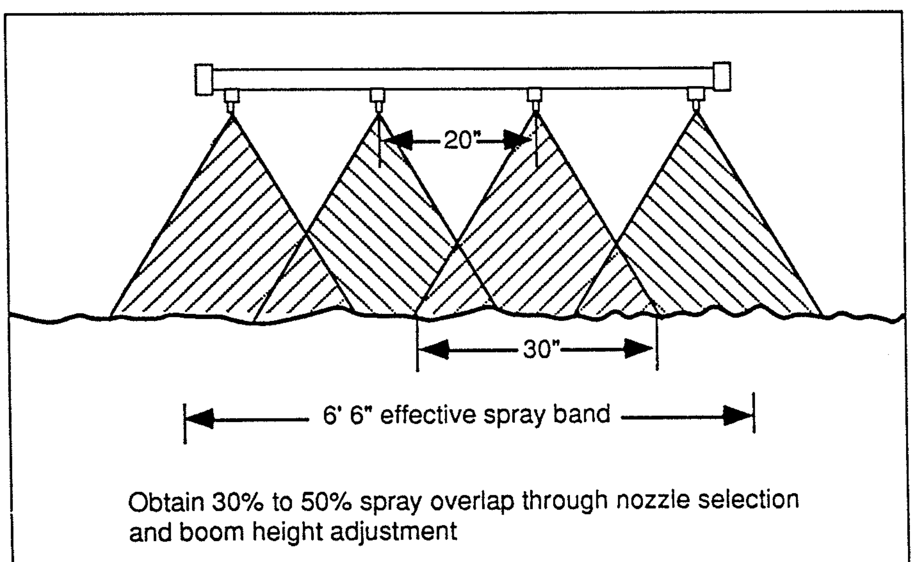
Additions to the tank mix—Weed control with glyphosate is improved by the inclusion of a surfactant in the tank. The manufacturer recommends that two quarts of a surfactant containing at least 50 per cent active ingredient be added per 100 gallons of solution. When weeds are under temperature or moisture stress, effectiveness of glyphosate is reduced. At such times glyphosate performance may be enhanced by adding ammonium sulfate to the spray solutions at a rate of 2 per cent by weight (17 lbs per 100 gallons of water). Low quality ammonium sulfate may contain material that does not dissolve readily and may cause nozzle clogging. When using ammonium sulfate, ensure that the material is completely dissolved in the spray tank before adding glyphosate or surfactant. Thoroughly rinse the spray system after using this combination to prevent corrosion.

Equipment—Most growers make their own spray boom using PVC pipe. For this or any other glyphosate use, galvanized metal should be avoided because glyphosate corrodes it. Figure 2 illustrates a typical boom used for applying herbicides between-the-row. Flat fan or low pressure nozzles should be used and selected to deliver the proper amount of solution. Most commonly used nozzle sizes are in the range 8001 to 8002. As the figure shows, there should be a spray overlap of 30-50 per cent. Depending on nozzle selection, boom height should be from 17-23 inches above the weed surface, and as close to the ground as is possible so as to minimize the likelihood that grapevines will receive spray drift. As mentioned above, it may be necessary to mow the weeds two weeks before application to effectively lower weed height. Many growers mount a second bar about 6 to 12 inches ahead of the spray boom and 6 to 12 inches above ground level to reduce effective plant height. The bar pushes tall weeds down, allowing the entire spray boom to be lowered. That helps to ensure coverage of both tall weeds and any low stature weeds growing under the taller ones.

Table 2.—Steps to easy calibration of row middle vineyard weed sprayers.

1. Clean all nozzle tips, lines and spray tank and fill tank with clean water.
2. Select an operating ground speed that will allow for safe, efficient travel through the vineyard.
3. Set pump pressure between 25-35 psi for flat fan nozzles. LP nozzles perform well at pressures as low as 15 psi which minimizes spray drift.
4. Multiply number of nozzles by distance between nozzles to determine band width. (Suggested boom construction is four nozzles spaced 20 inches apart giving a 6' 6" spray band width that receives full rate of spray). For typical vineyard with 9-foot rows and a three foot under trellis spray band, this will treat a 6' 6" center with slight overlap onto the weed band.)
5. Mark off 100 feet and time how long it takes spray rig to travel that distance a the set ground speed.
6. Collect water from all nozzles in the same time it takes the spray rig to travel the 100 foot test distance.
7. Multiply ounces collected by 43,560 (square feet in an acre) and then divide by 660 (100' test run x 6.6' spray width). This calculation gives ounces applied per treated acre. Divide by 128 to get gallons per treated acre.

   Example - It takes spray rig 20 seconds to travel 100'. In 20 seconds all nozzles together put out 19 ounces of water.
   19 oz. x 43,560 ft² = 827,640
   827,640 ÷ 660 ft² = 1,254 oz. per treated acre
   1,254 ÷ 128 = 9.8 gals. per acre



Suggested Boom Height	65° nozzles = 21" to 23" above effective spray surface
	80° nozzles = 17" to 19" above effective spray surface

Figure 2. Typical spray boom for controlling between-the-row weeds for grapevines planted in 9 foot rows.

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Objective

To further develop the Grape Expert System (GRAPES), and deliver the system to grape growers in Pennsylvania and New York.

A. Complete decision support rule base for horticulture, entomology, and plant pathology components, and link these problem domains to augment integrated problem solving.

B. Revise, field test, evaluate, and implement GRAPES in farm-level settings in Pennsylvania and New York.

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GRAPES : A FRAME-BASED EXPERT SYSTEM FOR VITICULTURE IN PENNSYLVANIA

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Abstract : GRAPES was developed on Macintosh™ microcomputers in the C language using the BruceShell™. GRAPES is a frame-based expert system which enables single inputs to be shared by all elements of the system to which the input is relevant. This approach enables GRAPES to simultaneously handle crop management scenarios that involve multiple problem domains in an integrated fashion. The graphically-oriented operating system of the Macintosh™ facilitated the use of graphics images within the program to help support information gathering and to explain recommendations. Traditional real-time explanation capabilities were replaced by real-time help routines explanation for system-generated recommendations has been retained as a separate module that can be accessed at the end of a consultation.

GRAPES is currently undergoing field testing with growers and county extension agents and is scheduled for general release in 1989.

Key-words : Expert system, grapes, viticulture, BruceShell, frames.

Résumé : GRAPES, écrit en langage C et développé sur microordinateur Macintosh, utilise BruceShell. GRAPES est un système expert utilisant la technique des «frames» et permet à une entrée unique d'être partagée par tous les éléments du système concerné par cette entrée. Une telle approche permet à GRAPES de prendre en compte, simultanément, et d'une manière intégrée, des scénarios de gestion de récoltes, qui entraînent des problèmes dans des domaines variés. Les capacités graphiques du Macintosh ont facilité l'usage d'images grahiques à l'intérieur du programme. Celles-ci servent d'aide au rassemblement des informations ainsi qu'aux explications des recommandations. Les procédures d'explication classiques en temps réel ont été remplacées par des routines d'aide en temps réel. Les recommandations émanant du système sont expliquées via un module isolé qui est accessible en fin de consultation.

GRAPES est à l'heure actuelle en phase de test auprès d'éleveurs et sa commercialisation est prévue pour 1989.

Mots clés : Système expert, graphe, viticulture, Bruce Shell, frames, scenario.

INTRODUCTION

Viticulture in Pennsylvania is a major component of the state's agricultural industry. With approximately 14,500 acres cultivated to grapes, the industry annually contributes a crop valued at $15,000,000, grape products (e.g. juices, jellies, jams) valued at $95,000,000, and wine valued at $7,000,000 (1984 figures). There are currently over 45 wineries located in Pennsylvania, each of which contributes 10,000 to 15,000 gallons of wine per year.

The majority of the grape acreage is located in Erie county along the Lake Erie grape belt, although the most vigorous expansion of the industry is occurring in the southeastern counties where more than 2,000,000 acres exist that are ideal for viticulture. The largest grape juice processing plant in the United States is located in Erie County. Pennsylvania vineyards rank fourth nationally for total production (ca. 70,000-80,000 tons), and second for yield per acre (ca. 6.0 tons per acre).

Over 90% of the grapes grown in Erie county are juice grapes such as Concord, Catawba, and Niagra. These grapes are machine picked and delivered to the processor according to pre-arranged schedules. Base prices are determined by the cooperatives with bonuses paid for grapes with above average sugar content. Erie county growers primarily belong to one of the major juice grape cooperatives (e.g., National Grape Cooperative-Welch Foods, Keystone Foods, Inc.).

Wine grapes, also grown in Erie County, are the dominant varieties grown in the southeastern counties. Although the wine grape acreage is considerably less than juice grape acreage, the value of the wine grapes is considerable higher, ranging to over $1000 per ton for some varieties. These grapes are destined for in state and out of state wineries. Typically, the wineries negotiate a price for the grape crops with the individual grower. The price varies as a function of the variety, and distance from the winery.

The success or failure of vineyard management is dependent on numerous factors, not least of which is the ability to make correct and timely management decisions. To establish a vineyard, a grower must choose a site, suitable varieties, training and trellising systems for that site, as well as determine the status and needs of the soil. Soil and plant analyses must be periodically conducted to determine deficiencies in the soil and suitable fertilization strategies to rectify those deficiencies.

From the day that the first vines are planted, insects, diseases, and weeds must be managed. Occurrence and severity of any one of these pest problems can be attributed to the time of year, the weather, the variety of grape, the conditions of adjacent land, or the past history of the vineyard itself. Management of pest problems might be accomplished through chemical, biological, and/or cultural methods.

There are numerous criteria that determine whether or not sound management decisions will be made. The level of a grower's experience, intuition, motivation, and perhaps prescience are important in arriving at good management decisions. Perhaps the most important factor in effective decision making, however, is timely access to information. This implies not only that information be available, but that this information be current, organized, relevant, and interpreted for use in problem solving.

To date, grape spray guides have been the dominant technique for pest management decision support (Travis et al. 1986), and specialist expertise has traditionally been disseminated via Extension literature (e.g. Saunders 1986). Extension service sponsored meetings are typically the only times in which growers have an opportunity to meet with more than one specialist at a time. Other sources of information include pesticide salesmen, farm products dealers, and neighbors.

Computer programs have been developed to help in information retrieval and decision support. In viticulture, computer applications have been developed to aid in insecticide selection (Jubb et al. 1985), forecasting black rot infection periods (Schwartz and Travis 1986), and prediction of crop phenology (Williams et al. 1985). Although valuable tools, these conventional information management systems and simulation models were not designed as tactical tools to deal with the wide array of problems faced by the vineyard manager on a daily basis. The outputs of these tools typically require interpretation by the user, and as a result, the software's utility in a management context is limited by the grower's ability to interpret its output (Coulson and Saunders 1987). Furthermore, the sources of these pieces of information are widely scattered, and not commonly available at the grower level for day-to-day use in decision making.

The most useful tool available for accomplishing the task of providing grape growers the level of day-to-day decision support needed to grow their crop in a sustainable fashion can be found in expert systems. Expert systems are capable of delivering quantitative information, much of which has been developed through basic and applied research (e.g. economic thresholds, crop development models, pest population models) as well as heuristics to interpret quantitatively derived values, or for use in lieu of nonexistent quantitative information. Furthermore, expert systems are capable of seamlessly integrating the perspectives of individual disciplines (e.g. entomology, pathology, horticulture, agronomy, meteorology, economics) into a framework that best addresses the type of *ad hoc* decision-making required of modern farmers (Coulson and Saunders 1987).

A further advantage of expert systems is that their development requires a concise recapitulation and formalization of existing knowledge and how that knowledge addresses real issues associated with the management system in question. This process greatly facilitates the identification of gaps in the current state of knowledge, thereby optimizing the direction of research efforts to those areas in greatest need of support.

An expert system has been developed to address viticultural management in the state of Pennsylvania. This GRAPe Expert System (GRAPES), is designed to address situations associated with the state of Pennsylvania and includes the expertise of Penn State's viticultural entomologist, pathologist, and horticulturist. This paper describes the design, development, and implementation of this expert system.

METHODS

Unlike specialists in non-agricultural problem domains, university extension/research specialists are charged not only with comprehending and developing the knowledge base associated with their area, but with educating their clientele in the proper application of that knowledge. The viticultural specialists at Penn State University spend a considerable amount of time together during each year travelling to grower meetings, discussing research results with one another, and developing spray guides and extension bulletins. As a team, the pomologist, pathologist, and entomologist are uniquely qualified to represent the viticultural problem area in a palatable format for growers.

Accordingly, these individuals underwent training sponsored by the Pennsylvania State University's Extension Computer Services to teach the concepts of expert system development. In tandem, the specialists conceived the system structure, and as individuals each specialist structured his problem domain. Each module was initially developed as a dependency network (e.g. figure 3) by a specialist. From this table a programmer developed a module which was evaluated by the specialist. Based upon the specialist's evaluation, the module was modified until it accurately represented his heuristics for solving the problem.

In order for problems to be solved by an expert system, the information needed to solve the problem must be identified and organized. The organizational scheme should have the problem solution as its main goal. The viticultural problem area can be reduced to several component parts each representing some category of viticultural management. There are several problem categories addressable by available specialists and representative literature. These components are;

1) Cultural Practices- Cultural practices are those activities that maintain the proper health and vigor of the plant. Sub-categories include fertilization strategies, vineyard site selection, and pruning strategies.

2) Insect Control- Sub-categories include identification and strategies for controlling the major insect pests affecting vineyards in Pennsylvania.

3) Disease Control- Sub-categories include identification and strategies for controlling most of the diseases associated with grapes. These diseases are more widely distributed than the targeted insects, and hence, this category has a broader geographic applicability than insect control.

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4) Weed Control- Sub-categories including the different control strategies for noxious plants based on vineyard age, and identification of the common gross distinctions between annuals and perennials, broadleafs, grasses, and sedges.

5) Integrated Pest Management- This category deals with all specified insect and disease problems, as well as potential diseases as indicated by varietal susceptibility, recent weather, and pesticide history. The recommendations derived from this activity are tank mixes of compatible fungicides and insecticides and a target date for application to deal with the complex of pests.

For GRAPES, the expertise of the specialists in entomology, plant pathology, and horticulture was used to develop modules that address the discrete problems associated with disease, insect, and weed control, as well as for fertilization and pruning recommendations. A function model (Figure 1) of the system shows how information gathering and processing is handled for decision support activities in GRAPES.

The problems addressed by GRAPES can be represented as a dependency network representing the conceptual flow of the system between and among the problem sub-domains (Figure 2). Hence, a session with GRAPES can involve discrete activities within each problem category with capabilities to move easily from one problem domain to another. All variables are global in nature to facilitate multi-domain decision support under the Integrated Pest Management routine.

GRAPES was developed on Macintosh™ microcomputers in the C language using the BruceShell™[1]. The BruceShell™ is a toolkit for development of object-oriented expert systems while in a C language programming environment. LightSpeedC[2] was the version of C used in the development of GRAPES. GRAPES is a frame-based expert system which enables single inputs to be inherited by all elements of the system to which the input is relevant. This approach enables GRAPES to simultaneously handle crop management scenarios that involve multiple problem domains in an integrated fashion.

As each component module was depicted as a dependency network by the appropriate domain specialist, care was taken to ensure that common variables were always referred to by the

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Product of Rules of Thumb, Inc. 7537 Buffalo Rd. Harborcreek, PA. 16421

Product of Think Technologies, 135 South Rd., Bedford, MA. 01730 same name. For instance, The value for the variety of grape in a vineyard block (e.g. Foch) is used in each of the individual disease management modules where the susceptibility of the variety to each disease is determined and used to assign a risk level for that variety. Similarly, in the chemical recommendations modules, the phytotoxicity of certain pesticides are assigned on the basis of the variety value. In certain insect management modules the variety value is utilized in calculating the value of the crop, and hence, the economic threshold for taking control actions.

GRAPES employs several novel innovations in expert system structure. The most significant differences involve the system's procedures for explanation, for accessing graphics-oriented screen displays, for dynamically pruning a Concord vine, and for profiling a vineyard.

Explanation: Typically, at any point in a session, a user can query an expert system regarding reasons for information requests, or why a particular recommendation was given. In GRAPES, this capability is replaced with the ability to request help (e.g. how to accurately scout a vineyard block for berry moth populations, how to determine if a black rot infection period has occurred). These help routines are often graphically oriented (Figure 4), and are intended to ensure that accurate information is provided to the system. The traditional explanation capabilities have been retained as sub-modules to each of the various problem category modules (Figure 5). After the presentation of a recommendation, the user can select the explanation option, and at that time a thorough explanation is presented.

Graphics: A graphics capability was created to allow the user to correctly identify problems and to enhance the information presented for solving problems. The graphics screens for GRAPES were developed using an image scanner (Thunderscan[3]) with its associated software, and a bit-mapped graphics development application for the Macintosh™ (Fullpaint[4]). After scanning, images were pasted into Fullpaint for editing, the addition of text, and size adjustment. The completed images were then copied to a resource file. An image is called up for screen display via a BruceShell™ library routine that identifies the appropriate image by its resource number.

Pruning: The pruning routine is a graphical, object-oriented model of a Concord vine trained to either the single curtain cordon, or the Geneva double curtain system (Figure 6). The user supplies information about the available wood (i.e. the percentage of wood issuing directly from a cordon, or from pruning spurs), relative vigor (on a scale of 1 to 10), and a bud count goal. GRAPES then "grows" a vine that consists of from 1000 to 2500 objects, each object being an internode and a bud. Upon "growing" each object, the system decides whether to continue growing, branch, and/or droop. Each vine is unique within the constraints of the user-specified

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[3] A product of Thunderware Inc., 21 Orinda Way, Orinda, CA. 94563.

[4] A product of Ann Arbor Softworks, 3081/2 State St., Ann Arbor, MI., 48104.

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parameters mentioned above. After the vine has been "grown" on the screen, the mouse cursor changes to a pair of pruning shears which are used to cut canes from the vine. If a cordon needs renewing, the user selects **New Cordon** from the bottom of the screen, and the shears become a hand which is used to grasp an appropriate cane from the healthy side of the vine and pull the cane to the side on which the cordon is being replaced. The pruning routine was initially developed as an aid to vineyard managers in training seasonal help in how to prune a vineyard, and as an educational tool for the viticultural specialist to use at grower meetings. A scoring procedure is under development that will evaluate the pruning of a vine. The score will be based on the reasonableness of the bud count goal relative to the described vigor, the distribution of buds, the lengths of the spurs, the orientation of the spurs, the removal of suckers, and the replacement of unproductive cordons.

Profiles: The profile is the means by which GRAPES records static elements of a vineyard (e.g. variety, location, soil type, woodland borders, age, estimated harvest date) and keeps season-long track of phenology, pest history, pesticide use, and weather. The profile for a vineyard block is stored alongside the program. When loaded into GRAPES, the profile checks the system clock to determine the present date and time. If the system clock is one or more days after the last profile update, the user is asked if the vineyard has entered a new stage of development, if any new insect or disease problems have occurred, if any pesticide sprays have been applied, and what the recent weather has been. By maintaining a current profile, the user can investigate most problems with little need for further interrogation by the system. Furthermore, at harvest the profile can provide the user with spray records for the season.

SYSTEM STRUCTURE AND OPERATIONS:

At the top level of GRAPES is the title screen, topped with the typical Macintosh™ pull down menus. These menus include **File**, **Edit**, **Culture**, **Insect**, **Disease**, **Weed**, and **IPM** (Figure 7a). Upon opening these menus, numerous options are revealed (Figure 7b).

Topics under **File** deal with saving or loading profiles, and changing the date and time to investigate hypothetical scenarios.

Edit topics include functions for resetting the variables in GRAPES. This erases the system's memory of any preceding investigations, thereby permitting the reinvestigation of a problem. Additionally, vineyard profiles can be edited from the **Edit** menu.

Culture selections include fertilization recommendations based on parameters of vine and site quality, and the results of a soil or petiole analysis. Pruning recommendations are also contained in this menu.

The **Insect**, **Disease**, and **Weed** menus list the major pests in each category. The modules associated with each pest contain the heuristics of the associated specialist for identification, evaluation, and control.

Integrated Pest Management (IPM) permits the user to simultaneously investigate all insects and diseases contained in GRAPES. An updated profile is important in the use of this option.

The heuristics associated with the selection of appropriate insecticides and fungicides are used in both the discrete insect and disease management modules, as well as in the integrated pest management routines. The frame-based routines for each pest have risk ratings as their goals. These risk ratings range from "no risk", to "high risk" for all insects and diseases. In the case of black rot, there are post-infection risk scenarios as well. These additional scenarios are to permit the proper use of sterol-inhibitor type fungicides which have eradicant capabilities. In the case of problem solving involving a single pest, the pest module passes the risk value to the pesticide modules where the effectiveness of the various chemicals against the pest are determined. The list of possible chemicals is then reduced according to legal restrictions on annual residue, pre-harvest interval, and phytotoxicity. The remaining chemicals are then sorted and displayed to the screen as treatment alternatives ranked in order from the most effective to the least effective. A date for application of the treatment is displayed based upon the presence or absence of active pesticide residues on the vines, and the risk level of the vineyard to the pest.

In the IPM routine (Figure 8), the pest modules are activated based upon the grower's entries in the vineyard profile. Diseases not specified in the profile may still be investigated by GRAPES based upon the varietal susceptibility, pesticide use, and recent weather. GRAPES determines the goal (risk rating) of all relevant pest modules, and passes these values to the pesticide recommendation modules. In addition to the pesticide sorting described under the single problem scenario, the pesticide modules also determine the priority of treating individual pests in the complex of insects and diseases (based upon the severity of risk), and tank mixing incompatibilities. The recommendation displayed by the integrated pest management routine is a ranked series of tank mixes of compatible fungicides and insecticides that deal with the entire pest complex. A recommended date for applying the treatment is also displayed. This date is typically determined by the most pressing of the disease problems.

The flow diagram of GRAPES is shown in Figure 9. Upon startup, a user is asked if a profile is to be loaded. Although the use of a vineyard profile is optional, the user is encouraged to maintain and load a profile to reduce the amount of questions the system will ask.. Upon presenting advice on how to address a problem, GRAPES provides the option to continue by selecting from the menu named for the current investigation. At this time, **Explanation** and information about the problem area (**About...**) may be requested to further support the

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recommendation. The user may also elect to **Print Recommendation, Print Explanation, Print About, Review the Recommendation, Reset Parameters** to initiate a new problem within that module, or **Exit the Module.**

DISCUSSION

An important consideration in the development of expert systems is to design the program in a form that is palatable to agricultural managers. In the development of GRAPES, keyboard commands were avoided as much a possible in favor of a mouse driven, graphics oriented user interface. Graphics oriented operating systems tend to bring in people who would never learn the concepts well enough to use a command-driven user interface (Pournell 1987). Additionally, the incorporation of graphics greatly enhances the accuracy of data provided to the system, in that pictures provide a more powerful means of depicting field phenomena that would otherwise require arcane terminology to describe (Saunders et al. 1987).

Also embodied in the philosophy of the GRAPES system structure is the replacement of real time explanation capabilities in favor of real time assistance in identifying and quantifying information for use in problem solving. We recognize the importance of explanation in expert systems as it permits the user to examine the logical chain whereby the program reached its conclusion. We retained explanation as a component of GRAPES, but present it at the end of a particular problem session. The "WHY?" capability that is generically associated with expert systems is more salient to systems targeted towards training specialists (e.g. engineers and medical professionals) than it is to systems directed toward individuals with a more practical, generalist view of a system. In the latter situations, "HOW?" may be a more useful utility.

GRAPES has been introduced to a select group of Pennsylvania growers for the 1988 growing season. These growers will be contacted on a bi-weekly basis in order to elicit critical feedback for further system development. By adopting this prototyping approach to the development and transfer of GRAPES, the growers have direct input into system design, and the final product will be tailored to their particular tastes and desires. By developing the components of GRAPES as separate, frame based routines, the addition and deletion of chemicals and pests will be greatly facilitated, and will not entail major modifications to the system structure. Viticultural specialists in Pennsylvania have contributed considerable time and effort to the development of GRAPES as they view it as a significant improvement in the dissemination of information and advice. GRAPES is scheduled for general release in Pennsylvania by the 1989 growing season.

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Objective

Generate and deliver weather forecasts with a high spatial resolution (1 km) to be used for local management decisions on pest development, cultural management, and timing of pesticide applications.

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VINE DISEASE ASSESSMENT USING HIGH RESOLUTION FORECASTS

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1. INTRODUCTION

Vine plants are subject to a variety of diseases throughout the world. If it were not for control practices, many of these diseases would reach pandemic proportions because of monocultural practices and the broad climatological conditions for their development. While many control tactics exist, they are costly and are, at times, employed needlessly because of the lack of suitable weather conditions for disease development during a growing season.

Knowledge of the weather conditions responsible for disease establishment and seasonal appearance has grown steadily during the present century. What began as field experience has evolved into empirical rules, and, more recently, into disease prediction models. The meteorological and biological variables identified for these models have been derived from controlled field and laboratory research. Weather data necessary to use these models as predictive tools have mainly came from on-site monitoring and through the interpretation of observations recorded at stations in regional or national networks.

This paper discusses how vine diseases, in particular downy mildew that infects grapevines, can be predicted using high resolution weather forecasts. Such forecasts have only recently become available because of the development of mesoscale models and techniques.

2. HIGH RESOLUTION FORECASTS

Kelley et al. (1988) developed a new mesoscale forecasting technique for generating high resolution data from an operational numerical weather prediction model. The technique, called Model Output Enhancement (MOE), interpolates upper-air numerical output, extrapolates the interpolated results to the surface, and enhances the extrapolated values with high resolution digital terrain data. The resultant screen-level forecasts have a temporal resolution of one day and a spatial resolution of about 1 km^2. The technique was first used to forecast maximum and minimum temperatures for clear skies, and later expanded to include all sky conditions (Sullivan, 1988). In addition to temperature, the technique has been used to generate the variables to relative humidity and precipitation.

High resolution forecasts generated by the MOE technique have been used as input into plant disease models. In a first attempt, temperatures and relative humidities, derived from archived 850 and 700 mb output of the National Meteorological Center (NMC) Nested Grid Model (NGM), were imputted into the Wallin System to give predictions of the likelihood of potato late blight infection (Russo et al., 1987). For this one-day case study, the disease predictions were limited to the Commonwealth of Pennsylvania and no field evaluation was conducted to determine their accuracy.

In another study (Seem et al., 1989) involving apple scab predictions, the MOE technique used the same archived NGM upper-air output to generate forecasts of temperature, relative humidity and precipitation. In an improvement over the earlier research, the high resolution temperature and relative humidity forecasts were available at a 2-hr temporal resolution, and the precipitation at a 12-hr resolution. The forecast domain was also extended to the northeastern U.S. Using the high resolution forecasts as input into the apple scab model, hours of wetting and infection severity were predicted one- and two-days in advance. An evaluation of six sites in New York State over a three day period in late spring, 1987, indicated an accuracy of 67% for plant disease predictions. While the results of the study were judged to be promising, they are still not accurate enough for operational decision making.

3. GRAPEVINE DOWNY MILDEW PREDICTIONS

This paper discusses another study underway to predict grapevine downy mildew sporulation and infection which is caused by the fungus, *Plasmopara viticola*. Blaeser and Weltzien (1979), in a series of field and chamber epidemiological studies, established the environmental conditions for grapevine downy mildew sporulation, sporangium survival, infection and dispersal of sporangia. Based on the sporangium survival and infection research of Blaeser and Weltzien, Pearson and Seem (personal communication) developed the Geneva Grapevine Downy Mildew (GGDM) model for predicting the occurrence and intensity of the disease in the northeastern U.S.

The GGDM model defines the meteorological criteria for sporulation, sporangium survival and infection. A combination of more than four hours of darkness, relative humidities greater than 90%, and a set of temperature ranges between the limits of 14 and 30°C determine a sporulation factor for each day. A sporangium survival factor is arrived at by comparing the sporulation factor to a mortality factor, which is dependent on temperature and relative humidity. The survival factor in combination with the hours of leaf wetness and temperature during the day determine the level of disease intensity. The intensity, which can range from no infection to severe infection, constitutes the GGDM mode output used for disease management.

High resolution forecasts of temperature, relative humidity, and precipitation, generated by the MOE technique from archived NGM 850 and 700 mb output were input into the GGDM model. It was assumed that a susceptible grapevine host and infectious fungi were present everywhere in the forecast domain. Predictions were made for case study days in late spring, 1987, for the northeastern U.S. and displayed as greyscale maps at a spatial resolution of about 1 km.

4. CONCLUSION

This paper reports on the use of high resolution forecasts as input into a grapevine downy mildew model. Together with previous research on other disease models, the present study represents another step in assessing the feasibility of mesoscale weather forecasts for local disease prediction.

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see example at left below in References

List of Scientific and Grower Meetings at which Results of the Project Were Presented and Training Was Provided in the Application of the Results to Viticulture

Gadoury, D.M., and Pearson, R.C. 1988. The use of dormant eradicant sprays to control grape powdery mildew. Phytopathology 78:1507. Presented at the Northeastern Division Meeting of the American Phytopathological Society. Attendance ca 300.

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