Proceedings of the

Nelson J. Shaulis VITICULTURE SYMPOSIUM

Integrated Pest Management of Grape Diseases: Present and Future Strategies

Jordan Hall Auditorium,
New York State Agricultural Experiment Station
Geneva, New York

March 5 and 6, 1991

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FOREWORD

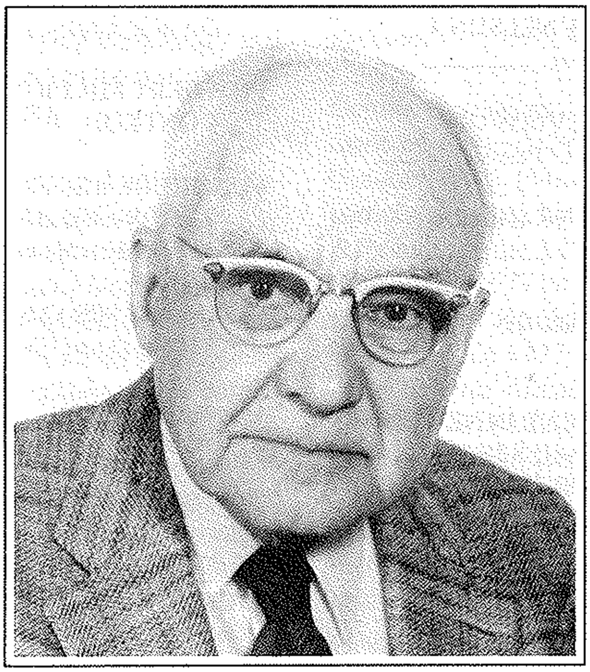
The first Nelson J. Shaulis Viticulture Symposium was held this year on March 5 and 6, 1991. This symposium came about for two reasons: the first was to provide the grape industry, especially that in New York State, with up-to-date in-depth knowledge of a well defined topic of broad viticultural interest. We are hopeful that this symposium is the first in a projected series which will serve as a resource for viticultural decision making. The second was to honor Nelson Shaulis, Professor Emeritus of Viticulture, Cornell University, for his lifetime of research on grapevine management and physiology.

Nelson Shaulis arrived at the New York State Agricultural Experiment Station in Geneva in 1944, and retired from the Department of Pomology and Viticulture in 1978. He remains active as a viticultural consultant and research collaborator. He is a world-recognized authority on grape culture and physiology, with research that has encompassed the conceptual as well as the practical. He used his graduate training in agronomy in research on mineral nutrition during his first decade at the experiment station. He later developed the concept of balanced pruning, the Geneva Double Curtain system of grapevine training, and he has played an important role in the development of mechanized harvesting. His investigations into the interactions between environment and vine physiology have stimulated significant changes in the way the grape industry practices grape culture and canopy management.

Dr. Shaulis is noted for his broad knowledge and broad interests in viticulture and for his efforts to take a generalized approach toward integrated vine and vineyard management. This broad interest carries over into the area of the management of grape diseases, which the grape industry itself has placed at the top of its list in its need for more information. The topic of integrated pest management of grape diseases came about through meetings with industry representatives and Cornell University research and extension staff who have commitments to grapes. In an interview with Dr. Shaulis after the symposium, he reflected approval of this topic by saying, "I felt the disease control theme was an appropriate one and the choice of topic and speakers would be difficult to improve upon." The program itself reflects the multidisciplinary approach to the subject. As you can see by perusing the table of contents, the research efforts directed at grape disease management are many. These proceedings record the presentations by the speakers who participated in the program.

The efforts of many groups and individuals assured that the planning and execution of the program and these proceedings were successful. The New York Grape Production Research Fund helped in funding out-of-state speakers and provided funds for publication of these proceedings. Thomas Davenport, of National Grape Cooperative Association, was instrumental in developing the concept of a series of symposia, whose proceedings could serve as a published resource of information of direct benefit to the grape industry. Cornell faculty volunteered in efforts to select guest speakers, to develop topics and to present research reports; this is especially true of Roger Pearson, who also wrote letters and helped in editing some of the manuscripts. The speakers at the program put on a quality performance that will be tough to beat. Cornell's grape extension specialists, Jim Kamas of Western New York and Dave Peterson of the Finger Lakes region, served as session moderators. Jim and Rick Dunst, Manager of the Fredonia Vineyard Laboratory, made sure meeting registrants could obtain pesticide applicator recertification credits. Sharon Kreliner deserves special mention for all the work she did before, during and after the meeting: handling registrations, making up information packets, handling the coffee breaks and luncheon arrangements, and other tasks. She was aided by Mary Jean Welser. Mary Jean and Mary-Howell Martens served as projectionists. Gary Howard handled wine contributions for the banquet. Sharon Kreliner and Betty Porterfield helped get manuscripts into word processors, while Communications Services at the experiment station handled the page layout and publication process. Special thanks to attendees and industry folks who furnished grape juice for breaks and wines for the banquet. Final proofing and collating of manuscripts for these proceedings were taken on by me. These proceedings, however, are the products of the individual contributors, who alone are responsible for their content.

Martin C. Goffinet
Extension Associate and Symposium Chairman



Nelson J. Shaulis
Professor Emeritus of Viticulture

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Thomas J. Burr: Professor of Plant Pathology at the New York State Agricultural Experiment Station (NYSAES), Geneva. He has degrees in plant pathology from both the University of Arizona and the University of California, Berkeley. He has been at Geneva since 1978, conducting research on the biology and control of diseases of fruit crops, with emphasis on bacterial diseases. His grape research includes studying the biology and control of crown gall, including its development, prevention and management in vineyards.

Thomas G. Davenport: Director of Viticultural Research and Regulatory Compliance, National Grape Cooperative Association, Inc. He graduated from Edinboro State College with a degree in Natural Sciences. He has worked for National Grape Co-operative since 1967, most recently as Area Manager of Member Relations for New York State, before his promotion to his current position. He is a member of several agricultural organizations and currently serves on the Boards of Directors for the New York State Grape Production Research Fund (also its President), Leadership Development Associates (also Secretary), and New York State Council of Farmer Cooperatives (also Vice President).

Michael A. Ellis: Department of Plant Pathology, Ohio Agricultural Research & Development Center, Ohio State University, at Wooster. Dr. Ellis received his B.S. (Science in Education, 1971) and his M.S. (Botany, 1973) at Eastern Illinois University, and Ph. D. in Plant Pathology at the University of Illinois (1979). He was Assistant Professor of Plant Pathology at the University of Puerto Rico, 1976–79, teaching tropical plant pathology and researching diseases and seed pathology of food legumes. From 1979 to date, he has been a professor of plant pathology at OSU's O.A.R.D.C. at Wooster, 65% research, 35% extension. His responsibilities include the development and implementation of disease control recommendations for all fruit crops in Ohio, which emphasize integration of cultural practices, biological control and chemical control. He also teaches a course on the diagnosis and control of fruit diseases at OSU.

David M. Gadoury: Research Associate at the NYSAES, Geneva, Department of Plant Pathology working with Robert Seem in epidemiology and control of grape fungal diseases. He received his doctorate in 1984 at the University of New Hampshire. From then until 1989, he worked with Roger Pearson on the epidemiology of the grape powdery mildew fungus, NYSAES, Geneva. Dr. Gadoury is best known for his work on the overwintering of plant pathogens, and the role of inoculum dose in development of epidemics. He is now developing a unified program for the simultaneous management of the major fungal diseases of grapevine in New York, with both Dr. Seem and Dr. Pearson.

Dennis Gonsalves: Professor of Virology, Department of Plant Pathology, NYSAES, Geneva. Dr. Gonsalves was trained in both horticulture and plant pathology at the University of Hawaii and in plant pathology at the University of California at Davis. From 1972–1977 he researched citrus diseases at the University of Florida. He has been at the NYSAES, Geneva, since 1977. He has an active research program in virus diseases of both vegetables and fruit crops. He is developing rapid methods for diagnosing virus deseases in grape rootstocks and scion cultivars.

W. Douglas Gubler: Associate Professor, Department of Plant Pathology, University of California, Davis. He has been Extension Plant Pathologist there since 1983. He has a B.S. degree in botany at Southern Utah State College, M.S. in plant pathology at the University of Arkansas, and Ph.D. in plant pathology at U.C. Davis. Major research responsibilities include fruit and nut crop diseases with emphasis on pathogen biology, disease epidemiology and control. Emphases in grape research include control strategies for Botrytis bunch rot, the life history and control of powdery mildew, as well as fungicide resistance.

Maria Lodovica Gullino: Associate Professor in Plant Pathology at the University of Torino, Italy, from which she received her doctorate degree. Dr. Gullino has spent sabbatic leaves at the University of Wageningen, The Netherlands (1981), the University of Maryland (1984), and at Cornell University, NYSAES, Geneva (1988–89). Her main fields of research are fungicide resistance, and biological and integrated control of foliar, soilborne and post-harvest pathogens.

Wolfram D. Koeller: Assistant Professor in Plant Pathology, NYSAES, Geneva. Dr. Koeller specializes in fungicide biochemistry. He received both a M.S. and Ph.D. in chemistry and biochemistry in Marburg, Germany, spent a post-doctorate at Washington State University, and from 1982–86 was involved with fungicide biochemistry work in Bayer, Germany. Since coming to the Geneva station in 1986, he has been investigating the mode of action and mechanism of resistance of fungicides.

Roger C. Pearson: Grape pathologist in the Department of Plant Pathology, NYSAES, Geneva. His graduate work was done in the Department of Plant Pathology at the Universtiy of California, Davis. He has been with Cornell since 1973, when he began pathology studies on apples and peaches at Cornell's Hudson Valley Laboratory. In 1977 he came to the Geneva station to begin investigations on grape fungal diseases. His special interests lie in epidemiology and control of fungal diseases, although he also has begun work on mycoplasma diseases of grapes and their insect carriers.

Robert M. Pool: Professor of Viticulture, Department of Horticultural Sciences, NYSAES, Geneva. He has had training in enology at the University of California, Davis, where he worked as a staff research assistant. He has a Ph.D. in viticulture from Cornell University. He served as the grape breeder at the Geneva station from 1974–80. Since 1980, he has been Cornell's viticulturist, with major research programs in pruning systems, growth regulators and cold hardiness.

Dennis A. Rapp: New York State's Deputy Commissioner for Natural Resources and Environmental Programs. Mr. Rapp has served in a number of executive and managerial posts, spanning more than 35 years of federal and state service. In New York State he has served as Director of the Office of Environmental Planning in the Department of Public Service (1970–77); Senior Deputy Commissioner for Economic Development and for Policy and Research in the Department of Commerce (1981–87); and Director of the Office of Policy and Program Analysis in the Department of Environmental Conservation (1987–89). Federal Service includes five years as Budget Examiner in the Bureau of the Budget (1960–65); Chief of Policy and Research for the Public Land Law Review Commission (1965–70); Managing Director of the Civil Aeronautics Board (1977–78); and Chief of Staff to Alfred E. Kahn, Advisor to the President on Inflation, Economic Policy, and Regulatory Reform (1978–81). Mr. Rapp has a B.S. degree from the University of Minnesota (1952), and a Master of Public Administration degree from Harvard (1958). In 1957 he was awarded a Ford Foundation Fellowship.

Bruce I. Reisch: Associate Professor in the Department of Horticultural Sciences, NYSAES, Geneva. Since 1980, Dr. Reisch has been developing new wine and table grape varieties, as well as new grape breeding techniques at the Geneva experiment station. Bruce studied plant breeding and genetics at Cornell University (B.S. 1976) and then at the University of Wisconsin (M.S. 1978, Ph.D. 1980). His program has released three white wine-grape and two seedless table-grape varieties since 1980. Currently he is developing some promising grape selections which merit attention. His traditional breeding methods are supported by experimental approaches utilizing genetic engineering and tissue culture, as well as molecular genetic approaches. He is active in national committees overseeing the preservation of grape germplasm.

Robert C. Seem: Associate Professor in the Department of Plant Pathology, NYSAES, Geneva. He is also serving in a split appointment (50:50) as the Station's Associate Director. He has been at the Station 15 years, and is responsible for studies of the quantitative epidemiology of fruit and vegetable crops. This includes the development of disease assessment techniques and forecast models for improved disease control and IPM methods.

Timothy Weigle: Regional Grape Pest Mangement Specialist for Western New York and Finger Lakes regions. He is stationed at the Taschenberg Vineyard Laboratory in Fredonia, New York. He received his B. S. in Plant Pathology and Pest Management and his M. S. in Horticulture from Iowa State University. He was a research technician in Fruit Crops at the Iowa State University Research Station and was the commercial fruit agent in the Hudson Valley prior to coming to Fredonia. He is actively engaged in implementing a grape IPM program in the state, in cooperation with growers, processors, and Cornell research and extension staff.

INDUSTRY RECOGNITION OF NELSON J. SHAULIS

Thomas G. Davenport
Director of Viticultural Research & Regulatory Compliance
National Grape Cooperative Association, Inc.
Westfield, NY 14787

It is my great pleasure to recognize Dr. Nelson J. Shaulis, in whose honor this symposium has been established. In Dr. Shaulis's distinguished 34-year career at Cornell University, he initiated research on pruning, vine spacing, canopy management, site selection, and mechanization that resulted in the improved production and quality of New York State grapes. These advancements have enabled New York State producers to remain competitive in the world marketplace.

Dr. Shaulis has been recognized by his peers as being one of the world's pre-eminent viticulturists. Many of his associates, including growers, processor representatives and researchers, are here today.

Dr. Shaulis also provided benefits to this industry in many other ways. He was an expert witness at the public hearings on a proposed electric generating plant to be constructed in the Lake Erie grape belt. His testimony was a major factor in the conclusion reached by the Hearing Examiners which, in part, required research studies on the proposed facility emission impacts on the grape industry. One newspaper account of the hearings stated this about Dr. Shaulis upon the conclusion of this testimony: "Although he's gone, he won't be forgotten – not by the public, not by the press, and certainly not by the attorneys for Niagara Mohawk. He's already regarded as the legend of the hearings."

One of my life-long goals has been to see that this industry gains the maximum benefit from this multi-talented individual who has contributed so much. This symposium is dedicated to Dr. Nelson Shaulis's commitment to excellence in the pursuit of knowledge.

SYMPOSIUM THEME AND REVIEW OF GRAPE DISEASES

Roger C. Pearson
Professor
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Cornell University
New York State Agricultural Experiment Station
Geneva, NY 14456

Grape growing today is a complicated proposition. Not only are growers faced with increasing costs of production, but once the grower makes the commitment to invest in the crop there is no guarantee that he will be able to recoup his investment, let alone make a profit. One complicating factor is disease control. Despite the grower's best intentions and a hefty investment in a disease control program, there is no guarantee disease will not be a problem. This is due to many factors beyond the grower's control, including survival of disease inoculum from the previous year, the weather conditions during the current season, and perhaps the development of fungicide resistance, to name a few.

An additional concern is the availability of fungicides. Just a few years ago our fungicide arsenal was plentiful and effective. However, due to the Federal government's re-registration requirement for all old pesticides, we have lost folpet, Karathane, Dikar, and the seven-day-to-harvest maneb products. The chemical companies have decided not to defend these fungicides largely because the market is too small to justify the cost of re-registration. Furthermore, due to the development of pathogen resistance to fungicides, we have lost Benlate for control of powdery mildew and Botrytis bunch rot. Recently we have documented declining effectiveness of Bayleton for control of powdery mildew and Rovral for control of Botrytis bunch rot. Due to public concerns over the use of pesticides, precipitated by the Alar issue, juice processors have banned the use of captan, even though it has been re-registered on grapes by the Federal government, and they have restricted the mancozeb products, such as Dithane M45, to prebloom usage only. Although Nova and Rubigan were recently registered, they are essentially competing for the Bayleton market and there are indications that they too will have resistance problems.

All of these concerns mean the grower is being forced to become more cognizant of how the decisions he makes in the vineyard interact and impact on the success of the disease management program. He is going to have to incorporate all aspects of disease control into an integrated package. <u>He must realize that all decisions regarding the vineyard, beginning with selection of the variety, will potentially impact disease development for the life of the vineyard</u>.

To help you become more aware of these interactions and the consequences of your actions, the Symposium will hopefully give you information about grape diseases and their control that you may not have been aware of, or reinforce those of which you were aware. We hope to examine the major aspects of control and various options available, from selection of planting material to understanding the effects of the training system on disease. We hope to provide a basic understanding of the biology and ecology of disease organisms, knowledge of how cultural practices influence disease, and what the chemical control options are under differing management strategies. Not only do we intend to give the current understanding of disease management options, but we hope to give you some insight into potential management strategies of the future. Finally, we have some guests on the program who will provide information on the disease control situation outside of New York. I think it is useful to know how other growers are coping with similar problems and hopefully we can learn from their successes or failures, as the case may be.

In order to start the technical program and to assist you in getting the most out of the Symposium that follows, I would like to briefly review the major fungal pathogens, including terminology you are likely to hear, life cycles, their period of activity in the growing season, and their response to weather events. (Color photographs of diseases and disease cycle diagrams can be found in the IPM Fact Sheet series or in the Compendium of Grape Diseases).

Powdery Mildew (*Uncinula necator*)

The powdery mildew fungus overwinters in New York as small, black, spherical fruiting bodies (called cleistothecia) on the surface of the vine, commonly on the bark of the trunk or cordons. We refer to these cleistothecia as the primary inoculum or the initial source of spores for disease initiation. During spring rains (0.1 inches or more) cleistothecia absorb water, burst, and release spores (called ascospores) into the air. In most years, between 75 and 100% of the cleistothecia release their ascospores between bud break and bloom. If these ascospores land on susceptible grapevine tissue, infection can occur if temperatures are at least 50F. Infection by ascospores can occur in free water or under relative humidity (RH) conditions as low as 58%. Under optimal temperature conditions (65-75F) a mildew colony will appear within four days and a new crop of spores (called conidia), which we refer to as secondary inoculum, will be available for wind dispersal in another day or so. Conidia are able to infect grapevine tissue under a wide range of humidity conditions (58-100% RH) but, unlike the ascospores, rarely in free water. Although distinct infection periods can be identified for ascosporic inoculum, based on rainfall and temperature, conidia can infect on most days and the major limiting factor is temperature above 90F. High humidity and low light intensity favor sporulation of the conidial stage. The first mildew colonies can usually be found, after approximately six inches of shoot growth, on the undersides of leaves in close proximity to bark on the trunk or head of the vine.

The fungal strands (called hyphae) from mildew colonies of opposite mating types must intermingle and fuse in order for the sexual stage (cleistothecia), to develop. Once the amount of disease in the vineyard increases to a level where chance pairings of opposite mating types can occur, formation of cleistothecia begins. On the contrary, if the amount of disease in the vineyard is held at a low enough level throughout the entire growing season, the cleistothecial stage should not form and, theoretically, the fungus should not be able to overwinter in that vineyard.

Shortly after cleistothecia develop a black color, they are readily dislodged from the fungus colony by rainfall and are distributed in water to other parts of the vine or to the

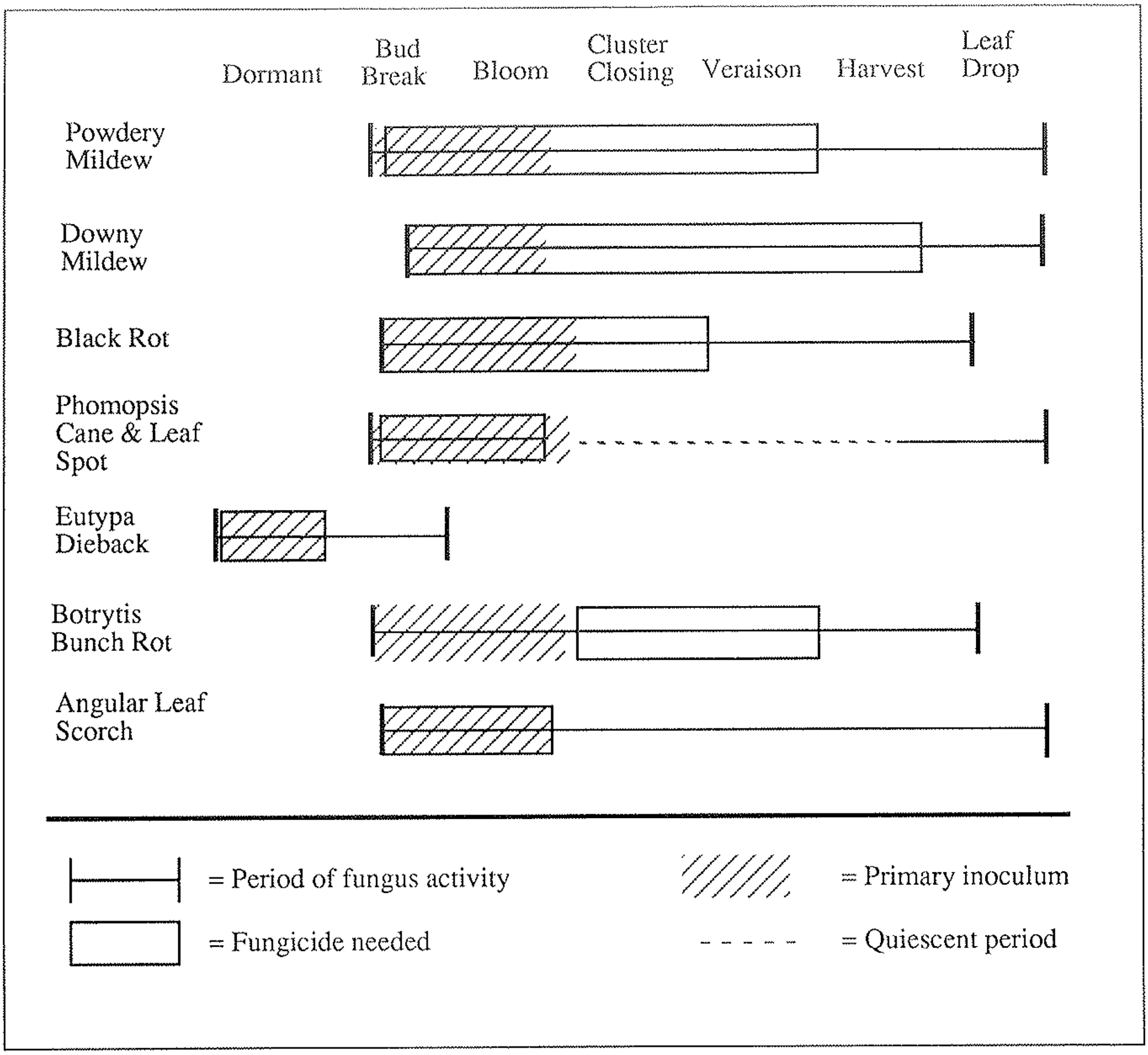

Figure 1. Fungal disease activity in relation to grapevine growth stages.

vineyard floor. Although those on the vineyard floor do not survive winter, a high percentage of those on the bark survive and serve to initiate the disease the following spring.

Downy Mildew (*Plasmopara viticola*)
The downy mildew fungus overwinters in structures called oospores imbedded in dead leaves on the vineyard floor. Shortly after bud break, during spring rains, the oospores germinate in a film of water to produce structures called sporangia. Motile spores called zoospores are formed within the sporangia and swim into the film of water where they are rain-splashed to grapevine foliage. Once on the foliage, the zoospores swim toward stomata (structures for gas exchange) where they encyst, germinate, and penetrate the grape tissue. The fungus grows between the cells in the tissue, and obtains nutrients from them. In the dark and at temperatures greater than 55F, the fungus produces spore bearing structures (sporangia) through stomata. The sporangia are wind borne or rain splashed which further disseminates the fungus. Once sporangia are in a film of water, they rapidly produce zoospores which infect healthy tissue. Infection periods for downy mildew can be identified by determining the length of wetting periods and the average temperature during the wetting period. At optimal temperatures (65-75F) infection can occur in as little as 2.5 hours.

Leaves, young shoots, tendrils, rachises, and berries are susceptible to infection as long as they have active stomata. Once the stomata cease to function or become lenticels, infection can no longer occur through them. Infection and sporulation on leaves are seen only on the undersides of grape leaves because stomata occur only there.

Black Rot (*Guignardia bidwellii*)
The black rot fungus overwinters in asexual fruiting bodies (pycnidia) or in sexual fruiting bodies (pseudothecia). The pycnidia produce spores called conidia and the pseudothecia produce spores called ascospores. Pycnidia may survive winter in cane lesions or in mummified fruit. Pseudothecia are produced in mummified fruit during the dormant season.

In spring, shortly after bud break and during warm rains, ascospores are forcibly ejected into the air and are carried by the air currents. If they land on juvenile grapevine tissue and if the length of wetting is sufficient at favorable temperatures, infection can occur. In the same rains, spores from pycnidia are rain splashed to nearby tissue where infection can occur if temperature and duration of leaf wetness are favorable (see table in Black Rot Fact Sheet or in the annual Pest Management Recommendations for Grapes). At favorable temperatures, lesions become visible within a week after infection and pycnidia form inside the lesion in an additional 3-4 days. Dissemination of spores from the new pycnidia occurs with each favorable rain event throughout the remainder of the season.

Phomopsis Cane and Leaf Spot and Fruit Rot (*Phomopsis viticola*)
The Phomopsis cane and leaf spot fungus overwinters on canes and rachises in fruiting bodies called pycnidia. During spring rains, spores ooze out of the pycnidia and are rain splashed to nearby tissues. Those that land on susceptible tissue infect if the temperature (65-80F is optimal) and duration of leaf wetness are sufficient. Leaves and internodes of shoot tips are susceptible to infection throughout the growing season, but they are more commonly infected between bud break and 6 inches of shoot growth, a stage when they are in closest proximity to inoculum on canes. Infection of the rachis can occur from the time clusters are first visible, at 2-3 inches shoot growth, until berries are pea size. Fruit infection occurs during or shortly after bloom until berries are pea size.

Symptom expression appears to be associated with growth of the vine. For example, lesions on shoots elongate and crack as the shoot grows in length and girth and typical shoot lesions appear 3-4 weeks after infection. Although juvenile tissue seems to be the most susceptible to infection, once infection has occurred the fungus appears to be more aggressive in senescing tissue. For example, on shoots the fungus is limited to cells in the lesion, but after periderm forms on the shoot, the fungus invades this tissue and eventually pycnidia may form throughout the internodal area, far beyond the original lesion. Some infections of the shoot may never develop symptoms, but will produce pycnidia during the dormant season. Similarly, some infected leaves may never develop typical symptoms, but as the leaves become senescent the fungus invades the tissue and produces pycnidia within it. In addition, symptoms of fruit rot and most rachis lesions do not begin to appear until 1-3 weeks before harvest.

Botrytis Bunch Rot (*Botrytis cinerea*)
The Botrytis fungus overwinters as hard, black structures called sclerotia. This fungus has a very wide host range and sclerotia may form on any dead infected plant debris. Hence, one has to assume there is always inoculum in the vineyard. With the onset of warm weather in spring, spores called conidia form on the sclerotia. The conidia are wind dispersed. In a film of water, at temperatures in a wide range (37- 86F), the conidia germinate and infect susceptible tissue. Healthy tissue is not generally susceptible to infection. However, if the fungus becomes established on pollen grains or other plant debris in contact with healthy tissue, it can use this as a food base, grow into the healthy tissue, and cause disease. Reports indicate young berries may become infected during bloom, but the infection lays dormant until physiological changes in the berry trigger reactivation of the fungus which ultimately causes a rot of the berry. More commonly however, the fungus becomes established on blossom debris retained in the cluster and from there infects healthy berries. Once berries begin to accumulate sugar (above 5%) the fungus is capable of penetrating the skin directly to cause infection. Growth of the fungus is favored by high humidity (above 94%), calm wind conditions, and low light intensity.

Eutypa Dieback (*Eutypa lata*)
Unlike most fungal pathogens of the grapevine, *Eutypa* is most active during the dormant season. The fungus survives from one season to the next in hard, black fungal tissue called a stroma which is formed on dead wood. This stromatic tissue contains fungal fruiting bodies called perithecia. Perithecia produce spores called ascospores which are forcibly discharged into the air during rainfall or snow melt. Ascospores that land on fresh pruning cuts are washed into the exposed vessel elements where they germinate and initiate the infection process. Because of this process, infection periods are not determined by length of wetting and the temperature during wetting. The only requirements for infection are water to stimulate

ascospore discharge and susceptible pruning wounds for sites of entry. Once infected, canker formation and foliar symptoms do not become evident for 3-4 years. During this time the fungus grows in the vascular tissue and presumably produces a toxin that is translocated to the developing shoot served by the infected vascular elements. The toxin eventually causes the typical stunted shoots with their cupped, chlorotic leaves. Only after the infected wood has been killed by the fungus and the outer bark has weathered away, does the fungus produce perithecia. This process may take an additional 5-6 years. Although all pruning wounds are susceptible to infection, only major cuts, those on the trunk or cordons which affect the main structure of the vine, need to be protected.

Angular Leaf Scorch (*Pseudopezicula tetraspora*)
Angular leaf scorch was described for the first time in 1985. The symptoms of this disease are identical to Rotbrenner, a disease of grapes in Europe. In fact, the fungus that causes the disease is closely related to the fungus that causes Rotbrenner. As the name implies, the most obvious symptom is the reddish-brown, necrotic tissue delimited by the major veins. On most varieties, a yellow border delimits the green, healthy tissue from the necrotic tissue. In Europe, the Rotbrenner fungus infects the stem of the berry which causes it to die shortly after bloom. Similar symptoms have been observed on clusters of angular leaf scorch infected vines in New York, but a causal relationship has not been proven.

The angular leaf scorch fungus overwinters in infected leaves on the vineyard floor. Shortly after bud break, following exposure to rain water, the fungus produces small, jelly-like fruiting bodies called apothecia. Apothecia produce ascospores that are forcibly discharged into the air and carried in air currents. Ascospores that land on susceptible leaves germinate and infect if a film of water is present and temperatures are near 60F. Typical symptoms usually develop in 21-30 days. Secondary spread is rare, but during periods of extended rainfall (4-5 days) apothecia containing infectious ascospores can form on the current season's infected leaves to further spread the disease.

Conclusion
The one factor that seems to be similar with nearly all of the diseases discussed is the fact that the period of primary inoculum availability in the vineyard generally occurs between bud break and bloom (Figure 1). When one realizes this common thread, the importance of prebloom, multiple disease control becomes obvious. Remember, it is much easier to prevent a disease outbreak than it is to stop one in progress.

With this somewhat sketchy background I think you can see many similarities and yet some distinct differences in how the various grape pathogens grow and respond to their environment. I hope you will be able to add to this base of information over the next day and a half in such a way that you will be able to better understand the disease problems in your own vineyards and be able to develop control strategies that provide the disease management level you desire, in the most economical and environmentally sound manner possible.

ASSESSING AND FORECASTING GRAPE DISEASES

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Assessing and forecasting of grape diseases at first appears to be a subject not well suited as one of the early papers in this symposium. However, assessment and forecasting is often the interface between the science of the disease and the grower's vineyard. We have placed the paper early because we hope to provide you with a foundation for understanding how studies on disease are moved to actual application.

The dual topics (assessing and forecasting) are very much interrelated. However, I would like to switch the order of the topics; first forecasting, then assessing. I must first lay a foundation for forecasting and then relate the importance of assessment to forecasting.

We all have some understanding of forecasting because we are constantly exposed to such things as weather forecasting, crop forecasting and economic forecasting. In all cases, forecasting is an attempt to describe some future event, whether it is a short-term event such as tomorrow's weather or a long-term event such as the price per ton of next year's grapes. While disease forecasting in many ways is similar to these types of forecasting, it is also uniquely different. Let us examine the unique features of grape disease forecasting.

Types of forecasts — Grape disease forecasts can encompass the past, present or future. Ideally, it would be most advantageous to forecast future events. But for a number of reasons, this is not practical in all cases. As we will learn, forecasts require accurate information, which often is not available. Unlike weather forecasts, plant disease forecasts do not have the backup of federal agencies whose responsibility is to collect rapidly vast amounts of information, process that information on supercomputers and distribute the resulting forecast through news media and private advisory firms. In order for grape disease forecasts to predict future events, we usually must know future weather conditions within a particular vineyard. We must also be able to predict the future behavior of both the grape vine (development stage) and the condition of the pathogen (will it be present, will it be ready to infect the vine, will enough of the inoculum be there for significant infection to occur). From a researcher's point of view, this is a tremendously complex set of information, especially given the fact that each component of information has its own uncertainty associated with it (that is, our information is not known with perfect accuracy). Future forecasts of disease allows a grower to plan ahead for disease control, and in most cases protective control can be practised.

More typical of plant disease forecasts are the current forecasts in which the currently available information (like rainfall, temperature, duration of leaf wetness, observed presence of disease) is combined into a forecast to determine if new infection or damage has occurred. Most typical grape disease forecasts, like those for black rot or downy mildew, are of this type. However, the response by growers must be reactive since the forecasts predict events that have already occurred. For chemical control, growers must rely on after-infection fungicides. Why do we still call the process a forecast? Because plant diseases go through an incubation period after infection, disease symptoms are not seen until the end of the incubation period. In essence, we are forecasting the future event of disease symptoms.

Forecasting past events, although it appears to be oxymoronic, is a process by which we can estimate such things as yield loss. In the case of yield loss, we take past infection events, which are already appearing as symptoms, and estimate how much loss or damage the disease will have on the crop. Such forecasts, although they can be quite accurate, are much less useful for the actual control or management of disease within the growing season. They are used more for long-range planning and marketing.

Origins of forecasts — Technically speaking, forecasts are models used to predict the future occurrence of some event. Models are simplifications of a complex system (like the interaction of a fungus with a grapevine). But there are many ways in which forecasts originate. We might consider the simplest form to be **learned experience**. For example, having dealt with a disease over many years, a grower may simply "know" what to do to control it. It may be very hard to explain to others, but the grower simply reacts to conditions almost automatically. While this may appear to be a simple method of forecast, it is actually a very complex process that scientists have been trying to duplicate with computer programs called "expert systems." Regardless, many growers regularly utilize learned experience even if we or they cannot describe precisely the actual forecasting process they use.

Another simple form of forecast is the **rule of thumb** in which a forecast may be based on a common association. As an example, we are testing a rule of thumb as a grapevine downy mildew forecast, in comparison with other forecast systems. The rule of thumb was suggested by Roger Pearson after his repeated observation that the first appearance of downy mildew occurs in vineyards by June 15. Thus the rule of thumb states that by June 15 a grower should have the first downy mildew spray on susceptible vines. On average this rule will work, but there will be those occasional years when the disease will occur earlier due to favorable conditions (a warm winter and spring), or it may occur significantly later if conditions are not favorable (a dry spring and summer). Nevertheless, rules of thumb work when no other, more sophisticated forecast systems are available.

One step above rules of thumb are **simple associations**. The forecast is more than one simple rule and these rules have some connection to reality. For example, there is a simple association used in Europe to forecast the first occurrence of grapevine downy. It is called the 10-10-10 rule. It does not refer to a fertilizer, but to three very important components of the disease. In expanded form, downy mildew can be expected to occur when the average temperature reaches 10 C (50 F), the accumulated rainfall reaches 10 mm (0.4 inches), and the vine shoot length reaches 10 cm (4 inches). The three associations are based on the fact that in order for overwintered inoculum to be able to infect vines, there must be sufficient warmth and moisture; a temperature of 10 C and rainfall of 10 mm provide this requirement. Also, susceptible leaf tissue must be available. But the downy mildew fungus can only infect through stomates, the tiny "breathing" pores on the underside of the grape leaf, and stomates are not fully functional until the leaf has matured sufficiently. The first leaves of the grapevine are not mature until the shoot has extended to about 10 cm. What appears to be a rather simple set or rules does indeed have real biological meaning.

The association can become more complex as more biological and meteorological information is incorporated into a forecast system. We can call these **complex associations**. As you will see in later papers in this symposium, the black rot disease of grape is predicted by use of an infection table which has been derived by detailed studies of the infection process. The table relates how average temperature and duration of leaf wetness (surface moisture on the leaf of susceptible grape tissue) contribute to infection. At some temperature and leaf wetness combination, infection will not occur while at others infection can occur rapidly. When a grower knows inoculum and susceptible tissue are present, and the appropriate weather information available, the table provides a very accurate forecast of black rot infection.

When more biological information, concerning both the pathogen and the vine is available, the resulting forecasts are called **bio-based rules**. Referring once again to grapevine downy mildew, we have been developing a bio-based forecast system. In this forecast model, hourly temperature, relative humidity, leaf wetness duration, and rainfall are used to estimate maturation of oospores (the overwintering stage of the fungus), vine development, infection, and sporulation of conidia (the seasonal repeating cycle for the fungus). Because there are many relationships described by this model and some are rather complex, a computer program is the only logical means of calculating the forecast. At this point, forecasts are very different from the simple rules of thumbs described earlier.

The most complex form of a disease forecast involves a complete **simulation** of the disease process (and possibly the host or plant too). Simulations attempt to account for all major steps of biological development. They are much more difficult to develop than the simpler forms of models, and in some ways they are less useful for practical forecasting since they usually require more information to start the forecasting process and the process itself takes larger computers and more time. For this reason we will not deal further with this class of forecast.

Forecasts of events — Forecasts can be used to estimate several different types of events. This is because at different times of the season, or for different kinds of control strategies, various types of forecasts are required.

Forecasts may be used to estimate the **maturity or viability of inoculum**. Inoculum, usually spores, is the means by which a disease can spread. Inoculum must survive the winter, blow through the air, or splash with rain in order to move either from one season to the next or one diseased plant to a healthy plant. Because inoculum may be immature, sufficiently limited, or lose viability, forecasts can be used to determine these factors. Typically, a model such as POM (Prediction of Oospore Maturity) utilizes weather conditions through the winter and spring months to determine if the oospores of the downy mildew fungus have matured sufficiently to be able to germinate and infect susceptible tissue. The same fungus produces spores on the lesions of the current season's lesions and these spores serve as inoculum for additional infections during the season. However, sunlight and low relative humidity can cause the spores to lose viability. Some forecasts incorporate these facts and will issue infection warnings only if the spores remain viable.

Infection is the most commonly forecast factor for plant diseases. Infection is usually the most critical, and vulnerable, stage in the development of the disease. It is also this stage that is easiest to control; once infection has been established, control is much more difficult and damage to the crop is more likely.

Symptom development can be forecast, although from management perspective, this is not a useful forecast since infection has already occurred. However, symptom forecasts can serve as an indicator of when further management action is required. For example, the same bio-based forecasts estimate when symptoms occur in order to forecast the development of secondary inoculum and the necessity of sprays to protect tissue from that inoculum.

Finally, **loss** can be forecast as a management aid to determine how to dispose of a crop or to estimate income from a crop. For most growers, a loss forecast is too late to be a useful management tactic. Loss forecasts are most often used by agricultural agencies relative to marketing and statistics.

Components of forecasting — All comprehensive forecasts have three components which are combined to form the final forecast. Past conditions, such as prior weather conditions, amount of previous disease, or disease inoculum are required to establish **prior knowledge** about the disease. This information sets the stage for **current knowledge** which is the present status of events: disease or inoculum level, current weather, and condition of the host. Finally, there must be a **future plan** which logically is to prevent all disease. But more typically now, growers are attempting to practice good pest management in which the plan calls for disease to be below an established threshold. In other words, some disease is tolerable, but careful planning must be made so this threshold is not exceeded.

Steps of forecasting — In order to execute a forecast, three steps must be carried out. These steps apply to all models, whether it is a learned experience forecast or a simulation forecast.

The first step is **information acquisition** by which all the necessary knowledge about the pathogen, crop, and weather is gathered together. The acquisition can be accomplished by simply walking through the vineyard, or it might be done by sophisticated monitoring devices that collect the information automatically. In any case, without having quality information to plug into a forecast, the results will not be useful. It is the classic computer axiom, GIGO, or garbage in, garbage out.

After acquisition, there must be **information processing**. A grower may simply stop and think about what he or she just observed in the vineyard. However, when the human brain is not used to process information, some alternative must be utilized. In some cases the look-up table described above for black rot does the processing. In that case, the temperature and hours of leaf wetness duration are plugged into the table to determine whether or not infection occurred. In the cases of more complex forecasts, the information might be processed by a personal computer or an in-vineyard microprocessor device that, after collecting the weather data, will process current and past weather information to determine the likelihood of infection.

The final step to forecasting is **information delivery** which can take many forms. For the grower who was mentally "processing" the observed condition of the vineyard, the information is delivered internally, from one brain cell to another. However, in most other forecast systems the delivery is more formal. If someone other than the grower or manager does the processing, then the results of the forecast must be passed to the growers in a timely manner. If a consultant provides the information, then delivery is a note or conversation with the grower. Telephones, radio, and computer-based networks are usually the domain of the Extension Service and these methods have worked effectively when they provide the forecast. In the case of the computer or in-vineyard device, the information is delivered by means of a display or print-out.

If all this appears to be too formal of a representation of a forecast system, please bear in mind that, in future, it is likely pest control tactics involving chemicals will only be permissible when a documented prescription is provided. The simple forecast systems will, by necessity, be replaced by those systems which are more formal and provide a "paper trail" to establish the necessity of using the chemical.

ASSESSMENT — Now let us return to the topic of assessment and see how it relates to forecast and other important aspects of grape disease management. By now you should be getting the idea that successful management of grape diseases is not only knowledge about the casual organism (fungi, bacteria, viruses), but it is also about weather, vine phenology (growth stages), and the complex relationships between all these factors. Assessment is the means of measuring these factors. Certainly assessment involves measurement of disease, but it is only a part of several different types of assessment.

The first important disease measurement is **inoculum assessment**, representing either presence or absence of inoculum, or actually quantifying the amount or level of inoculum. Assessing the inoculum provides important preliminary information for forecasts or management of disease. Unfortunately, there are not many good examples of established inoculum assessments. You will learn in the symposium that the powdery mildew fungus overwinters in New York in resting bodies called cleistothecia, and then only on the bark of grape vines. We are attempting to assess the amount of inoculum in vineyards by use of simple filter paper funnels that are attached to the trellis post. As rain splashes cleistothecia, a certain portion will land in the funnel and the number captured will represent a relative amount of inoculum for the next season. Knowledge of inoculum is important for other fungal diseases of grape, such as black rot, Phomopsis cane and leaf spot, and downy mildew; but no usable assessment techniques have been developed for these diseases.

Similar to inoculum assessment is **disease assessment** for the presence/absence or amount of symptoms (lesions or colonies). Disease symptoms are easier to detect and measure compared to inoculum, but the task is still formidable. Trained observers can quickly determine the area of leaf or fruit tissue affected by disease usually based on standard area diagrams or general area estimates of disease. More simply, the presence or absence of disease is assessed by determining whether the disease is present on tissue. Usually a sampling procedure is developed to accompany the assessment technique in order to make the procedure repeatable as well as to determine the level of certainty associated with the assessment. We developed a detection procedure for downy mildew in Australian vineyards. The assessment was designed to determine when the management program for downy mildew control was to be initiated. Because downy mildew can spread very quickly in a vineyard, the assessment technique has to be sensitive enough to detect one lesion within three vines, or about one infected leaf among 2000 leaves. A sampling procedure was designed and tested in the vineyard that achieved the necessary sensitiviy. However, the statistical component of the procedure had to contain two components. First was the probability of having the minimum number of infected leaves within the sampled vines. The second component involved the probability of actually finding an infected leaf given it was present in the vine. Nothing is ever easy!

Assessments must also be made of **crop development or condition** in connection with disease assessments. They provide necessary information about the susceptibility and health of the crop. Some of the bio-based forecast systems include vine growth information as an input into the model. Different cultivars have different susceptibilities to diseases, so a grower must have some knowledge about the level of susceptibility of each cultivar being managed. The seasonal development of vines (or phenology) is assessed by comparison to known stages or categories of growth. One typical categorization of vine growth is the Eikorn-Lorenz scale in which each stage is defined as a numeric value. Forecasts can then refer to the stage of growth regardless of cultivar.

Finally, the most important assessment for grape disease forecasts is **weather information**. The information may be gathered by a grower, by a regional office (such as the regional Extension Specialist or the IPM Program), or by the National Weather Service. The most accurate weather assessments are made within each vineyard, but the expense and maintenance of such an operation is usually prohibitive. One weather station per farm is reasonable, but it still requires constant maintenance and calibration to insure that the measurements are accurate. If the maintenance responsibility is left to a regional source of weather information, then the information is less accurate for the specific farm or vineyard location. One alternative, although expensive, is by use of the in-vineyard devices that compute disease forecasts. They also collect weather information for use in the forecasts and store that information with the general record for that site.

No matter which type of assessment is used, there is direct involvement by the user. Rarely can one simply push a button a get a printout on a computer of the desired assessment. It requires getting out into the vineyard, searching through the tangled vines, searching the ground for dead, diseased leaves, or placing and collecting monitoring tools (spore funnels, sprayer cards, hygrothermograph charts, etc.). Sometimes the foray must be in the winter, or in the rain, but at all times the assessments must be carried out with care and accuracy. Remember, GIGO applies to assessments as well.

SUMMARY — Forecasting and assessing grape diseases is an important process that is used to link information developed in the laboratory and research vineyard to the growers' vineyard. Forecasts serve as a tool growers can use to manage or control grape diseases. There are different kinds of forecasts for different plant disease situations. Simple forecasts may work in some situations; more complex ones may be necessary for other situations. However, forecasting is not just looking towards the future, bu it involves assessment of the past and current conditions of the vines, the pathogen, and the weather. Assessment therefore becomes a key step in the process towards forecasting. Successful grape disease forecasts must be based on sound knowledge and assessment of the pathogen, the vine and the weather.

Disease Management Options

GRAPE DISEASE MANAGEMENT IN NEW YORK: IMPACT OF CHANGES IN THE INDUSTRY, CULTURAL PRACTICES, AND TOOLS

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A well designed vineyard disease management program considers four important factors: 1).the disease pressure, 2) the available management tools, 3) the economic cost of using the tools, and 4) the environmental cost of using the tools. During the two decades I have been working for the New York grape industry there have been many changes which affect all four of these factors. I am charged with describing these changes and predicting others, so that growers can anticipate how to begin to design management programs for the future.

Changes in Juice production

Before 1970 Concord grape production had changed only slowly since the establishment of the industry at the end of the previous century. Different training systems had evolved, some of the fungicides we now depend upon had begun to be widely used, but copper and lime/sulfur sprays were still the basis of most disease management programs. DDT was the most important insecticide. From a pest management and environmental standpoint there is little difference between DDT and the lead arsenate sprays of a previous period. Cultivation, both between and under the rows, was still a very important floor management technique.

The grape markets ensured that the industry would have to change. The decade of the seventies was a time when the demand generated by the wine sector limited the supply of grapes available to juice processors. Retail grape juice prices rose to the point where it was quite expensive compared to other juices; as a result, the market shrank. When the demand by the wineries in turn slacked in the late seventies and early eighties, there was a precipitous fall in prices. Nationally, juice grape growers came under considerable pressure to reduce cost of production. This meant both an emphasis on high yield (the easiest way to reduce cost of production) and on methods to reduce cash inputs.

The eighties have seen a restructuring of the Concord juice market. New products using Concord concentrate have been developed. Concord-flavor, blended juices whose price does not depend upon that of a single component have been a market success. Increased population and health awareness, especially in the west, has contributed to increased consumption. A new export market to the Pacific rim countries has been developed. The resultant increased demand for Concord grapes has again raised prices for Concord concentrate to a point of buyer resistance. A market for Niagara grapes to produce white juice has developed.

During the same period labor, especially skilled labor, became more expensive. In the west there is a good supply of expensive skilled agricultural labor to produce grapes. However, in the east the supply of vineyard labor has just about dried up.

These changes have tended to encourage expansion of production in the west at the expense of the eastern producer. It has pressured the eastern producer to reduce his cost of production so as to remain competitive with his western neighbors, and to attempt to find ways to reduce the labor requirement for Concord grape production. The two primary ways we have responded to these changes are to maximize yield and to adopt mechanical production methods. Both of these trends profoundly impact disease management in the juice grape vineyard.

The first important labor saving tool developed was the grape harvester. Essentially all juice grapes in New York are machine harvested. In terms of disease management harvester use brings two consequences. First in comparison with hand harvest, machines leave less fruit in the vine to harbor overwintering spores. Secondly, while hand harvest removes both the grape berries and the rachis, machine harvest removes only the grape berries. Potentially diseased rachises are retained in the canopy.

Recently there has been a trend to machine pruning. Machine pruning is best done on high cordon trained vines. However, both the use of cordons and machine pruning mean that more old, potentially-diseased, wood is retained in the canopy. Combined with machine harvest, this can substantially increase overwintering disease inoculum.

The concern with maximum yield tends to reduce the ability of vines to endure modest levels of disease without permanent damage. The historic practice of under cropping enhances vegetative vigor and leaf area production. With a large leaf/fruit ratio, some loss of function can be tolerated. When the leaf/fruit ratio is low, any loss of effective leaf surface through disease infection will negatively impact the vine. It is for this reason that the economic threshold damage levels for both disease and insect damage to Concord grapes are being currently re-evaluated.

Not all the changes that result from machine pruning are negative. Minimal pruned grapes tend to have many short shoots and very many small, loose clusters. As a result fruit exposure tends to be high and within-cluster disease spread lower with the machine pruned vines.

Changes in wine grape production

Native American varieties: Much of the fluctuation in the supply vs. demand ratio for Concord juice grapes can be attributed to the changes in the US and New York wine markets during the last 25 years. The changes in national and international wine markets have produced effects which have lead to a complete re-structuring of New York wine production. It has substantially changed the use and value of our traditional American varieties, has created a whole new category of grape production - the

French/American hybrids, and has lead to the emergence of vinifera as an important commercial component of New York's wine industry.

Except for the interruption caused by prohibition, the American wine market changed little during the first half of the century. Per capita consumption was low and stable. Most wines consumed were dessert wines, ports and sherries, and most of the table wine consumed was red. During the 1960's this stability was lost, and grape growers have been in a frantic race to keep pace with changing markets ever since. First, *per capita* consumption increased greatly, but the increase was primarily in table rather than dessert wine. For a while the traditional ratio 70% red table wine vs. white table wine held, but by the mid-1970's the white wine revolution hit and the majority of the wine sold was white table wine. In the early 1980's the impact of the strong dollar on imports was at a maximum and all US producers suffered from the invasion of low cost European (mostly Italian) wines. Then in the mid-1980's blush wines and coolers dominated the entry level markets. The demand for grapes they produced rescued many growers from bankruptcy.

If these changes caused disorientation in national markets, they gave New York producers vertigo. The result of all these changes has been a complete reversal of New York wine grape production. The historic New York market was based upon high quality dessert and sparkling wine production using native American varieties. Our traditional grapes were well suited for these products. In general, our wine grape vineyards had lower yields than did juice grape vineyards, but the need for high quality grapes justified more liberal pricing.

With the wine revolution all of this changed. Because of its high quality wines, New York gained a larger and larger share of the dessert wine market. However, because this was a rapidly shrinking market the need for ripe native American grapes decreased. It has proved almost impossible to make a marketable dry table wine from our native varieties. As a result, the only segment of the wine market left for native grapes is coolers or what might be generously called "standard quality" wines. The outlook for demand in these areas is pretty dismal. Thus the decades of the 70's and 80's left the growers of American grapes with even more incentive to reduce cost of production than the growers of juice grapes. Again the emphasis has been on maintaining high yields and developing mechanized production systems. The only advantage that wine grape growers have over their juice producing brothers is that fruit maturity is of small concern to the buyers. The grower can freely crop the vines without concern for losing quality.

French-American varieties: If the wine revolution caused shrinkage in demand for native American varieties, it established the need and the market for French-American hybrid varieties. They were introduced to meet the demand for adapted varieties which could make the neutral, dry table wines the public desired. During the 1970's demand for generic table wines was high, the hybrids were eminently suited to their production. Their only drawback was that most required special cultural practices to avoid overcropping and loss in quality. Thus they were somewhat more expensive to produce than the best of the native grapes. However, demand, price and acreage increased. This held true until the strong dollar opened the doors to imports. US producers just could not match the price of low cost imports. Perhaps because of the quality of these imports, or perhaps because US consumers became more sophisticated, the demand for generic table wine declined. The present jug wine market is dominated by very large, efficient giant California (and New York) producers. Competition within the category is fierce. The result is predictable. The market for these grapes is shrinking, prices fell, and the remaining incentive for producing quality grapes was lost.

As a result there are now two markets for growers of New York hybrid grapes. Some wineries produce high quality wines from hybrids. They pay a premium for ripe, high quality grapes. The rest of the production goes into the same cooler/jug wine market that utilizes the bulk of the native grapes. The problem is that primary producers of the more expensive hybrid wines are the small, estate wineries which began to emerge in the late 1970's. By personally marketing their products, they have been able to convince consumers to give them a try, but the industry as a whole has not been able to establish a national identity for the hybrids. As a result, the majority of hybrid producers are in the same position as growers of native grapes. Their need is to minimize cost of production per ton by increasing yield and decreasing inputs.

There is some reason to hope that the public's current concern with pesticide use may serve to re-vitalize the market for hybrid wines. A marketing program for wines made from environmentally responsible grape varieties might create a new awareness and attitude about wines made from resistant varieties.

Vitis vinifera varieties: The emergence of the small, estate winery in New York and the current growth of the market for premium wine have created demand for vinifera grapes. There are four reasons that vinifera grapes are desired by small wineries.

1. **Recognition.** It is difficult for new wineries to find a place in the market. It is much easier when the winery is marketing varietal wines which have wide consumer recognition.
2. **Quality.** New York grows grapes from certain vinifera varieties which make wines of world class quality.
3. **Cash flow.** Premium priced vinifera wines generate more revenue per bottle sold than do good quality hybrid table wines. Wineries can increase cash flow without having to increase winery investment.
4. **Opportunity.** Historically attempts to grow vinifera in the east have failed. Current success is based upon improved understanding of nutritional requirements, cultural practices and improved methods of disease control.

The changes outlined above have created two categories of grape growers in the state, those whose priority must be reduced cost of production and those who are supplying the premium market. Current returns from juice production allow greater than minimal production cost, but because of the challenge from western growers, efficiency will remain the priority. For the most part the wine grape market is extremely competitive and reduced cost of production is the only path to survival for the average grower. The premium market for wine grapes is smaller, but at least for vinifera, it is expanding. As the quality of New York wines improves, there is every reason to think the quality market will increase. There is a small quality market for labrusca and hybrid grapes.

The challenge for the researcher is to identify improved disease management programs which have reduced environmental impact and which are appropriate for the two categories of grape grower. Growers of premium grapes can adopt more costly management procedures. However for the average grower in the state, reality suggests that any changes to the disease management program must not substantially increase cost of production or decrease the yield per acre. Failure to identify economic disease management programs will mean an erosion in the size of the industry as it fails to meet the efficiency challenge posed by other production areas.

How cultural practices impact disease

Cultural practices can have direct or indirect effects on disease organisms or on the host/pathogen relationship. Direct effects include selection of resistant hosts, reducing inoculum or avoiding practices which create infection courts.

Cultural practices which directly affect disease - host resistance

Many of the older *Vitis labrusca* derived native American varieties have tolerance or immunity to the common fungal pathogens, however, resistance among currently important native varieties is moderate at best (Table 1). French/American hybrids have been selected for disease resistance, but the commercial varieties are not always the most resistant ones. For instance, the disease resistance rating for New York's most widely grown hybrid, Aurore, is generally not much better than for the vinifera varieties. Although these ratings give the appearance of little difference among classes of grape varieties, field experience shows that disease management with varieties rated as slightly tolerant is much easier than with highly susceptible varieties. However, this table shows that grape breeders can make substantial improvements in providing more resistant varieties.

Disease resistance is not the only important resistance to consider. Crown gall is an important disease of vinifera in New York, but is rare in most production areas in the world. It is not the lack of disease resistance, but the lack of cold resistance that is the problem. Cold injury is, in effect, part of the crown gall disease cycle in New York, and selection of cold hardy cultivars will greatly reduce incidence of the disease.

Within variety selection may be as important as between variety selection. There is natural variation among individual vines of a given variety. These may result from random mutation or from the introduction of foreign DNA or RNA,. Whatever the source of the variation it can result in important differences in disease susceptibility. Within variety selections are called clones, and where a specific variety is grown over a large area for many years, there is likelihood that specimens which have undergone beneficial change can be found. In Europe clonal evaluation programs are an important method of variety improvement. Figure 1 shows the differential resistance of Pinot noir clones to field infection by *Botrytis cinerea* and other bunch rot causing organisms. The causes for this variation in adaptation can be many and include differences in cluster compactness, canopy form, floral debris content, phytoallexins, and epidermal or cuticle characters.

The final variety choice which a grower may make is rootstock. When considering rootstock resistance we

Table 1. Relative disease susceptibility among New York commercial grape cultivars

Variety Class	Black Rot[1]	Downy Mildew[1]	Powdery Mildew[1]	Botrytis[1]
Native American Varieties				
Catawba	+++	+++	++	+
Concord	+++	+	++	+
Elvira	+	++	++	+++
Niagara	+++	+++	++	+
French/American Hybrid Varieties				
Aurore	+++	++	+++	+++
Baco Noir	+++	+	++	+
Cayuga White	+	++	+	+
Chancellor	+	+++	+++	+
Foch	++	+	++	+
Melody	+++	+	+	+
Rosette	++	++	+++	+
Seyval	+++	++	+++	+++
Vidal blanc	+	++	+++	+
Vignoles	+	++	+++	+++
Vitis vinifera Varieties				
Cabernet Franc	+++	+++	+++	+
Cabernet Sauvignon	+++	+++	+++	+
Chardonnay	++	+++	+++	+++
Gewürztraminer	+++	+++	+++	++
Merlot	++	+++	+++	++
Pinot blanc	+++	+++	+++	++
Pinot noir	+++	+++	+++	+++
Sauvignon blanc	+++	+++	+++	+++
White Riesling	+++	+++	+++	+++

[1] + = slightly susceptible or sensitive, ++ = moderately susceptible or sensitive, +++ = highly susceptible
Adapted from Cornell Cooperative Extension information CENET database, 1991.

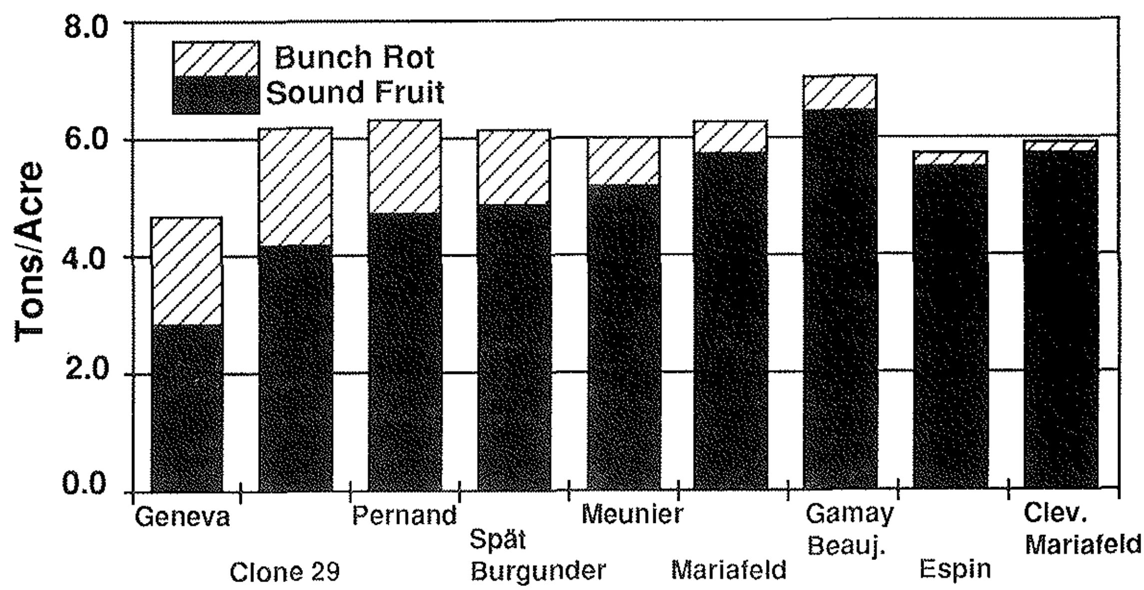

Figure 1. Yield of healthy and bunch rot infected fruit of different clones of Pinot noir growing in Geneva, NY (1988).

usually think in terms of insect or nematode resistance, but Dr. Gonsalves has shown that rootstock is an important source of resistance to the nematode-vectored ringspot virus complex. Selecting a rootstock which has a hypersensitive reaction to the virus effectively prevents movement of the virus to the scion.

Cultural practices which directly affect disease infection or spread

Some cultural practices can reduce the likelihood that infection will occur. For instance, the organism which causes Eutypa die-back enters the vine through pruning wounds, especially large wounds. When vines are hedge or minimally pruned, few large wounds are made and the likelihood of infection is reduced.

Cultural practices can also retard the ability of disease to spread once infection has occurred. Practices which impact cluster compactness are especially important. To produce quality fruit, many of the French/American varieties must be thinned to avoid over cropping. The most efficient hand crop control method is flower cluster thinning. This effectively reduces crop, but increases cluster compactness and bunch rot. In her Master's thesis, Alice Wise showed that almost 50% of the variation in bunch rot of Aurore grapes could be explained by evaluating factors related to cluster compactness. Alternate crop control methods may reduce both crop and cluster compactness. We have shown that both growth regulator or machine thinning can simultaneously reduce crop, cluster compactness and extent of bunch rot spread within clusters.

Cultural practices which affect disease by changing the vine micro-climate

Three factors dominate disease development, host susceptibility, presence of the pathogen and favorable environment. Often the buyer, rather than the producer makes the variety decision and pathogens are sometimes ubiquitous in an area. This means that grower's ability to manage disease often comes down to influencing the environment in a way that disease development is discouraged. The grower does this by selecting and preparing the site (aspect and soil and air drainage), and by growing vines that have a favorable meso-climate (the climate within the vineyard) and micro-climate (the climate within the vine canopy). Because disease usually develops inside the canopy, its micro-climate is critical in determining the success of a management program.

Many cultural practices indirectly affect vine microclimate, usually by influencing the total amount of vegetative growth (vine vigor or vine size). Some of these such as rootstock or vine and row spacing are pre-plant decisions and, once made, must be lived with. Others are annual decisions. The general goal is to balance the desire to have a large, exposed leaf area that maximizes photosynthesis with the desire to avoid dense, shaded canopies. Disease development is encouraged in dense canopies because humidity is high and light, air movement and spray penetration are low.

Preplant decisions affect the vine micro-climate.

Rootstock, vine and row spacing are the primary preplant decisions which influence vine size. Most of the native American and French/American varieties produce sufficient vegetative growth for adequate yield when grown on their own roots. A few (e.g. Delaware, Marechal Foch and Seyval) often benefit from grafting to a phylloxera resistant rootstock. Vinifera varieties are rarely planted on their own roots in New York.

Couderc 3309 is the most commonly used rootstock for grape vines in New York. It is usually satisfactory, but often produces too much vegetative growth for the typical New York vineyard. Most of the other commonly available rootstocks such as 5BB, SO4 or Rupestris du Lot (St. George) produce even larger vines and so are rarely suitable. Research is attempting to identify rootstocks which produce healthy, small vines. To date we have been unsuccessful. Rootstocks such as Elvira, Concord or C. 1616E produce small vines, but the small size is due to inefficient root systems which do not supply the scions with sufficient nutrients, growth regulators or water to grow healthy vines. Such vines have greater winter injury, lower yields and produce fruit of mediocre quality.

In general, reducing the between-row spacing and increasing the within-row spacing decreases vine size and canopy density. Equipment commonly used in New York vineyards requires a minimum of 8 feet between rows, 9 feet is more common, but there is much interest in exploring closer row spacing to better optimize vegetative growth and light interception. Vine spacing in-the-row should be close enough to ensure that leafless gaps do not form. Most common spacing is 8 feet between vines, but low vigor vines benefit from closer spacing. However, when vine spacing is reduced to less than 6 feet (with an 8 ft. row distance) canopies usually become undesirably dense. Very vigorous vines may benefit from wider than 8 foot in the row vine spacing.

Annual cultural practices affect micro-climate.

Decisions which affect vine size (and hence canopy density) include growth stimulating practices such as adding fertilizer (especially nitrogen), reducing competition from other plants via floor management, or preventing water stress from limiting vine size by irrigating. Factors which affect crop size relative to the vegetative growth capacity of the vine are also very important. Balance pruning has been a way to directly match vegetative growth potential and crop size so that large vine size is maintained. More recent trends such as hedging or minimal pruning result in high crop size and reduced vegetative growth. These vines often have open canopies. However, crop size should not be maintained at a level that long term capacity for growth is reduced or so that fruit quality is reduced below the requirements of the processor.

Cultural practices directly affecting microclimate.

Practices which indirectly affect micro-climate primarily do so by altering canopy size. Those that directly affect micro-climate do so by changing the display of the vegetative growth. Vine training refers to the arrangement of shoots and leaves on the trellis. In general, head training concentrates growth and so increases canopy density and positions fruit in a region of maximum leaf density. With cordon training, average shoot density may not change, but there is better distribution of shoots along the trellis. Divided training systems such as GDC or Lyre further reduce canopy density by distributing growth along multiple cordons. To further reduce canopy density, some very extensive training systems have been devised which divide the canopies both vertically and horizontally. None of these have been evaluated in New York. The final training system impact on fruit micro-climate is determined by fruit placement. With varieties which have a procumbent growth habit such as Concord, high cordons place the fruit at the top of canopies. Shoot positioning of high cordon vines can ensure that fruit exposure is maximized. For varieties with erect growth, vertical shoot positioning by tee-tops or by moveable catch wires are often used in conjunction with low head training such as Guyot or Pendlebogen. Because the fruit is positioned at the bottom of the canopy, shading can usually only be avoided when this practice is combined with summer pruning to prevent shoot growth from overtopping the trellis and shading the lower parts of the vine.

Summer pruning and leaf removal.

In the perfect vineyard growth is optimized by matching soil, rootstock and scion to row space, vine space and training system. In that vineyard annual decisions regarding floor management, fertilization and cropping establish an optimum number of shoots and leaves to fill, but not over-fill the trellis with leaves so that shade and canopy crowding do not result. In such a vineyard summer pruning and/or leaf removal, which control micro-climate by removing growth rather than controlling it, would not be beneficial. In the real world,both of these practices can help to prevent shade and ensure that leaves do not prevent air movement and spray penetration in the fruit region of the canopy.

Cultural practices which affect the disease inoculum

We have spoken of host resistance and managing the vine environment so that pathogen growth is not enhanced. The final consideration is disease inoculum. Some air borne pathogens, such as Botrytis, are essentially ubiquitous, but most of the fungal pathogens overwinter in or around the grapevine. Practices which destroy or remove them from the vineyard reduce disease hazard. Finally, other pathogens are usually introduced along with the planting stock. The use of certified, disease free planting stock to avoid virus or crown gall infection will largely prevent the disease.

Spores of many diseases overwinter on the vineyard floor in mummies or diseased leaves. Traditionally cultivation has been a way to destroy this fruit or prevent spore dissemination. Because cultivation is energy inefficient, reduces soil organic matter, prunes surface vine roots and encourages soil erosion and compaction, it is being replaced by herbicides, mulches or cover crops. The extent to which these practices encourage overwinter survival of disease inoculum is not documented, but for the present it is felt that the disadvantages of cultivation outweigh potential benefits.

Traditional hand harvest and pruning remove much potential disease inoculum from the vine. Infected fruit and rachises are removed as is much of the diseased wood. Mechanical harvest probably has had little direct impact on disease inoculum, but the development of machine or minimal pruning means that little wood is removed from the vine. It has been shown conclusively that this results in more overwintering inoculum of at least two diseases, black rot and Phomopsis cane and leaf spot. Up to now fungicides have been able to handle the extra disease pressure on machine pruned vines, but at the cost of extra sprays. Present research approaches to robotic pruning are not aimed at duplicating hand pruning which removes all but the minimum amount of canes required to produce a crop.

The future

Most of us have been aware that the cultural practices which we are using affect not only yield and quality, but also disease. We know that some of the practices we use are selected to optimize vineyard economics, not disease management. However, things tomorrow will not be as they are today. Many of the traditional disease management tools we have depended on are being lost through loss of registration. Processors, who must market the grapes we sell, are further restricting the amount and number of pesticides we use. This means that new tools and management decisions will be required in the future. The development of IPM tools will be based upon a better understanding of the host and the pathogen biology, on better monitoring of the environment and on more timely advice obtained from computers and expert systems. We can also hope that someday biotechnology will give us more resistant varieties. However, in developing these new management programs, the first line of defence will probably be to reduce disease pressure by altering our cultural practices to reduce inoculum and to produce vine microclimates which do not favor disease development.

The prognosis

Unlike the deciduous tree fruit crops, New York's grape varieties have commercially important resistance. Grape production does not have a large impact on the environment as do most of the annual and dairy crops. Most importantly, in spite of the severe erosion in support, New York presently has a coterie of scientists developing and applying modern tools. Thus, in a climate of reduced tolerance of pesticides, the prognosis for continued grape production is good. It is the survival of the scientists who will develop the new tools which is most immediately endangered, not the grape industry.

IMPACT OF CULTURAL PRACTICES ON DISEASE

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Dr. Pool has reviewed recent changes in the grape industry and the reasons for these changes. He has also briefly outlined some effects these changes and changes in vineyard practices can have on disease development by affecting factors such as vine microclimate, disease inoculum, and host susceptibility. I would like to address the effect of cultural practices on disease inoculum survival and dispersal and also touch on the effects some cultural practices have on grapevine susceptibility to disease. Similarly, Dr. Gubler will address the impact of cultural practices on microclimate in his talk on canopy management for disease reduction.

Impact of cultural practices on overwintering disease inoculum

Pruning practices

The development of mechanical harvesting was credited with saving the New York grape industry over 20 years ago when the scarcity and high cost of hand labor became a limiting factor. Now, growers are again faced with economic constraints and the industry is responding by moving toward nonselective mechanical pruning and minimal pruning. Unfortunately, this practice seems to be associated with an increase in certain diseases.

Phomopsis cane and leaf spot:

Surveys of Concord vineyards in the Lake Erie grape belt in 1986 and 1987 by Dr. Jay Pscheidt showed a significantly higher incidence of Phomopsis cane and leaf spot in top-wire cordon, hedged vineyards than in Umbrella Kniffin (UK)-trained, hand-pruned vineyards. Furthermore, when hedged vines were retrained to UK and pruned by hand, the incidence of disease was reduced significantly in the first year, even in the absence of fungicide sprays.

Once it was determined that hedged vineyards had significantly more disease, studies were conducted to determine the reason. Various environmental parameters in the canopy of UK-trained vines and in hedged vines were measured. No significant difference was found in temperature, duration of leaf wetness, or relative humidity within the two canopies when measured continuously between bud break and bloom. Since this is the time of most *Phomopsis* activity, environmental conditions could not account for the differences in disease development between the two canopies.

Inoculum production within the two canopies was studied to determine its influence. Canes were collected from various vineyards prior to bud break. Each node was cut to a length of 1 inch and then cut in half lengthwise. The half with the bud was retained, soaked in water for a short time, placed on a wet paper towel, and incubated in a plastic crisper at room temperature for 1 week. The samples were allowed to dry and the number of pycnidia of *Phomopsis viticola* was counted on each half-node. There was no significant difference between the number of pycnidia per half-node segment collected from UK vineyards and hedged vineyards.

Although the number of pycnidia per node was the same, the number of retained nodes in hedged vineyards was much greater than that in UK vineyards, hence the total amount of inoculum was greater in hedged vineyards. In an effort to simulate increased numbers of retained nodes found in hedged vineyards, bundles of one-year-old canes were suspended above the trellis of UK-trained vines prior to bud break in 1987. As bundle weights increased (and therefore node number) in half-pound increments from 0.5 – 2.0 lbs, the amount of disease on leaves, internodes, and summer laterals increased. In the absence of sprays, the amount of Phomopsis fruit rot on vines under the 2-lb bundles (ca 250 extra nodes) was 5% versus 0.5% on the check vines. Surprisingly, there was also a significant increase in the amount of black rot under the 2-lb bundles.

During the 1988 season the bundle experiment was repeated. The 1987 prunings were saved and placed over UK vines as one treatment and 1988 prunings were placed over other vines as an additional treatment. The bundles were suspended above the vines prior to bud break on April 4, 1988. In spite of the dry growing season, several days of wet weather in mid-May provided conditions for infection. The check vines had only 6% internode infection and 3.5% rachis surface area infection, whereas the vines under the 1987 bundles and the 1988 bundles had 25.5% and 19% internode infection, and 21.8% and 15.4% rachis surface area infection, respectively. Not only did the bundles increase disease in a relatively dry year, but the bundles from 1987 continued to provide inoculum in 1988. The amount of inoculum in hedged vines appeared to be additive from year to year.

The bundle experiment was repeated in 1989 and bundles from 1987, 1988, and 1989 were placed over UK vines. Vines under the 1987 and 1988 bundles had more disease than vines under the 1989 bundles (Table 1). We learned two things from this experiment. First, the dead one-year-old canes continued to provide inoculum for two or more years, and second, the amount of disease in year two was related to the severity of disease in year one. The 1987 and 1988 canes were grown in 1986 and 1987, respectively, years with severe Phomopsis cane and leaf spot, whereas the 1989 wood was grown in 1988, a dry year with little disease.

Table.1 Effect of cane prunings suspended above Concord vines on Phomopsis cane and leaf spot at Fredonia, NY in 1989

	Phomopsis infection		
	Internodes	Rachises	Rachis area
Treatment	%	%	%
Untreated	14.0 a[1]	9.5 a	0.2 a
1987 Prunings	68.4 bc	85.2 c	4.6 c
1988 Prunings	70.6 c	81.0 c	3.7 c
1989 Prunings	57.9 b	54.2 b	1.8 b

Prunings placed above trellis prior to bud break
Data: Sept. 27, 1989

[1]Values followed by different letters differ statistically from one another.

Studies by Dr. Pscheidt indicated only one-year-old wood provided inoculum. He seldom found sporulating pycnidia in live wood older than one year of age. Perhaps pycnidia do not survive in the exfoliating bark of older wood. By contrast, one-year-old infected wood that dies in the first year retains its pycnidia-laden bark and apparently continues to provide inoculum in subsequent years.

To determine if there is an interaction between training/pruning system and effectiveness of fungicide applications, a fungicide trial was initiated in a Concord vineyard at the Vineyard Laboratory in Fredonia during 1988. The vineyard was trained to the UK system for approximately 25 years. In 1985, two-thirds of the vineyard was converted to a top-wire-cordon system. Since then, half of the cordon-trained vines have been pruned by hand and the other half have been machine hedged with no hand follow-up. The fungicide trial was superimposed over the three training/pruning systems. Half of all the vines were sprayed with an intensive program of Dithane M45 at 4 lb/acre, whereas the other half was sprayed only with Karathane to control powdery mildew.

Sprayed, hedged vines developed about the same amount of disease (both internode infection and rachis infection) as non-sprayed UK-trained vines (Table 2). Furthermore, sprayed UK-trained vines had significantly less rachis infection than did sprayed hedged vines. Non-sprayed hedged vines had the most disease and they continue to have the most disease after three years of this trial. It appears that growers who elect to hedge their vineyards to reduce the costs of hand pruning should reinvest some of those savings into a more intensified spray program.

Black rot:

The black rot fungus generally overwinters on the ground in mummified fruit. However, in machine-harvested, machine-pruned vineyards, black rot mummies retained in the canopy and pycnidia-bearing black rot lesions on canes may be additional sources of inoculum.

In an experiment similar to the one conducted by Dr. Pscheidt, Dr. Chris Becker and Tim Weigle collected canes with black rot lesions in the spring of 1990 and suspended them over UK-trained Concord vines in a vineyard free of black rot at the Vineyard Laboratory in Fredonia. No fungicides were applied to the vines for the entire growing season. On August 2, 65% of the clusters and 5.5% of the leaves on vines beneath cane bundles had black rot, whereas 11% of the clusters and none of the leaves on vines without bundles had black rot.

During the summer of 1990, Dr. Becker noticed clusters of black rot mummies from the previous season hanging in the trellis of hedged vines. He then surveyed two Aurore vineyards, one hedged and one hand-pruned, on July 24, 1990. Even though both vineyards were on a fairly intense fungicide program, he found 52% of the clusters and 10.5% of the leaves in the hedged vineyard had black rot, but the hand-pruned vineyard was clean. During February 1991, Dr. Becker observed mummies from 1989 and 1990 still hanging in the trellis of hedged vineyards.

To determine if black rot mummies in the trellis could provide inoculum, mummies were collected from the ground and from the trellis within a Niagara vineyard at various times during the summer of 1990 and examined

Table 2. Effect of training/pruning system on Phomopsis cane and leaf spot of Concord at Fredonia, NY during 1988

Treatment	Spray Program	Phomopsis infection: % internodes infected	% rachises infected	% rachis area infected
Umbrella Kniffin	spray[1]	2.6 a[2]	3.0 a	0.8 a
Top Wire Cordon	spray	2.6 a	5.5 ab	1.6 ab
Hedged	spray	4.3 ab	15.5 b	4.4 bc
Umbrella Kniffin	no spray	8.8 bc	16.0 b	4.6 bc
Top Wire Cordon	no spray	12.3 cd	28.0 c	7.0 c
Hedged	no spray	16.2 d	43.5 d	13.9 d

[1]Spray Program: Dithane M45 4.0 lb/acre applied 10,18 May,7,15,29 June, 1988.
[2]Values followed by different letters differ statistically from one another.

in the laboratory. Mummies were soaked in water for two hours and the number of ascospores released into the water was determined. The assays were not initiated until July so we do not know when the mummies began releasing ascospores. However, from July through September much higher numbers of ascospores were released from mummies in the trellis than from mummies on the ground (Table 3). We are continuing studies to determine the significance of mummies in the trellis and the reasons for the difference in the spore release patterns.

Data from the training/pruning trial on Concord at the Fredonia Lab in 1990 indicated that non-sprayed, hedged vines had significantly more black rot than non-sprayed, hand-pruned vines on either the UK or top-wire-cordon training system.

Powdery mildew:

New information on the functional role of cleistothecia of the powdery mildew fungus (*Uncinula necator*) alerts us to the potential for increased disease in minimally pruned vineyards. Cleistothecia are removed from their site of origin by rainfall and are distributed in the water to other parts of the vine or to the soil. Cleistothecia that are retained on the vine, usually in bark crevices, are the ones that survive winter best and provide primary inoculum in spring. The increased surface area of bark and other vine parts in minimal-pruned vines allows for retention of greater numbers of cleistothecia and hence increases the potential for disease.

Eutypa dieback:

When *Eutypa* infected trunks are cut out and the grower is not careful to cut below the canker area, as noted by brown wood in the cut surface, the fungus will continue to grow into the crown of the vine and eventually into the renewal trunk. Not only will the renewal trunk show symptoms, but the entire vine may die. Furthermore, if a stub of the old trunk is left on the vine the fungus will eventually produce fruiting bodies on it which contributes to the inoculum load in the vineyard. After infected trunks are cut out, the wood should be removed from the vineyard and burned or buried. If the wood is simply piled at the edge of the vineyard, the fungus will continue to multiply and spores will be released from the wood pile and carried by wind currents back into the vineyard.

<u>Ground cover management</u>

In the past, when growers routinely cultivated beneath the trellis, black rot mummies and leaf debris containing oospores of the downy mildew fungus were covered with soil, decayed, and were prevented from contributing to the inoculum load in the vineyard. Since growers have reduced cultivation and increased their usage of herbicides beneath the trellis, black rot mummies and leaf litter are commonly retained on the soil surface. In the absence of cultivation as a way of destroying mummies and leaf litter, we have initiated studies to determine if commonly used herbicides have a detrimental effect on survival of the black rot fungus in mummies.

Abandoned vineyards and wild Vitaceae as a reservoir of disease

Abandoned vineyards are reservoirs for disease organisms that cause powdery mildew, downy mildew, and black rot. An example of the role an abandoned vineyard may play in spreading disease was observed in a trial conducted in 1990. An abandoned vineyard was situated approximately 30 feet from the north side of an Aurore vineyard. The Aurore vineyard was on a reduced spray program and once powdery mildew built up in the abandon block it began spreading into the Aurore block. By mid-July the amount of disease ranged from 5% infected clusters on vines 12 panels into the vineyard to

Table 3. Relative numbers of ascospores from black rot mummies that overwintered on the ground and within the grapevine canopy of a Niagara vineyard at Varick, NY during 1990.

Date	Ground	Trellis
26 July	88,672	3,690,972
20 August	18,473	4,817,846
25 September	0	29,557

Data are the means of three replications of 20 mummies each.

20% infected clusters on vines in the end panel nearest the abandon block.

Wild Vitaceae, the family of plants to which grape belongs, includes Virginia Creeper and wild grapes commonly found in hedge rows and in stream beds. These relatives of cultivated grape are susceptible to many grape diseases such as powdery mildew, black rot, and angular leaf scorch. In particular we have noticed that these two plants are commonly infected with the angular leaf scorch fungus and can contribute inoculum to the vineyard. In addition, wild grape may harbor grapevine yellows (a mycoplasma disease) and its leaf-hopper vector. The removal of these sources of inoculum near vineyards is advisable.

Impact of cultural practices on inoculum dispersal

Training systems

New shoots developing from canes on vines trained to the Umbrella-Kniffin system rarely grow in close proximity to the old wood on the head and the trunk of the vine. By contrast, new shoots on vines trained to the top-wire-cordon system commonly grow near or beneath old wood on the cordon. Since spores of *Phomopsis* are rain splashed and distributed in water from infected old wood, shoots on cordon-trained vines are more likely to be exposed to these spores than shoots growing on Umbrella-Kniffin-trained vines. Therefore, the efficiency of inoculum produced on the cordon system is likely to be increased since an individual spore has a greater chance of landing on susceptible tissue.

Spreading pomace

When pomace is spread in the vineyard and is followed by a wet spring, the grape seeds commonly germinate and the seedlings are readily infected with the downy mildew fungus. The fungus sporulates on the seedlings and the spores are wind blown to the vines. Although we have seen an occasional oospore in the flesh of downy mildew infected berries, we do not know if downy mildew inoculum is introduced into the vineyard with pomace. Perhaps susceptible seedlings are simply growing in close proximity to the source of inoculum in the leaf litter surviving in the vineyard from the previous year. Whatever the explanation, it is a good way to get early season downy mildew evenly distributed throughout the vineyard. In order to prevent this increase in downy mildew inoculum in the vineyard, seedlings should be removed by cultivation or herbicide application as soon as they germinate.

Impact of cultural practices on host susceptibility

Time of trunk renewal

Eutypa dieback:

Grapevines are most susceptible to infection by *Eutypa lata* during the dormant season. In addition, spore release by *E. lata* is greatest from January through April. The fact that these two factors coincide with the normal pruning season, increases the chances for success by this pruning wound pathogen. However, this knowledge allows us to suggest an approach to trunk renewal that should reduce the chances of infection. When a grower renews trunks during the normal dormant pruning season, he should leave a stub of 6 inches with the intention of returning during the growing season to remove the stub and leave a flush cut. If a flush cut is made during the dormant season, it may become infected which allows the fungus to grow directly into the base of the vine eventually killing it. If a stub cut is made, and the stub becomes infected, this slow growing pathogen can not grow into the base of the vine in only one season so removal of the stub in summer will remove the infected wood. A flush cut made during the growing season is unlikely to become infected because of low host susceptibility at this time of year and the low amount of inoculum available.

Removal of *Eutypa* infected trunks should be done at 12-18 inches of shoot growth when foliar symptoms are most visible. Cut below the canker so that the cut surface is white, indicating healthy wood. If dark brown wood is observed in the cut surface, you have not cut beneath the canker, and if not removed, the fungus will continue to grow into the base of the vine and eventually into the renewal trunk.

Cluster compactness

Botrytis bunch rot:

Botrytis bunch rot is most severe in varieties with tight, compact clusters, such as Riesling Chardonnay, and Vignoles, where the fungus can easily move from berry to berry within the cluster. Botrytis bunch rot has even been observed on Concord clusters that were compact due to high application rates of Alar. Studies using gibberellic acid at 6-8 inches of shoot growth on Aurore resulted in elongated rachises with less compact clusters. In the absence of fungicides, these clusters had the same incidence of bunch rot, but they had significantly less nesting of *Botrytis*, hence lower severity of disease (Table 4). Individual berries were still susceptible to

Table 4. Control of Botrytis bunch rot on Aurore using gibberellic acid during 1980.

		Percent clusters	
Rate (ppm)	Single berry infection	Nested	Clean fruit
0.0	7 a[1]	18 a	68 a
2.5	4 a	13 ab	76 ab
10.0	4 a	7 bc	82 bc
25.0	5 a	4 c	85 c

Sprays applied dilute at 12-14 inches growth on May 28, 1980.
Data collected September 5, 1980.
[1] Values followed by different letters differ statistically from one another.

infection, but the fungus could not easily move from berry to berry to cause the nesting effect.

Minimal pruning can also result in less compact clusters. Dr. Pool's data from a four-year study on Concord indicated that minimal-pruned vines had more shoots/vine, fewer clusters/shoot, fewer berries/cluster, and smaller berries than conventionally trained hand-pruned vines. These clusters were obviously less compact than "normal" Concord clusters. We have observed the development of Botrytis bunch rot in a trial on hedged and minimal-pruned Umbrella-Kniffin-trained Chardonnay vines, conducted by Dr. Shaulis in Vintner's International vineyards at Dresden. Non-thinned, minimal-pruned vines had only 7% infected clusters, whereas hedged vines and manual-pruned vines had 26.5 and 40.5% infected clusters, respectively. The minimal-pruned vines had slightly lower sugar levels at harvest than the other two treatments which could also impact on rot development. Clusters with higher sugar levels were probably susceptible for a longer period of time than fruit with lower sugar levels.

Summary

It is obvious that decisions regarding cultural practices can have direct impact on the amount of inoculum surviving from one season to the next, as well as on the potential losses from disease in any one season. Fortunately, cultural practices comprise one area of disease management where growers have options and can adjust procedures to tackle particular disease problems.

CANOPY MANAGEMENT FOR DISEASE REDUCTION

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Foliar diseases and fruit rots of grapevine in California account for significant losses in production. Among the diseases that commonly occur in virtually every grape production area are Botrytis bunch rot, caused by *Botrytis cinerea* and the summer bunch rot complex, caused by *B. cinerea* in addition to *Cladosporium* sp., *Penicillium* spp., *Aspergillus niger*, *Diplodia natalensis*, *Rhizopus* sp., and *Acetobacter*. Though the summer bunch rot complex occurs primarily in the San Joaquin Valley, Botrytis bunch rot may occur statewide but is generally more a problem in the cooler and more moist coastal production areas. In addition to the above diseases, powdery mildew caused by *Uncinula necator* also is a significant disease in nearly all production areas and recently downy mildew, caused by *Plasmopara viticola* was found in an isolated vineyard in northern California but currently is not considered to be a significant threat to the California grape industry.

While fungicide spray programs were readily adopted for disease control, serious efficacy problems have occurred and have been attributed to poor chemistry or resistance by grape producers, poor coverage, timing or improper concentration by others.

More often than not the problem was one of canopy density which did not allow fungicides to reach their primary target, the grape cluster. Because vigorous growth often resulted in canopy curtaining, environmental conditions become progressively more conducive for bunch rot as berries themselves become more susceptible due to ripening.

In 1984, trials were initiated to investigate canopy management practices which would affect spray coverage and potentially change canopy microclimates. Treatments examined included hedging, shoot removal, leaf removal and a control. All tests were conducted at cluster set. Disease readings taken at harvest showed a significant decrease in incidence and severity of Botrytis bunch rot in treatments in which leaves were removed. Fungicides applied at bloom, pre-close and veraison resulted in no further significant disease reduction. Subsequent research trials conducted on Chenin blanc, Chardonnay, and Zinfandel showed similar results (Table 1-3). In all cases disease was reduced by leaf removal.

Because removal of leaves by hand is both laborious and in many cases expensive, mechanical leaf removal was tested in several vineyards over a three year period. Two machines were tested, the Nairns Leaf Blower and the Gallagher Leaf Plucker. The Nairns equipment was used on both 2-wire vertical and shoot positioned vines while the Gallagher was used only on shoot positioned vines. Results from three of theses trials were shown in Tables 4-6. The Nairns equipment resulted in excellent leaf removal and subsequent disease control in all trials except the 1989 Napa trial (Table 5). In this trial, tractor speed was a problem in that speed could be reduced only to 4 mph. Results from use of the Gallagher machine on shoot-positioned vines were favorable in every trial. Results from these trials showed conclusively that machine leaf removal was as effective in reducing disease incidence and severity as hand leaf removal.

Further research has shown that reasons for the success of leaf removal are many. However, the most important result of leaf removal appears to be increased wind speed through the canopy and thus the grape clusters. Work by Thomas and Marois showed that wind speeds in excess of

Table 1. Effect of canopy management practices on incidence and severity of Botrytis bunch rot of grape – var. Chenin blanc.

	Percent Rot Per Cluster				
	Hedged	Leaf removal	Shoot removal	Control	Mean
Sprayed	8.05	1.69	11.3	9.3	7.58
Non-sprayed	9.08	2.85	10.2	15.3	9.35
Mean	8.56	2.27*	10.7	12.3	

	Percent Diseased Clusters				
	Hedged	Leaf removal	Shoot removal	Control	Mean
Sprayed	44.1	16.9	47.0	46.8	38.7
Non-sprayed	47.4	23.9	42.9	55.0	42.3
Mean	45.7	20.4*	44.9	50.9	

*Differences significant at P = 0.05

Table 2. Effect of leaf removal and fungicides of incidence and severity of Botrytis bunch rot of grape – var. Zinfandel, Lake County[1].

	Percent Diseased Clusters				
	Non-sprayed Control	Bloom	Bloom, Postbloom	Prebloom, Bloom, Postbloom	Mean
Leaf removal	5.7	5.9	3.4	6.4	5.4 b[2]
No leaf removal	29.2	31.1	22.7	18.7	25.2 a
Mean	16.9	18.5	13.0	12.6	

	Percent Rot Per Cluster				
	Non-sprayed Control	Bloom	Bloom, Postbloom	Prebloom, Bloom, Postbloom	Mean
Leaf removal	1.2	1.0	1.1	2.9	1.6 a
No leaf removal	10.7	14.2	11.2	8.2	11.1 b
Mean	5.9	7.6	6.1	5.6	

[1] Sprayed with Rovral at 1.5 lb/A at phenotypic times above.
[2] Values followed by different lower case letters are significantly different from each other.

Table 3. Effect of leaf removal and fungicides on incidence and severity of Botrytis bunch rot of grape – var. Chenin blanc, Napa County[1].

	Percent Diseased Clusters					
	Control	Bloom	Pre-close	Veraison	Bloom, Pre-close, Veraison	Mean
Leaf removal	6.2	7.1	4.0	18.3	5.1	8.1
No leaf removal	30.5	29.2	29.2	47.6	20.7	31.4

	Percent Rot Per Cluster					
	Control	Bloom	Pre-close	Veraison	Bloom, Pre-close, Veraison	Mean
Leaf removal	0.38	0.43	0.14	1.25	0.27	0.49 a[2]
No leaf removal	3.36	5.14	3.65	7.51	3.06	4.54 b
Mean	1.87	2.78	1.89	4.38	1.66	

[1] Sprayed with Benlate + Captan at 1 + 4 lbs/A at the times indicated in columns.
[2] Values followed by different lower case letters are significantly different from each other.

over 3 mph prevent *Botrytis cinerea* from producing aerial mycelium and sporulation from infected berry surfaces when relative humidities were less than 100 percent thus reducing potential for spread from berry to berry in a cluster.

Also, as a result of leaf removal, other microclimate factors are affected. Relative humidity is reduced, temperatures are increased and light intensity also is increased. These changes may more affect the berry cuticle than they do the pathogen. When grape clusters are confined to heavy, darkened canopies, cuticle formation may be restricted. As a result of direct, early exposure to sunlight, in addition to increased temperatures and light and a reduction in relative humidity, the berry generally will develop a heavier cuticle making it more resistant to attack by B. cinerea. Subsequent work also has shown that by use of atmometers, which directly measure evaporative potential, growers can judge whether an infection period might have occurred and thus choose whether to spray. Measuring the amount of water evaporated in grams per hour from grapevine canopies with and without leaf removal indicates that an evaporative potential of 0.2 g/hr of water would be sufficient to prevent mycelial and conidial production.

Table 4. Comparison of Nairns Leaf Blower and hand leaf removal on incidence and severity of Botrytis bunch rot – var. Johan. Riesling, Napa County.

Treatment[1]	Disease Rating Incidence[2]	Disease Rating Severity[3]
Leaf Blower	7.01 a[4]	1.36 a
Hand Leafed	10.03 a	1.94 a
Control	20.15 b	5.44 b

[1] Vines on 2-wire vertical trellis.
[2] Percent of clusters with rot.
[3] Percent rot per cluster.
[4] Values followed by different lower case letters are significantly different from each other.

Table 5. Comparison of Gallagher Leaf Plucker and hand leaf removal on incidence and severity of Botrytis bunch rot – var. J. Riesling.

Treatment[1]	Disease Rating Incidence[2]	Disease Rating Severity[3]
Leaf Plucker 2 sides	4.07 a[4]	0.55 a
Leaf Plucker 1 side	7.93 a	1.58 a
Hand Leafed	10.03 a	1.94 a
Control	16.88 b	4.91 b

[1] Vines vertically shoot positioned.
[2] Percent of clusters with rot.
[3] Percent rot per cluster.
[4] Values followed by different lower case letters are significantly different from each other.

Table 6. Comparison of hand and machine leaf removal on incidence and severity of Botrytis bunch rot of grape – var. J. Riesling.

Treatment[1]	Disease Rating Incidence[2]	Severity[3]
Control (2 wire vertical)	28.15 a[4]	7.09 a
Control (shoot positioned)	13.48 ab	3.09 b
Gallagher 2 sides	9.42 b	1.24 c
Gallagher 1 side	8.34 b	1.24 c
Nairns 2 sides	19.83 a	4.17 b
Nairns 1 side	21.17 ab	4.88 b
Hand leaf 2 sides	9.99 b	1.94 c

[1] Treatments conducted at BB-sized berries. No fungicides used to control *Botrytis cinerea.*
[2] Percent of clusters with disease.
[3] Percent rot per cluster.
[4] Values followed by different lower case letters are significantly different from each other.

THE EFFECT OF TOMATO RINGSPOT VIRUS INFECTION ON GRAPEVINE GROWTH IN THE FINGER LAKES

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Tomato ringspot virus (TmRSV) is a nematode-transmitted virus that is widespread in the Northeastern United States. It infects a number of fruit crops including peaches, cherries, plums, and grapevines. In the Finger Lakes region, TmRSV causes significant damage to certain French-American hybrids, such as DeChaunac, Baco noir and Cascade. More recently, TmRSV was recovered from Vidal blanc which did not have leaf symptoms or reduction in vine growth. This is in contrast to the above mentioned varieties which show distinct reduction in vine growth. However, very little work has been done on the viticultural responses of grapevines to TmRSV. Some information on this aspect are summarized in this abstract. A full report will be given elsewhere.

Test plants included vines of DeChaunac and Vidal blanc that indexed positive or negative for TmRSV by the serological ELISA test. The vines were then divided into small and large sized vines and pruned to various degrees of severity. Over a two year period, the vines were monitored for distribution of TmRSV and for viticultural responses. Observations indicated that an important visual symptom of TmRSV on DeChaunac was yellow-leaved shoots that became most obvious in the fall of the year. Other symptoms included stunted growth and reduction in the number of berries in a cluster. Infected vines lost vigor over time, and subsequent growth was stunted. Virus detection by ELISA showed that TmRSV was not distributed uniformly in the grapevine, although the virus was detected most frequently in suckers. Symptoms on Vidal blanc were quite different. Infected vines did not have obvious yellow leaves and vegetative growth was generally vigorous. The most obvious symptoms were the presence of small berries and the lack of berries in fruit clusters. Like DeChaunac, TmRSV was not evenly distributed in Vidal blanc but the virus was most frequently detected in suckers. Specific aspects of vine growth and yield responses of DeChaunac and Vidal blanc to TmRSV will be given in another communication. However, data indicate that TmRSV reduced the fruit yield in both DeChaunac and Vidal blanc.

PREVENTION OF CROWN GALL IN NURSERIES AND VINEYARDS

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Crown gall is a very serious disease of grapevines particularly in cold climate regions and on *Vitis vinifera* cultivars. The disease is caused by the bacterial pathogen, *Agrobacterium tumefaciens* biovar 3. This pathogen has recently been renamed as Agrobacterium vitis. The pathogen survives systemically in vines and therefore is spread in propagation material. Controlling crown gall is based on prevention since there are no chemicals that can eradicate the disease once it is established in the vineyard. In our laboratory we have developed methods for indexing propagation material for the pathogen and are working on ways to produce clean propagation material. We are also testing the effectiveness of biological control as a way of preventing infection of vines from soil inoculum.

Indexing of dormant cuttings is done by isolating the pathogen from callus tissue present at the basal end of the cuttings. Isolations are made on selective culture media and colonies of bacteria that are suspected to be *A. vitis* are checked using an ELISA procedure with a monoclonal antibody that is specific for *A. vitis*. This procedure takes about 4 hours and is very reliable for identifying the pathogen.

Two methods have been tested for producing clean stock. One involves propagation of vines from small shoot tips using tissue culture methods. This method has been proven successful for excluding the pathogen from vines. Vines produced in this manner have been planted in vineyards and after three years, no pathogen has been detected on them. This method or a variation of it may also be useful for excluding viruses from stock material.

A second approach is to use hot water treatments of dormant cuttings for eradicating the pathogen. A treatment of 50 C (121 F) for 30 minutes has been tested with some success. However, we know at this point that complete eradication of the pathogen is not achieved with this method. We are currently testing variations of the treatment using higher temperatures, multiple treatments and different timing regimes. We determined that dormant vinifera cuttings can withstand temperatures higher than 50 C depending on when during the dormant season they are treated.

An important question concerns how long the crown gall pathogen can persist in soil or plant material once infected vines are removed. Continuing experiments show that the pathogen is very persistent and that after 18 months it can still be recovered from fragments of decaying grape canes and roots. Therefore, if clean material is planted into contaminated soil the possibility of reinfection from soil inoculum exists. For this reason we are testing biological controls as a means of preventing infection from soil inoculum.

Biological control of crown gall on many crops has worked very effectively, however, the same control organism has not worked on grape. Several research groups worldwide have attempted to identify biological controls for grape crown gall. We have tested several of these potential biological controls in our laboratory. Most of them show some level of activity in culture but have not been highly successful on vines in the greenhouse. Recently however, we have obtained a biological control from South Africa that looks very promising. When inoculated onto wound sites on vines it prevents gall formation following subsequent inoculations with the pathogen. Several questions are being studied regarding the potential commercial use of the biological control. For example we need to determine the amount of biological control in relation to the amount of pathogen that is needed for control. We also need to determine proper timing of biological control application. We are hopeful that it will be possible to treat non-infected plants with the biological control and that they will remain protected for some time in the vineyard.

Unfortunately at this time there is no program for certifying that grape propagation material has been tested for the presence of *A. vitis*. However, we are developing methods that will make such a certification program possible. We will never eliminate the crown gall pathogen from our vineyards, however, by producing vines that are not systemically infested with the pathogen and by using methods to prevent re-infestation from soil inoculum we should be able to dramatically reduce the severity of the disease in cold climate viticulture.

MODE OF ACTION OF FUNGICIDES AND FUNGICIDES OF THE FUTURE

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Introduction. The goal of disease control with chemicals is to interfere with vital processes in fungal pathogens without harming the host plant and, with increasing importance, the applicator, consumer and the environment. Obviously, these goals are challenging, and it is not surprising that the history of fungicides is a mirror of improvements made over the last few decades. Part of the progress is our increased understanding of why and how fungicides act as toxicants to fungal pathogens. Knowledge about this aspect of fungicide action allows us to understand the benefits but also the shortcomings of certain classes of fungicides used for the control of fungal plant diseases. Although the scientific literature on these aspects has exploded over the last two decades, the principles of fungicide action are relatively simple to comprehend. The understanding of these principles helps us to select and apply fungicides based on their benefits and limitations.

If a fungicide is to inhibit the growth of a fungus, it has to interfere with a vital process inside the fungal cell. Most of these processes in fungal and all other living cells are chemical in nature, and they are maintained by biocatalysts named enzymes. The structure of these enzymes is relatively complex, but they are all involved in the utilization of nutrients and the synthesis of cellular components necessary for growth. Thousands of chemical reactions must be maintained in a living cell, but only one specific enzyme is the driving force for a particular reaction. Consequently, all enzymes present in a cell have to work in concert with each other, and the deactivation of only one enzyme would disrupt the network of interconnected reactions. The term **mode of action** describes which enzyme or group of enzymes is blocked in the presence of a fungicide. From a mode of action point of view, the currently available fungicides can be divided into two distinctly different groups.

Multi-site Fungicides. The early history of fungicides is intimately connected with the control of grape diseases. When powdery mildew of grapes was introduced into Europe in the middle of the nineteenth century, **sulfur** dusts and lime sulfur preparations became a popular remedy to cope with this new disease. The **copper** era and the then new opportunity to control downy mildew was initiated with the discovery and the introduction of the bordeaux mixture in 1885. Both sulfur and copper preparations are still in wide use; only the formulation and chemical preparation of the products has been improved since their introduction a century ago. In the 1930s, progress made in the synthesis and manufacturing of organic chemicals yielded the first fully organic fungicides. The first representatives were derivatives of dithiocarbamates such as **ferbam** and the related ethylenebisdithiocarbamates (EBDCs) such as **mancozeb**. The discovery of another early class of organic fungicides, with **captan** as the most widely used representative, was announced in 1952. Although under recent toxicological scrutiny, these representatives are still in use in US vineyards. Dinocap (Karathane), a powdery mildew material no longer available, also belongs into the class of early organic fungicides.

Although ferbam, mancozeb and captan are usually more efficacious than sulfur and copper, all of the older compounds share a more or less common mode of action. A great number of enzymes contain a sulfur group as a component essential for their activity. These essential sulfur groups react with copper, mancozeb and captan, and the modified enzymes become biologically inactive. Consequently, growth of the fungus is inhibited. Because many enzymes are affected, these compounds have a **multi-site** or **non-specific** mode of action.

Unfortunately, sulfur-containing enzymes are abundant in nature and not restricted to fungal organisms. A non-specific mode of action therefore implies that not only fungal but also plant enzymes are prone to inhibition, and that plant tissue would be damaged if the fungicide entered the plant. Fungicide entry is prevented by the plant cuticle, the waxy layer that covers the surface of all green tissues. The major biological function of the cuticle is to prevent tissue water from rapid evaporation, but it also protects the plant from the damaging effects of chemicals in the environment, including this class of potentially phytotoxic fungicides.

Since the non-specific fungicides are restricted to the plant surface, they generally have **protective** but not curative activity. They only can interfere with a fungal pathogen before it becomes established underneath the cuticle. Once this outer barrier has been breached, the fungus has escaped the fungicide restricted to the surface. Because diseases are initiated by the germination of fungal spores on plant surfaces, all of the compounds in this group of **protectants** must be good inhibitors of spore germination. Once the tissue has been infected, the fungicides cannot reach the growing fungus. The principle limitations of protectants is that they cannot stop disease development and sporulation if they are applied after infection.

It is frequently asked whether spores in lesions would remain viable after treatment with a protective fungicide. For mancozeb and captan, the question can be answered with no. Spores would be soaked with the toxicant and germination and thus survival would be prevented. As described below, copper requires acidic compounds released by a germinating spore to be activated, and spores in lesions would not be penetrated. They would still germinate, but the surrounding surface would be protected by the protective spray and reinfection would be prevented. Some activity on spore survival can also be expected with sulfur. Although the mode of sulfur action is still not entirely clarified, the most plausible explanation for activity is that sulfur reacts with air to form sulfur dioxide. This gas, also generated in many industrial processes as a major air pollutant, reacts with water and generates a very strong acid. Spraying sulfur creates a micro-environment on the plant surface so severely "polluted" that spores would not germinate. This micro-pollution is also the reason for phytotoxic side effects under certain conditions such as high temperatures and with certain varieties more sensitive to the "micro-pollution" than others.

In summary, fungicides with non-specific modes of action are potentially phytotoxic and thus must stay on the plant surface. Consequently, they are only active in the protective mode and are mainly restricted to the inhibition of spore germination. They lack after-infection activity and do not prevent sporulation, although some inactivate spores when sprayed into lesions.

The potential for phytotoxic side effects has immediate implications for the way protectants should be applied. While mancozeb and captan stay on the plant surface and do not diffuse into the underlying tissue, care has to be taken with copper. Copper sulfate as one of the components of the bordeaux mixture is very soluble in water. In this form, copper would penetrate through the cuticle and would cause phytotoxicity. Lime as the second and very essential component converts copper sulfate to copper hydroxide, a salt completely insoluble in water. This insoluble deposit on leaves does not penetrate the cuticle. Copper in this insoluble form is not phytotoxic, but it would also not affect spores. However, spores release acidic compounds while they germinate, and these acids dissolve copper from the deposit. The small amounts of solubilized copper in immediate vicinity to the germinating spore are sufficient to act as a toxicant to the fungus, but they are too small to cause damage to the plant. The more recently developed fixed coppers are insoluble in water and would, in principle, make lime dispensable. However, water and rain are often slightly acidic and would, in the absence of lime, dissolve substantial quantities of soluble copper from the deposit. Therefore, lime should also be used even with the fixed copper preparations. Even in the presence of lime, some of the insoluble copper can be dissolved over time by the natural acids present in rain and heavy dew, and some plant damage can occur under extremely wet conditions.

A second important aspect for all protectants is related to the spray coverage. Obviously, spore germination is not inhibited in the absence of the compound on the surface, and only good coverage of all susceptible tissue will result in good protection.

Site-specific Fungicides. The principle disadvantage of protective fungicides is their non-specific mode of action and, thus, the need to confine them to the plant surface. More desirable would be a fungicide that could penetrate into the plant tissue and thus control a pathogen after infection has already taken place. As mentioned above, it is not essential that fungicides inhibit more than one enzyme, as is common with the protectants. The inhibition of only one enzyme would be sufficient to inhibit fungal metabolism and thus growth. Consequently, inhibitors that block one specific target in fungal cells but not in cells of the host plant could be taken up by the plant without phytotoxic side effects, and fungal pathogens could be reached subsequent to infection. Growth of a pathogen within the plant tissue is stopped, and lesions will not develop. **Systemic** and **site-specific** are the terms commonly used to describe fungicides with these characteristics.

The after-infection activity of systemic compounds does not imply that they are not active in the protective mode.

Although germinating spores are in most cases less sensitive than later stages of fungal growth (since many compounds crucial for germination are stored in the spore, new synthesis is not required and thus cannot be inhibited), the infection is blocked as soon as the fungus starts to grow a mycelium within the plant. At this stage the fungus will encounter the inhibitor applied prior to infections and localized inside the host tissue. In addition to these advantages, specific inhibitors are in general much more effective than multi-site inhibitors, and they are not prone to weathering. Therefore, application rates are usually lower and spray intervals longer than with protectants.

It has to be emphasized that not all site-specific inhibitors are systemic. To be systemic, a fungicide first has to diffuse through the cuticle. The penetration of the cuticle, however, is not dependent on the mode of action; it is only determined by chemical properties. It also has to be mentioned that movement of systemic fungicides within a plant is limited. They move within a leaf, not very well within berries or clusters, and never downwards or from one leaf to another. Therefore, good coverage remains important even when systemic fungicides are being used. Even within a leaf, many of the systemic compounds are not always evenly distributed. They move more or less rapidly to the leaf margins and are thus depleted from the middle parts. Substantial areas would not be protected if too long spray intervals were chosen.

The first class of fungicides with systemic properties was the benzimidazoles. Out of this class, only **benomyl** (Benlate) has been used on grapes in the US. Benomyl was indeed identified as a highly specific inhibitor of a single yet vital process in fungal cells. The inhibitor blocks the formation of intracellular structures crucial for the expansion and division of most fungal cells. The particular process is not inhibited in certain fungi, for example in the pathogen that causes downy mildew.

The second class of systemic fungicides introduced into the grape market was the sterol inhibitors with **triadimefon** (Bayleton) as the first compound, followed by **fenarimol** (Rubigan) and **myclobutanil** (Nova). **Flusilazole** (Nustar) as a fourth member of this class is not registered at the present time. As indicated by the name "sterol inhibitors", all of these compounds inhibit a specific step in the synthesis of fungal sterols. Sterols are widespread in nature (the human sterol is the famous cholesterol), but the chemical structure of fungal sterol is different from sterols produced by other organisms. The inhibitory action of the compounds is thus restricted to fungi, and sterol synthesis in plants is only inhibited at very high doses. However, exceptions exist. The downy mildew pathogen does not produce sterols (they are taken up from the plant), and the pathogen is insensitive to the sterol inhibitors. Although *Botrytis* is not different from sensitive fungi with regard to sterol synthesis, the pathogen is not affected at normal rates. The reason for this lack of activity is not known, but it exemplifies a property relatively common to specific fungicides. The spectrum of disease control can be relatively narrow.

The **dicarboximides**, for example, are fungicides with such a narrow control spectrum. In grapes, the activity of these compounds is restricted to the control of *Botrytis* bunch rot. **Iprodione** (Rovral) is the only representative registered on grapes; **vinclozolin** (Ronilan) is used on other crops in the US and might become available for grapes as a second dicarboximide. The most likely mode of action of this class of fungicides is the deactivation of a system protecting the cell from the damaging effects of oxygen. Some forms of oxygen are highly reactive and aggressive, and all living cells have developed sophisticated options of protection from damage caused by these reactive forms of oxygen. The precise nature of these protective systems differs among organisms, and the dicarboximides might be highly specific because they only inhibit one of the optional systems. The dicarboximides are a classic example of site-specific yet non-systemic fungicides. Although distinguished by a single-site mode of action, they can only diffuse into but not through the cuticle. Consequently, they are not distributed within the plant and have to be used in a **protective** mode.

None of the systemic fungicides described above is active in the control of downy mildew. This important niche is filled by the **phenylamides**, a class of compounds used widely in Europe and other parts of the world. Thus far, only **metalaxyl** (Ridomil) has been registered on some crops in the US. It might become available for use on grapes in the future. The phenylamides are only active against a certain class of fungi such as the downy mildew pathogen. Here, they inhibit an enzyme necessary for reading the genetic code. The block of this step is detrimental to growth and development.

Resistance to Fungicides. The advantages offered by the class of systemic compounds were substantial. However, shortly after the introduction of benomyl, the most profound disadvantage inherent to site-specific inhibitors emerged. Pathogens became resistant, and in many cases, benomyl became relatively useless. Resistance development had never been a problem with multi-site protectants, and considerable research efforts had to be dedicated to this new problem. With the exception of benomyl, all other site-specific compounds listed in Table 1 have been in use in Europe for more than a decade, and all have encountered problems with resistance. The status-quo of resistance and currently recommended countermeasures are described elsewhere by Drs. W. D. Gubler and M. L. Gullino. Thus, only the principles of fungicide resistance will be treated here.

Table 1: Characteristics of fungicides.

Fungicide (Trade name)	Protec tive	Sys-temic	Inhibition of spore germination	After infection activity	Affect on spore survival
Multi-Site					
Sulfur (several)	+	-	+	-	+/-
Copper (several)	+	-	+	-	-
Ferbam (Carbamate)	+	-	+	-	+
Mancozeb (Dithane, Manzate, Penncozeb)	+	-	+	-	+
Captan (Captan, Captec)	+	-	+	-	+
Site-Specific					
BENZIMIDAZOLES					
Benomyl (Benlate)	+	+	+/-	+	-
STEROL INHIBITORS					
Triadimefon (Bayleton)	+	+	-	+	-
Myclobutanil (Nova)	+	+	-	+	-
Fenarimol (Rubigan)	+	+	-	+	-
Flusilazole (Nustar)*	+	+	-	+	-
DICARBOXIMIDES					
Iprodione (Rovral)	+	-	-	-	-
Vinclozolin (Ronilan)*	+	-	-	-	
PHENYLAMIDES					
Metalaxyl (Ridomil)*,**	+	+	-	+	-

*not registered on grapes in the US
**marketed in mixture with protectant

An important and interesting question is, why only site-specific fungicides and not the multi-site protectants have encountered problems with resistance. The question has not been answered. One theory implies that it is much easier for a fungus to overcome the inhibitory action at one site rather than at multiple sites. Another theory is that the deactivation of multi-site inhibitors requires so much energy by the pathogen that pathogenicity is lost. The correct answer to this question has no immediate impact on practical disease control; it is important for the design of future fungicides which hopefully will be less prone to development of resistance.

More important for practical considerations is research on the development of resistance to single-site compounds. It is now recognized that site-specific fungicides do not cause resistance. Rather, fungal pathogens have to be considered as a population of individuals (genotypes), and some of the individuals are resistant to the fungicide before it is even introduced into the field. The percentage of these resistant strains is very small, and the fungicide under risk will control the vast majority of the population. Initial performance is excellent, but the resistant strains suddenly gain a tremendous advantage over their sensitive counterparts. They will grow and multiply even in the presence of the inhibitor, and they will increase in frequency.

It is the quality of resistant strains that is different for the various compounds. For benomyl (Benlate) and metalaxyl (Ridomil), the resistant strains are literally insensitive. They are not inhibited at all, and they will multiply rapidly. The speed of selection is fast, and loss of control can be sudden. This type of resistance selection has been named **disruptive** or **qualitative**. For example, resistance of grape powdery mildew to benomyl developed after only 4 years of use in New York State and became widespread within a few years thereafter. Metalaxyl has been identified as a compound with a similar high risk of resistance.

For the sterol inhibitors such as triadimefon (Bayleton), a different type of selection has been identified. It has been named **directional** or **quantitative**. The sensitivity of individual strains is widely different and ranges from highly sensitive to relatively resistant. In contrast to the situation with benomyl, these resistant strains are still inhibited to some extent, although only at initially high fungicide concentrations. The percentage of resistant strains is initially small, but these resistant strains are the first to overcome the initial inhibitory action of the compounds, in particular when applied at low rates and with long spray intervals. They will recover from the inhibitor earlier, and they continue to grow and sporulate much more readily than their sensitive counterparts. Consequently, they reproduce faster and increase in frequency. The first sign of performance loss due to resistance development in New York was observed after 8 years of Bayleton use. As described by Dr. W. D. Gubler elsewhere in these proceedings, resistance has become a problem in California.

It could be argued that development of resistance after 4 years for Benlate or 8 years for Bayleton is not a substantial difference under practical conditions. Unfortunately, the final outcome and consequences of resistance to the sterol inhibitors such as Bayleton remain unknown. For example, there is evidence that powdery mildew can still be managed with other sterol inhibitors at sites where Bayleton has already developed resistance. This phenomenon is a clear departure from the former rule that all specific inhibitors with the **same mode of action** were **cross resistant** to each other. This rule applies to the dicarboximides, and vinclozolin would fail where resistance has developed to iprodione. For the sterol inhibitors this is not necessarily the case. The understanding of this lack of full cross resistance is the subject of current research, and the future development of resistance to the sterol inhibitors has to be carefully observed and managed. This applies also to black rot, where signs of resistance have not been reported thus far.

Since the 1970s, when resistance to specific fungicides first occurred, many solutions to the problem have been proposed. Most popular was the use of mixtures of a specific fungicide with a conventional protectant. The strategy was thought to prevent or at least delay the development of resistance. The current experience with this countermeasure is not overly optimistic, and more caution is advised. In order to preserve the lifetime of a valuable compound, it should be used according to its optimal benefit, but as infrequent as possible. This does not exclude the application of mixtures as insurance so that the disease does not get totally out of control if resistance develops. For example, in Europe metalaxyl is marketed as a mixture with mancozeb, and a prepacked mixture with a protectant (most likely copper) is also expected in the US. In general, resistance could be managed best if alternatives with different modes of action were available. Only with these alternatives at hand could a particular class of compounds be used "infrequently".

Fungicides of the Future. A speculation on the future of fungicides for grape disease control has to acknowledge that the future in the US is most frequently the present in

Europe. It also must be acknowledged that US registration requirements have become prohibitive in some cases. For example, Curzate is a downy mildew compound developed by DuPont for the European market. There, it has gained in importance as a tool in the management of metalaxyl resistance. The same applies to fosetyl-Al (Aliette), a compound also under development in the US. However, its registration for grape downy mildew remains unsure. Dimethomorph, a third new downy mildew compound, is in the last stages of development in Europe, but it has an unknown future in the US. For some other grape diseases such as *Botrytis* bunch rot, no new classes of fungicides are under development even in Europe. The high standards of efficacy set by our modern fungicides, in combination with increased safety requirements comprise the two major reasons for the slow progress made over the last decade.

The general future of chemical disease control is expected to emphasize target sites with even greater specificity. These compounds would not inhibit the growth of a pathogen; they rather would interfere with highly specialized steps in the establishment and the development of diseases. Of similar interest are chemicals that would stimulate the natural defenses of a plant. Such compounds with an "indirect mode of action" can be expected to be highly specific and thus completely harmless to non-target organisms. When they will be found and how successful biotechnology will be in the engineering of disease resistant plants remains an open question. For the control of grape diseases today and in the foreseeable future, these questions are of little relevance. Even if a new fungicide were discovered today, it would take at least 10 - 20 years before we could expect it to become available in the US. In the meantime, we have to rely on the declining number of fungicides registered on grapes, and careful management, in particular with regard to resistance, will become increasingly important.

DEVELOPMENT OF DISEASE FORECASTING PROGRAMS FOR GRAPE BLACK ROT AND DOWNY MILDEW

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Black rot of grape, caused by the fungus *Guignardia bidwellii* (Ellis) Viala & Ravas, and downy mildew, caused by the fungus *Plasmopara* viticola [C. Berk. and Curt) Berl. and de Toni], are two of the most economically destructive diseases of grape in the midwestern and northeastern United States. Although black rot generally causes little damage to the vine, it can result in fruit losses of 70-100% under conditions favorable for disease development. Prior to the development and introduction of effective fungicides, yield losses of 25% due to black rot were common. Downy mildew can result in similar levels of fruit loss in addition to causing early defoliation of vines, which makes them less winter hardy and more susceptible to winter injury. In order to successfully produce grapes in the eastern United States, both diseases must be controlled, often simultaneously.

Both fungi require free water on the surface of susceptible plant parts in order for their spores to germinate and penetrate (infect) the plant. Thus, wetter growing seasons generally result in more disease. Temperature also has a direct effect on the infection process. At the optimum temperature for infection, the duration of free water required for infection is shortest. As the temperature deviates up or down from the optimum, the length of the wetness period required for infection increases. This basic principle has many implications in our disease management program and it must be understood in order to comprehend what an infection period is. For the purposes of this discussion, an infection period is the duration of free water on the plant surface that is required for infection to occur at a specific temperature.

Today, black rot and downy mildew are controlled in most vineyards through the use of protectant fungicides. In protectant spray programs, a barrier of fungicide protection must be established and maintained on all susceptible plant parts prior to infection by these fungi. Applying protectant fungicides after infection has occurred will not provide adequate control. This generally implies that sprays need to be repeated after 7 to 10 days of new vine growth or after one inch of rain, which washes off the barrier of fungicide. The protectant program is strictly prophylactic and requires that the protective chemical barrier be maintained regardless of whether infection periods of these diseases have occurred. The protectant spray program is literally the "backbone" of our current disease management program for black rot and downy mildew, and although it is generally effective, it can be very costly. In southern Ohio, 10-14 fungicide sprays per season may be required to provide adequate disease control. Additionally, improper timing of early to mid-season sprays often results in yield loss in spite of a full-season protectant program.

Other concerns related to our current protectant programs include the increasing public concern about pesticide residues on food crops, the loss of fungicide registrations on grape, and the fact that certain grape processors are unable to accept grapes that are treated with certain fungicides. All of these factors are causing growers and plant pathologists to carefully scrutinize our current disease management programs.

An alternative to the protectant fungicide program is a post-infection or curative spray program. In a curative program, the fungicide is applied after the initiation of an infection period but before symptom development. During dry growing seasons, this approach should result in reduced fungicide applications. During wet growing seasons, this approach may not reduce the total number of fungicide applications but may improve efficacy by optimizing spray timing. Since Spotts published the temperature-wetness relations necessary for grape vine infection by the black rot fungus, we have had reliable guidelines for determining black rot infection periods under vineyard conditions (Table 1). Research in Ohio and New York has provided information on the temperature-wetness relations for grape vine infection and subsequent sporulation by the downy mildew fungus, which should be beneficial in determining downy mildew infection periods in the vineyard as well.

Table 1: Leaf Wetness Duration-Temperature Combinations Necessary for Grape Foliar Infection by Black Rot.

Temperature (C)	Temperature (F)	Minimum Leaf Wetness Duration for Light Infection (Hr)
0.0	50	24
13.0	55	12
15.5	60	9
18.5	65	8
21.0	70	7
24.0	75	7
26.5	80	6
29.0	85	9
32.0	90	12

Although the environmental parameters required to determine infection periods for both black rot and downy mildew have been defined, they have not been widely used in disease prediction or forecasting systems. One factor contributing to the lack of interest in developing and implementing disease forecasting systems for these diseases has been the days after the initiation of an infection period. Obviously, it is of little value to have a predictive system indicate that an infection period has occurred, if the only fungicides available are protectant that must be applied prior to infection. The introduction of new fungicide chemistry such as the ergosterol-biosynthesis-inhibiting (EBI) fungicides (Bayleton and Nova), which have good curative activity against black rot, and metalaxyl (Ridomil) and fosetyl-Al (Aliette), which have curative activity against downy mildew, should make forecast-based control a more practical possibility.

Another factor that may limit grower acceptance and implementation of disease prediction systems is the lack of systems that provide rapid, simple and dependable information or predictions. Recent developments in computer technology have resulted in instrumentation that combines electronic environmental monitoring sensors with a microcomputer to provide simple and rapid on-site determination of grape black rot and downy mildew infection periods. This type of instrumentation combined with fungicides that have curative activity should make disease-forecasting or predictive systems practicable.

Validation of a Disease Forecasting System for Grape Black Rot Control: Since 1982, we have conducted fungicide trials annually to compare a full season protectant program with a curative program where fungicides were *applied in response to predicted infection periods.* These trials consisted of applying Ferbam (carbamate) at the rate of 3 lb/acre in a full season protectant program on a 7 to 14-day spray interval. For comparison, Bayleton was applied to different treatments (vines) within 3 to 4 days after the initiation of a predicted infection period. We assumed that curative applications of Bayleton would provide at least 7 days of protectant activity; therefore, infection periods that occurred within 7 days after a curative application were disregarded. After 7 days, curative applications were made in response to the next infection period. All curative treatments were made in response to electronically predicted infection periods made by a microprocessor (Reuter-Stokes Disease Predictor RSS-411 or 412). Disease ratings were conducted on all treatments.

A comparison of the number of spray applications between the curative and protectant spray program is presented in Table 2. For each year between 1982 and 1988 a minimum of 3 fungicide applications were saved by using the curative program. In 1988, which was a drought year, 8 applications were saved. In all years, excellent disease control was obtained in all treatments, with no significant difference in the level of disease control between the curative and protectant spray program. Detailed information describing the methodology and results of these studies has been published (1,2). In addition, an economic analysis has been conducted using the results of these studies to compare the cost of the protectant and disease-forecast-based (curative) spray programs (2). Although Bayleton is more expensive than Ferbam, and there is an initial cost for purchasing a predictive unit, the reduced number of applications, together with labor and equipment savings, resulted in *substantial cost reductions.*

Our results indicate that the development of dependable disease predictive units combined with curative fungicides such as Bayleton or Nova, that are currently registered for use, makes disease predictive or forecasting systems coupled with curative spray programs an alternative to prophylactic fungicide applications in standard protectant programs.

Summary and Conclusions. Whereas the progress towards developing an effective disease predictive system for grape black rot and downy mildew is encouraging, there are some major limitations that must be recognized. One of the most important is the fact that we have several diseases in eastern U.S. that may require fungicide application in order to be effectively controlled. In addition to black rot, downy mildew, powdery mildew, *Phomopsis* cane and leaf spot and *Botrytis* bunch rot (gray mold) also need to be considered. Thus, predictive systems ideally should be capable of predicting infection periods for all of these diseases, and these predictions should be integrated into a single fungicide spray program. With the current technology it is feasible to have predictors that are capable of simultaneously monitoring for and predicting several diseases. Through research to better understand the biology and epidemiology of the major grape pathogens, it should be possible to develop integrated disease management programs that can simultaneously use multiple disease predictions. Although we feel that this is possible, we recognize that it will require a great deal of research.

Table 2: Comparison of the Number Fungicide Applications in a Curative and Protectant Fungicide Spray Program for Control of Grape Black Rot in Ohio, 1982 to 1988.

	Number of sprays	
Year	Curative	Protectant
1982	7	10
1983	6	10
1984	7	11
1985	6	6
1986	6	10
1987	5	13
1988	2	10
TOTAL	39	73

Another concern is the lack of fungicides with curative activity for the various diseases that need to be controlled. Currently Bayleton and Nova are available for black rot control. At present, there is no fungicide registered for downy mildew control in the United States that has curative activity. Metalaxyl (Ridomil) and fosetyl-Al (Aliette), which have curative activity for downy mildew, may eventually be registered for use in the U.S. In addition, new fungicide chemistry is constantly being developed by the chemical industry. As new fungicides with curative activity are developed, they can be readily adapted for use with disease predictive systems.

Although the availability of curative fungicides should facilitate the most effective use of disease predictive systems, the value of predictive systems in the absence of such fungicide chemistry should be recognized. The use of systems that inform the growers about the biological events that are occurring within the vineyard should be beneficial regardless of the type of spray program being used. For example, information on the history of infection periods that have occurred within the vineyard, should be a useful tool in helping growers on protectant spray programs to make management decision related to shortening or lengthening the protectant spray interval.

The development of fungicide resistance to the currently available fungicides is a major concern in modern agriculture regardless of the type of spray program being used. If the use of curative fungicides in combination with predictive systems is further developed, the use of fungicide resistance management strategies must be an integral part of the program.

The cost of predictive devices or systems is probably the most immediate or major concern to the grower. In most situations, the cost of new technology is initially high, but as the use of the technology becomes widely spread the costs generally decrease. If the use of predictive systems in agriculture increases significantly in the future, their costs may be reduced. When considering the cost of any predictive system, it is important to consider the long term economic effects that the system may have on total production costs. When most growers consider the economic benefits of reducing the number of fungicide applications, they generally consider only the cost of the fungicide saved. In an economic analysis of protectant and disease-forecast-based fungicide spray programs for control of apple scab and grape black rot in Ohio, the curative fungicide program resulted in a reduced number of sprays and lower fungicide costs; however, the greatest savings were primarily due to reductions in labor and equipment costs (2).

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INTEGRATED CONTROL PROGRAMS FOR MULTIPLE DISEASES OF GRAPEVINES

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Introduction

Scheduling fungicide applications by monitoring weather and pathogen development is an approach that has been used successfully in certain diseases of several crops. Generally speaking, when the circumstances that initiate infection are sporadic but predictable, then fewer sprays are used than in a normal protectant schedule. However, the task becomes somewhat more complex when there are two or more diseases to control simultaneously. We are currently developing a disease management program to simultaneously control two major grape diseases: black rot, caused by *Guignardia bidwellii*, and powdery mildew, caused by *Uncinula necator*.

Ascospores produced within overwintered mummified berries are the primary inoculum for black rot. Five years ago, we learned that cleistothecia on the bark of the vine were the principle source of primary inoculum for grape powdery mildew in New York. Ascospores of both pathogens are released by rain during a 6-week period beginning at bud break and lasting until shortly after bloom. In the case of black rot, infection is determined by the duration of leaf wetness and temperature during leaf wetness following ascospore release.

Less was known about release of ascospores and infection by *Uncinula necator*. After observing ascospore release since 1986 in the laboratory, and trapping ascospores in vineyards, we now know that ascospore release is likely to occur whenever rainfall exceeds one-tenth of an inch, and temperatures are above 40 F. Although the ascospores are discharged above 40 F, they germinate very poorly or not at all below 50 F. So, release of ascospores is not the only consideration in identifying infection periods, it must be sufficiently warm for the discharged ascospores to germinate and infect the host.

Vineyard studies

At this point, we had identified several similarities in the epidemiology of the two pathogens, and the next step was to formulate some simple rules based upon these similarities to allow us to time post-infection fungicide applications for both diseases. The rules were based upon the presence of primary inoculum for either black rot or powdery mildew, and suitable rainfall, temperature, and leaf wetness conditions for either pathogen. Post-infection sprays were applied within 3-6 days after infection periods. In 1988, after a spray was applied we waited 21 days and then sprayed again following the next infection period, and continued in this pattern until berries reached 5% sugar in early August and became resistant to black rot and powdery mildew. In 1989, the minimum interval between post-infection sprays was shortened to 14 days, but the sprays were terminated once primary inoculum was exhausted in late June. As a standard for comparison, we applied 5-6 protectant sprays at 14-day intervals beginning at 1 inch of shoot growth. We tested both schedules on the *Vitis* interspecific hybrid cultivar Aurore, which is susceptible to black rot and powdery mildew.

The fungicides that we used were Bayleton in 1988, and Nova, in 1989. Both inhibit a demethylation step in sterol biosynthesis. Both have about 72 hours of post-infection activity, provide about 14 days of protection against black rot, and also provide 14-21 days of protection against powdery mildew. We had no information at the start of these experiments on how these fungicides would work as post-infection materials against ascospores of *Uncinula necator*.

The year 1988 was one of the driest growing seasons on record in the northeast. Consequently, incidence and severity of black rot and powdery mildew were quite low at our test site on all treatments. Six protectant sprays were applied, but only three post-infection sprays were needed. Because of the drought, 1988 was not a fair comparison of the efficacy of the post-infection and protectant treatments under severe conditions. Nonetheless, it demonstrated the potential savings in fungicide use that a post-infection program can yield in a year when environmental conditions do not favor severe disease.

In 1989 there were 11 infection periods identified during the period of primary inoculum release and an additional 6 secondary infection periods in July and early August. However, only two post-infection applications were sufficient to protect vines during the time that primary inoculum was available. In fact, powdery mildew was controlled as well by 2 post-infection applications as by 5 protectant applications at the same rate. The incidence of black rot increased, due to secondary infection, when spraying was terminated to coincide with the depletion of primary inoculum, but severity remained low, and the increase was not sufficient to affect crop quality or yield. The cost of the post-infection program was less than one-half that of the protectant program.

Integration of downy mildew control

We were pleased with how the post-infection program had worked for black rot and powdery mildew in 1988 and 1989, but we did encounter problems in control of downy mildew. Downy mildew is not affected by Bayleton or Nova. We had ignored the control of downy mildew in 1989, thinking that the cultivar Aurore would suffer only mild infection. Unfortunately, downy mildew removed nearly 40% of the leaves by mid-September, and by October 16th, the vines which were not protected against downy mildew dropped nearly all of their leaves.

In 1990, we attempted to improve our control of downy mildew by using a weather-driven disease forecast model to determine when a control program for downy mildew should be initiated. The model was developed in France, and is called EPI, and it delivers a forecast based upon the suitability of winter weather for survival of the downy mildew pathogen. 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 as before, by using simple rules to identify combined black rot and powdery mildew infection periods. Downy mildew infection was forecasted by the EPI model.

Electronic weather stations, which incorporated a computer to use the powdery mildew, black rot, and downy mildew forecasting systems, were donated for the trials by Neogen Corporation. These units were installed in four vineyards of the cultivar Aurore, shortly after bud break, in Dresden, Dundee, Watkins Glen, and Romulus in the Finger Lakes Region, and in a Concord vineyard in western New York.

At the 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 full season, or were terminated when the supply of ascospores for *G. bidwellii* was exhausted. These were called the primary season treatments.

Results of the 1990 vineyard trials

At Dresden, the full-season post-infection programs, which used five sprays, 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 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, this was not especially illuminating considering that there was no downy mildew on control vines in this vineyard. Powdery mildew did increase in <u>incidence</u> on leaves and fruit after sprays were stopped in mid-June in the post-infection primary-season treatment. However, considering the low <u>severity</u> of infection, it is doubtful that there was a significant effect on yield.

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 lead to some early defoliation of vines. A single application of captan in late-July recommended by EPI prevented downy mildew 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. There was a clear relationship between proximity of the abandoned vineyard to our research plots at Watkins Glen, and the incidence of cluster infection. While it may be a safe practice to terminate the spray program in vineyards that are reasonably isolated from abandoned plantings of susceptible cultivars, it was certainly not a good idea in this situation. Surprisingly, 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 there was any measurable effect on the vines.

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 again lead to some early defoliation of post-infection treatments.

On the cultivar Concord at Westfield, downy mildew was of less concern than *Phomopsis* cane and leaf spot and fruit rot. 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.

Early season control vs full season control

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 even greater consequence on cultivars with a later harvest date than Aurore.

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.

Downy mildew

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. 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 with the DMI fungicides that are used 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.

Future research

One approach 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.

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 berries 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 summer. 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.

POWDERY MILDEW — EPIDEMIOLOGY AND CONTROL

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The disease cycle of grapevine powdery mildew in California is more complex than once was thought (Fig. 1). The pathogen may overwinter in one or both of two forms in virtually any vineyard, each giving rise to primary inoculum. Hyphae of the pathogen may overwinter in buds and give rise to infected shoots the following spring. Disease incidence from infected shoots is rapid and disease spreads both within the canopy and from vine to vine—thus initiating the epidemic. Preliminary studies on the effect of temperature on disease onset and subsequent sporulation suggest that low to moderate temperatures during budbreak result in almost immediate infection. Sporulation occurs within 7 days at 70-80 F but required 16 days at 65 F. Temperatures above 85 F resulted in rapid budbreak and shoot elongation but infection was inconsistent. Budbreak at 90 F and above resulted in 100% clean buds and shoots for the duration of the study.

Ascospore released from cordon, spur and cane-bound cleistothecia are the second form of primary inoculum produced by *U. necator*. Cleistothecia are formed on infected leaves in late summer and fall. In order for these structures to successfully function in the disease cycle, they must be dislodged from the leaves on which they are borne and wash onto the exfoliating bark of the vine where they reside until the following spring. Cleistothecia abort when formed during periods of high temperatures

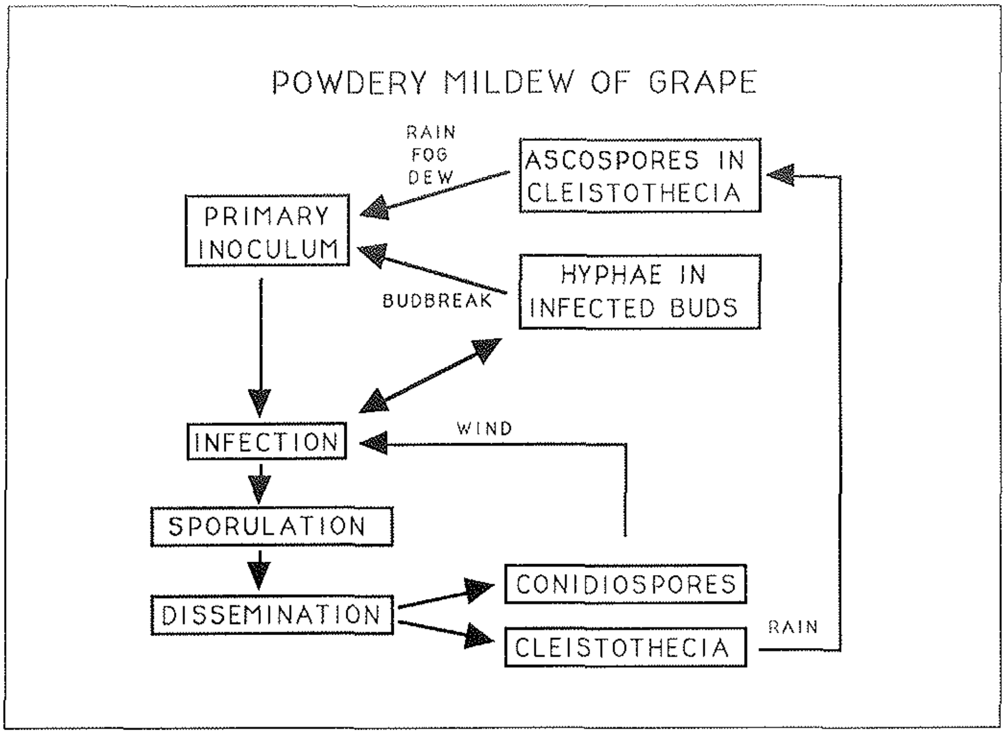

Figure 1. The California disease cycle of grapevine powdery mildew caused by Uncinula necator.

and therefore one would expect that high temperatures during late summer and fall would result in a reduced number of viable cleistothecia especially if rains and frost follow close on the heels of such weather. However, it is common in coastal production areas to have moderate temperatures which often last well into the fall and the pathogen produces large numbers of cleistothecia which eventually end up on the wood.

In California, viable, current season ascospore release has been documented to occur as early as August in some vineyards but the major release peaks occur in late winter and spring during and immediately following rains, sprinkler irrigation, heavy dew, and fog periods. Optimum temperature for ascospore release is between 60 and 70F and optimum temperature for infection is 60 F. No ascospores were released at 40F and 95F therefore cold winter rains would probably not play a major role in depleting inoculum potential prior to budbreak.

Ascospores released after budbreak generally require only approximately 12 hours for infection to occur and initial colony development has occurred within 3 days. Sporulating colonies can be observed in 5-7 days.

Symptom development resulting from ascospore infection can consistently be observed on the lower surface of basal leaves. A useful proven method of early season detection is to randomly collect 15-20 basal leaves from the length of both cordons and examine the undersides for white-gray mildew colonies. Oftentimes, if leaves are pubescent, careful observation using a hand lens must be made but colonies are readily visible with the naked eye on varieties such as Chardonnay and Sauvignon blanc. Disease incidence from ascospore infection can range from 38 to 96 percent of the vines infected just 7 days following spring rains or other wet events.

Infection from conidia reoccurs throughout the summer and depending on temperatures may repeat every 5-10 days.

Resistance to DMI fungicides. Bayleton belongs to a class of fungicides known as demethylation inhibitors (DMI). Two other DMI fungicides, Rally and Rubigan, also belong to this fungicide class and have the same mode of action in killing the pathogen even though their chemistries are somewhat different.

In 1985, many vineyard owners in California reported difficulty in controlling powdery mildew. Because the product had only a 3 year history of use, the most common reasons given for control problems were poor application, stretching intervals and reduced concentrations. On the other hand the manufacturer was being blamed for altering the product or selling old product. While some talked about resistance we were unable to document resistance in 1985. In 1986, serious powdery mildew epidemics swept the state, hitting virtually every production area. Isolates of *U. necator* collected in 1986 showed a significant variation in sensitivity to Bayleton with resistance factors high enough for them to be termed resistant. However, because baseline sensitivity data was lacking for Bayleton in California, we could not conclusively make the statement that resistance was the key blame for crop loss in 1986.

In 1987, several isolates with differing sensitivity to Bayleton were used to inoculate grape seedlings which had been treated with Bayleton at the rate of 4 oz/A. Sensitive isolates were unable to attack treated grape leaves for 20-22 days while one isolate which had been labeled resistant could attack similarly treated leaves the same day of the fungicide treatment. Yet another isolate labeled resistant but with an intermediate EC_{50} value was able to attack leaves in 7 days. This data proved conclusively that resistance or reduced sensitivity had occurred in some California vineyards.

In 1989, a new research project was initiated to investigate the extent of resistance in California vineyards, to develop baseline sensitivity data for Rally and Rubigan, to determine if cross-resistance had developed to Rally and Rubigan and to determine if resistance was being maintained over winter in ascospores.

Isolates from seven out of 19 vineyards surveyed showed some degree of resistance to Bayleton and where resistance was severe, isolates also were cross resistant to Rally and Rubigan. Testing of isolates from a vineyard which never had been treated with DMI fungicides shows them to be consistently sensitive to rates as low as .3-.4 ppm Rally and Rubigan and to .9 ppm for Bayleton. This is in contrast to the sites where severe resistance had occurred in which isolates had mean EC_{50} values to Bayleton of 17-40 ppm, to Rally of .9-7.9 ppm and to Rubigan of .9 ppm.

Sequential sampling was done in each of 2 vineyards; one with resistance (R), the other with wild isolates (W). Isolates (R) derived from ascospores in January had high levels of resistance to Bayleton and were cross resistant to both Rally and Rubigan. As the season progressed, resistance increased and cleistothecia produced in the fall contained ascospores which also were resistant. This work also has documented that resistance in *U. necator* to DMI fungicides is maintained through genetic recombination via the sexual cycle. This also partially explains why resistance developed so rapidly.

Though sampling from the wild-type vineyard has not been extensive enough to make a statement regarding selecting for resistance from a population possibly already spiked with resistant propagules at the time of product introduction, our sampling has shown that the variation in sensitivity in the wild-type vineyard is minimal and we have detected nothing to lead us to suspect resistance in this vineyard.

Disease Control Recommendations. Vineyards should be treated with a dormant application of lime sulfur or with micronized wettable sulfur at full budbreak (1"-2"). If spring weather is cool and wet, a second application should be applied 10 days later. If weather persists and shoot growth is delayed, continue with another wettable sulfur application. Begin DMI applications or dusting sulfur when shoots are 8-10" and continue through veraison.

Managing DMI Resistance. Resistance to the DMI fungicides is maintained from year to year through sexual reproduction which results in ascospores. For this reason it is imperative that early season control programs be initiated that control ascospore infection. Research in California has shown that early season use of micronized wettable sulfur applied at budbreak significantly reduces incidence and severity of disease initiated by ascospores. Two to three applications prior to DMI fungicide use eliminates most infections and reduces selection pressure which occurs when the materials are applied directly to sporulating colonies.

In addition to early season sulfur use, it is recommended that some form of sulfur be used later in the season in tank mix with DMI fungicides or alternated with same. DMI fungicides should not be used to eradicate powdery mildew but can be used in combination with sulfur approximately 5 days after washing existing infections with a sulfur + wetting agent spray.

Spray programs using DMI fungicides should be set on a 14-18 day application schedule. Should one want to stretch the interval between DMI applications, a sulfur application should be made on day 14 or 18 and the DMI should be applied 7 days later.

FUNGICIDE RESISTANCE IN ITALIAN VINEYARDS

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Introduction

Controlling of the three most important grape pathogens, *Uncinula necator* (powdery mildew), *Plasmopara viticola* (downy mildew), and *Botrytis cinerea* has improved during the past twenty years, due to availability of new, highly effective, specific fungicides. Unfortunately, highly specific fungicides are often prone to development of resistant strains in the pathogen population. This phenomenon has occurred in Italy with the four major groups of fungicides currently used for controlling the three major grape diseases. The four major groups of fungicides used in Europe are: 1) Ergosterol Biosynthesis Inhibitors (EBIs), 2) phenylamides, 3)benzimidazoles and, 4) dicarboximides (Staub and Diriwaechter, 1986).

The current situation regarding fungicide resistance in Italian vineyards specifically involving Botrytis bunch rot, powdery mildew and downy mildew, will be described. Special reference to possible anti-resistance strategies will be discussed.

Benzimidazole and dicarboximide resistance in Botrytis cinerea

Resistance to benzimidazoles (e.g., Benlate) by *B.cinerea* developed quickly in Italy, as well as in other European countries. However, in Italy benzimidazole resistance, although present in all grape growing areas, occurs at a low frequency. In some areas, on varieties very susceptible to bunch rot, the frequency of benzimidazole resistant isolates is about 30%, which is much less than that observed in the Champagne region in France (Leroux, 1987). Today, benzimidazoles are not used much for the control of bunch rot in Italian vineyards.

Dicarboximides (e.g., Rovral), to some extent filled the niche left by benzimidazoles in spray programs for the control of bunch rot. The first dicarboximide to be introduced on the market was vinclozolin (Ronilan), followed by iprodione (Rovral), procymidone (Sumisclex) and chlozolinate. The first dicarboximide resistant strains of *B.cinerea* were detected in Italian vineyards in 1981 on the variety Moscato, which, being very susceptible to bunch rot, is frequently sprayed. The incidence of dicarboximide resistance was very low in 1981 (< 1% of bunches carried resistant strains), but it has since increased year by year. In 1986, about 6% of infected bunches carried dicarboximide resistant conidia of *B.cinerea*. In 1987, in the presence of severe disease, control failures in several 'Moscato' vineyards were clearly related to the presence of dicarboximide-resistant strains (Gullino, et al., 1988).

Unfortunately, dicarboximide resistance developed in strains of *B.cinerea* which were already resistant to benzimidazole (double resistance). This phenomenon complicates bunch rot control in some situations. Surveys carried out in different Italian grape growing areas showed that the phenomenon of dicarboximide resistance was serious only in 'Moscato' vineyards. In seasons with severe disease, dicarboximides, if used alone, no longer provide complete control of bunch rot in 'Moscato'. Nevertheless, on varieties that are less susceptible to *Botrytis*, dicarboximides are still performing well.

Since dicarboximides are still the most active fungicides against bunch rot, it is important to find ways to cope with resistance. A simple monitoring technique was developed to help technicians working in the extension service follow the progress of fungicide resistance in individual vineyards. A spore suspension is prepared from a number of *Botrytis* infected, sporulating berries, obtained from as many bunches as possible. The suspension is then streaked over the surface of agar (glucose 10 g/l, agar 20 g/l) in a three-sector plate. The sectors of the plate contain, respectively, unamended agar (control), agar + benomyl (5 mg/l) and agar + vinclozolin (5 mg/l). The concentrations of benomyl and vinclozolin chosen are higher than the respective Minimal Inhibitory Concentrations (MIC) for benzimidazoles and dicarboximides. Plates are incubated at room temperature and after 16-18 hours conidial germination is observed with a light microscope at 100X magnification. One hundred conidia in each sector are examined. This technique is accurate, rapid, detects low-level fungicide resistance, and reduces problems caused by storage and shipping of samples. Furthermore, it requires minimal equipment (a microscope, plates, tubes, pipettes, agar medium) (Gullino and Garibaldi, 1986).

Since 1987, this monitoring technique has been transferred to the extension service operating in the grape growing areas of Piedmont and Tuscany. The results obtained by monitoring vineyards indicated that dicarboximide resistance is most common in Northern Italy and on the variety Moscato. In other areas and on other varieties, dicarboximide resistant strains of *B.cinerea* are present at much lower frequency. In some Moscato vineyards, over 50% of the *B.cinerea* population is resistant to dicarboximide (Table 1). This high incidence of dicarboximide resistance is particularly evident in years such as 1987 that are characterized by severe disease (Table 1). In vineyards where dicarboximide resistance is widespread, advice on disease management is based on avoiding the use of dicarboximide fungicides. Further considerations are given based on the fact that fungicides with specific activity against *B.cinerea*, other than dicarboximides and benzimidazoles, are not available, and that alternative fungicides, registered for use in Italy, are chlorothalonil (Bravo), thiram, and dichlofluanid (Euparen). Grower acceptance of fungicide resistance monitoring is very good and over the years their cooperation in collecting samples has increased.

Diethofencarb, a recently developed compound structurally related to carbamate herbicides, has shown negative cross resistance to benzimidazoles. It is currently registered for use in France. Diethofencarb controls strains of *B.cinerea* resistant to benzimidazoles and double resistant to benzimidazoles and dicarboximides, although it does not control the sensitive isolates of the pathogen. Where registered for use, diethofencarb is used as a tank mix with a benzimidazole.

In Italy, in the presence of dicarboximide resistance, satisfactory control of bunch rot is achieved by treating twice each season with a tank mix of a dicarboximide plus thiram (Gullino, et al., 1988). However, this mixture, although satisfactorily controlling bunch rot, does not decrease the incidence of dicarboximide resistance (Gullino, et al., 1989).

EBI resistance in *Uncinula necator*

Decreased efficacy of some EBI fungicides against grape powdery mildew was observed in the summer of 1988 in some vineyards of Central Italy. The phenomenon occurred in the presence of severe disease in vineyards sprayed frequently (8-10 sprays/season) for several years with fenarimol (Rubigan). The population of *U.necator* isolated from those vineyards showed reduced sensitivity

Table 1. Results of monitoring for dicarboximide resistance in *B.cinerea* carried out in Northern Italy during the years 1987-1990. Number of vineyards with resistant strains of *Botrytis*, categorized by percent of resistant conidia in the vineyard.

Cultivar		Year	Number of Vineyards with Resistant Conidia (categorized by percent)					
			0%	1-10%	11-25%	26-50%	51-75%	>75%
Moscato	(74)*	1987	17	14	16	12	10	5
Moscato	(34)	1988	9	7	13	5	0	0
Moscato	(14)	1989	0	2	6	6	0	0
Moscato	(14)	1990	3	10	1	0	0	0
Barbera	(22)	1987	2	12	7	1	0	0
Barbera	(11)	1988	1	6	3	1	0	0
Barbera	(7)	1989	0	3	4	0	0	0
Barbera	(6)	1990	0	5	1	0	0	0
Dolcetto	(7)	1987	2	2	1	1	0	0
Dolcetto	(4)	1988	1	1	2	0	0	0
Dolcetto	(3)	1989	0	1	1	1	0	0
Dolcetto	(2)	1990	0	2	0	0	0	0
Nebbiolo	(19)	1987	1	3	13	1	1	0
Nebbiolo	(4)	1989	0	2	2	0	0	0

* Numbers in parentheses are numbers of monitored vineyards

to fenarimol and triadimefon (Bayleton), the two EBIs first marketed in Italy and most widely sprayed (Tables 2 and 3) (Garibaldi, et al., 1990). This phenomenon remains localized in Central Italy, in an area where severe disease occurs and a high number of sprays are applied each year Decreased sensitivity to EBIs in grape powdery mildew has also been observed in California (Cavenaugh, 1987), Portugal (Steva, et al., 1988) and France (Steva and Clerjeau, 1990).

Phenylamide resistance in *Plasmopara viticola*

Resistance to phenylamides (e.g., Ridomil) in grape downy mildew developed quite rapidly in many grape growing areas of South Africa and Southwestern France (Staub and Sozzi, 1981). It developed in spite of the use of mixtures with residual compounds, such as folpet and mancozeb. Nurseries with very serious disease may have been the first sites of resistance. Subsequent development of fungicide resistance in different areas varied, depending on phenylamide usage. In Italy, phenylamides were introduced later than in France and have always been marketed as mixtures with fungicides having different modes of action. The first resistance problems, under practical conditions, were observed in 1990 in Northern Italy (Mezzalama, et al., 1991). This situation appears to further confirm that the use of fungicide mixtures can help prevent severe performance problems (Staub and Diriwaechter, 1986).

Conclusions

Fungicide resistance problems in Italian vineyards seem less dramatic than those observed in France (Leroux and Clerjeau, 1985). Dicarboximide resistance is a practical problem only in the variety Moscato, while resistance to EBI and phenylamide is presently very localized. Nevertheless, in order to avoid the spread of fungicide resistance to larger areas, careful and responsible use of fungicides is recommended. Monitoring fungicide resistance helps detect distinct and critical situations, thus allowing rapid shifts in fungicide use when needed. Successful implementation of resistance management, of which monitoring is one component, relies on constant awareness and cooperation of all people involved with fungicide use, from manufacturers to users.

In future, new techniques based on recombinant DNA will be available for detection of resistance. The development of DNA probes to identify resistance genes is an exciting future prospect that may greatly aid implementation of anti-resistance strategies (Hollomon, 1990).

Table 2. Effectiveness of some EBIs against populations of *U.necator* isolated in Central Italy in three different trials

Fungicide	Dosage (g/100L)	Percent Infected Leaf Area in Trial I	II	III
--	--	72 c*	46 e	43 b
Fenarimol (Rubigan)	1.2	27 b	14 d	25 ab
Cyproconazole	1.0	0 a	not tested	0 a
Fenpropimorph	80.0	3 a	not tested	not tested
Myclobutanil (Nova)	3.0	not tested	0 a	not tested
Propiconazole	1.5	not tested	1 b	not tested
Triadimefon (Bayleton)	3.0	not tested	10 c	not tested

* Data within columns followed by the same letter are not significantly different according to Duncan's Multiple Range Test (P = 0.05).

Table 3. Effectiveness of increasing dosages of fenarimol (Rubigan) against *U.necator* isolated in Central Italy.

Dosage of Fenarimol (g/100 L)	Percent Infected Leaf Area
--	42 c*
1.2	23 b
3.6	12 ab
5.4	3 a
7.2	4 a

* Data within a column, followed by the same letter, are not significantly different according to Duncan's Multiple Range Test (P = 0.05).

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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 fluorescein 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.

3. There are several potential uses for eradicant treatments:

   a. 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.

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

   c. Eradicant treatments could be used to augment control of powdery mildew in low input systems.

STRATEGIES FOR THE DEVELOPMENT OF DISEASE RESISTANCE

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Disease resistant varieties offer a number of opportunities. Most importantly they can reduce the environmental and economic costs associated with the usage of common pesticides. Resistant varieties are an important alternative in the event that pesticide registrations are revoked. In vineyards planted to resistant varieties, there would be less concern about inoculum remaining in hedged vineyards, and there would be less need for cultural practices to alleviate disease, such as leaf removal or multiple trunking systems. Resistant varieties would also increase the options available for vineyard floor management practices which are known to influence inoculum concentrations. Finally, the need for biological control practices, and any associated expenses would be lessened with the use of resistant varieties.

Disease resistant varieties should play a key role in the development of modern viticultural practices. The following lines were written on 1 Nov. 1989 by Dr. R. Coffman, Chairman of the Department of Plant Breeding and Biometry at Cornell University: "The four components of an effective integrated pest management (IPM) program are (1) host resistance, (2) cultural practices, (3) biological control, and (4) chemical pesticides. Host resistance in the form of crop varieties resistant to disease and insect pests is the foundation of IPM. If susceptible varieties are used, other components of IPM generally are found wanting in providing effective pest control. Cultural practices and biological control methods are most useful when they augment host resistance. Susceptible varieties often render these approaches ineffective and result in the excessive use of chemical pesticides. However, if an appropriate resistant variety is utilized and further augmented by effective biological and cultural control practices, it usually is not economical to employ chemical pesticides."

Pest resistant grape cultivars have been under development for over 100 years. The introduction of the North American pests, phylloxera and powdery mildew (*Uncinula necator*), into Europe in the mid-1800's was devastating to grape growing enterprises. This created great incentives to develop new cultivars using American species resistant to phylloxera, powdery mildew and other diseases. Breeders rushed to the market with the results of their crosses in an effort to solve the industry's crisis. The first products of these programs (developed by breeders and nurserymen such as Seibel, Couderc, Kuhlmann and Bertille Seyve) were widely planted in Europe but received mixed reviews - wine quality was disappointing when compared with the traditional varieties. Additional time was required to hybridize and select improved types. Also, initial crosses utilized low quality *vinifera* grapes such as 'Aramon' as quality parents. 'Aramon' is used widely for bulk wine production in the South of France. Later products of French breeding programs, including 'Seyval', 'Vidal blanc' and 'Vignoles', reached higher levels of acclaim for their wine quality. High quality *vinifera* wine grapes were increasingly used as parents. The development of resistant rootstocks solved the phylloxera problem. International efforts continue to develop disease resistant scion cultivars.

Although the French efforts attained their goal of producing phylloxera-resistant wine grapes, it was only coincidental that some of these hybrids were adapted to the cold climate and brief growing seasons of the Northeastern USA. Many of these hybrids did not have resistance to powdery mildew, downy mildew, black rot and Botrytis bunch rot, the major diseases of this region. Though some were rated to be highly disease resistant in Europe, these classifications have not always held true in North America. Some varieties have been very susceptible to disease when tested in New York. Newer hybrids being developed in New York and elsewhere carry enhanced levels of resistance to multiple diseases. These will be discussed later.

Several approaches are available for the development of new disease resistant varieties: 1) Hybridization and seedling selection - this is the traditional approach requiring the selection of desirable parents, production of new seedlings, and careful selection among them for the desired traits; 2) Induction of mutations - chemicals or radiation can be used to induce genetic changes in important cultivars which are then screened for the desired trait; 3) Clonal selection - variation for important characters is sought by surveying existing plantings for elite vines and propagating such vines to test for trait stability at multiple sites; and 4) Genetic engineering - important cultivars can be improved by inserting a gene for disease resistance utilizing technological innovations in molecular biology which have become available in just the past 5 years.

When utilizing traditional breeding approaches, entirely new varieties are produced, combining characteristics of both parents. With clonal selection, genetic engineering and mutation breeding, important commercially accepted varieties can be modified and improved. This is extremely important in viticulture, especially where wine sales rely heavily upon consumer name recognition. A disease resistant 'Cabernet' or 'Chardonnay' would quickly become important to the industry. Clonal selection has already been successful in identifying improved forms of Pinot noir, some of which have enhanced levels of resistance to Botrytis bunch rot. On the other hand, mutation breeding has met with only limited success in grapevine improvement because most induced changes have proven either deleterious or disadvantageous. Genetic engineering is a new technology which offers the opportunity to make significant directed improvements in important cultivars, whereas mutation breeding and clonal selection rely upon the rare chance that a specific improved trait can be found. Already, crop plants have been altered for improved virus resistance, production of toxins which kill insects and, more recently, production of general anti-fungal compounds via the techniques of genetic engineering. The Geneva grape breeding program utilizes both traditional hybridization and genetic engineering technology in its program to develop improved disease resistant cultivars.

In the traditional breeding program at Geneva, the first step is to identify parental grapevines to be used as sources of disease resistance and other desirable attributes. This knowledge is derived from the literature, as well as from multiple years of vineyard observations. Parents are selected for crossing based on the traits that are desired in the resulting seedling population. Each year, 10 to 40 crosses are made and 50-150 seedlings from each cross are planted out for evaluation. New wine and table grape seedlings are planted in vineyards under conditions which encourage disease development. These vineyards receive a maximum of 3 to 4 pesticide sprays per season, thus allowing the selection of seedlings that tolerate a minimal spray program without a crop loss. The most recent seedlings, produced from parents carrying high levels of disease immunity or tolerance, are now planted in vineyards receiving 0 to 1 spray per season. Disease resistant vines are selected simultaneously for other important traits such as cold tolerance, productivity, sugar/acid balance, adequate vine size, etc. The best selections are propagated for further testing at Geneva, and later testing at multiple locations.

Once a seedling population is produced, it may be screened and selected for disease resistance before or after planting. Pre-planting selection is advantageous since it permits the planting of only the most promising seedlings and reduces vineyard costs. Techniques for pre-planting selection are listed in Table 1. A commonly used technique utilizes direct inoculation of seedlings with the disease-causing organism. This has been used with varying degrees of success. Seedling inoculation is complicated by the possible existence of multiple races of the pathogen which vary in their disease-causing abilities. Also, the response of a seedling grown in a greenhouse may differ from that of a mature, field-grown vine because of anatomical and physiological differences. A new approach under development at Geneva involves the use of genetic markers which are tightly linked to disease resistance genes. Once these markers are located, a simple lab test utilizing extracted genetic material from each seedling may be used to determine whether it possesses an important gene for disease resistance. However, once plants are established in the vineyards, it is still possible to screen for resistance either by observing disease symptoms on young vines, or by inoculating test tube-grown plantlets or greenhouse-grown cuttings in a laboratory setting (Table 1).

The genus *Vitis* has an extremely broad range of diversity. Wild vines are found growing throughout North America and into Mexico and Central America. The European grape, *Vitis vinifera*, originated between the Black and Caspian Seas in the southern part of the Soviet Union, near Turkey and Iraq. The Asian group of *Vitis* species are found throughout China, the northern part of the Soviet Union and in Japan and Korea. With the exception of the muscadine grape and just one or two other American species, all 70+ species are interfertile, meaning they can be used successfully for cross-fertilization to obtain viable hybrid seedlings. This permits breeders to utilize most wild grape species, and the diversity of traits they contain, for the development of new varieties.

Table 1. Selection techniques to screen for disease resistance.

Pre-Planting Selection:
1. Inoculation of cuttings and/or seedlings
2. Phytoallexin production
3. Genetic selection with molecular markers

Post-Planting Selection:
1. Field screening
2. In vitro screening of plantlets
3. Inoculation of cuttings

The most important species used in grape variety development are listed in Table 2. Genes for resistance to major diseases of grapes can be found in an assortment of species. Since these species are native to the areas in which the disease causing fungus originated, they have evolved resistance mechanisms over the duration of many years. Species such as *V. riparia*, *V. cinerea* and *V. rupestris* are commonly used in developing new hybrids because they combine resistance to multiple diseases with other attractive traits. In the case of *V. riparia*, disease resistance is combined with adaptation to short seasons and extremely cold climates. Since native *riparia* grapes have such a broad natural range, selections from the northern parts of the range (e.g. Manitoba, North Dakota and Minnesota) are most desirable because they are best suited to cold regions. *V. cinerea* has very high levels of resistance to powdery mildew and black rot and is being heavily utilized in the Geneva breeding program. One drawback to the use of wild species in breeding is their poor viticultural characteristics. Many native vines have very small berries, loose clusters, high acidity and low sugar content. Therefore, it is important that seedlings are simultaneously selected for both disease resistance as well as other viticultural criteria. These include yield-related factors such as berry size and cluster weight, as well as quality-related criteria such as fruit acidity and sugar content, flavor, and color.

The French-American hybrids were derived from crosses between the European grape, *V.vinifera*, and several American species, including *V. rupestris*, *V. lincecumii*, and *V. riparia*. The French-American hybrids were developed as a reaction to the damage caused by phylloxera and grape diseases transferred from North America to Europe in the 1800's. French hybridizers searched for North American species that co-existed with phylloxera,

Table 2. Primary germplasm for tolerance to major diseases.

CROWN GALL	V. labrusca, V. amurensis
PIERCE'S DISEASE	V. rotundifolia, V. simpsoni, V. shuttleworthii, V. rupestris
BOTRYTIS BUNCH ROT	V. vinifera, V. riparia, V. rupestris, V. rotundifolia
ANTHRACNOSE	V. labrusca, V. simpsoni, V. champini, V. lincecumii, V. rotundifolia
BLACK ROT	V. riparia, V. candicans, V. cinerea, V. rupestris, V. vulpina, V. rotundifolia, V. berlandieri
PHOMOPSIS	V. rotundifolia
DOWNY MILDEW	V. riparia, V. rupestris, V. lincecumii, V. labrusca, V. amurensis, V. candicans V. yenshanensis, V. berlandieri
POWDERY MILDEW	V. aestivalis, V. cinerea, V. riparia, V. berlandieri, V. rotundifolia, V. labrusca, V. rupestris

powdery mildew, and black rot. These species were then crossed with French *vinifera* varieties in efforts to obtain wine grapes which carried sufficient levels of genetic resistance to tolerate attacks of phylloxera and fungal diseases.

The New York Grape Breeding Program is currently focusing on the improvement of techniques to screen for powdery mildew resistance. Studies on genetic resistance have shown that there are several plant characteristics responsible for resistance: 1) Formation of papillae or hair-like projections in leaf surface cells; 2) Deposition of silica following infection; and 3) increased cuticle thickness on the leaf epidermis. The latter factor has the greatest degree of association with resistance to powdery mildew and accounts for the high level of susceptibility of young vs. mature leaves on the same shoot. Young grape leaves have a thin cuticle layer on the leaf surface. In one special case, the low level of susceptibility of the variety 'Concord' to powdery mildew is due to the inability of the fungus to penetrate beyond the epidermis, or surface layer, of the leaf. Since the mesophyll and palisade layers of photosynthesizing cells are rarely damaged, photosynthesis is just slightly affected. The New York program utilizes several species as sources for powdery mildew resistance. These include selections derived from *V. labrusca*, *riparia*, and *cinerea*.

Field studies to define the resistance of grape germplasm are hampered by the chemical control of the disease in most field situations and by the non-uniformity of infection in any given field. These factors make it difficult to determine if a variety is genetically resistant or has merely managed to "escape" field infection. As part of our efforts to define the resistance existing in grape populations, we have initiated a project sponsored by the USDA-ARS Germplasm Repository at Geneva. A key feature of this project is the direct inoculation of potted vines with fungal spores. This ensures that each vine is exposed to the pathogen, and leads to precise measurements of pathogen growth. Each variety tested is exposed separately to three isolates of powdery mildew which differ in rate of growth on previously tested varieties. The most resistant varieties in this initial test will be re-checked to verify the accuracy of the rating system. Data collected in this project will be entered into computer files on the Germplasm Resources Inventory Network (GRIN) and become available nationally.

Already, a wealth of disease resistant germplasm is available to the Geneva breeding program and has been used for the development of improved varieties. Over the past few years, pollen exchanges have permitted the use of improved hybrids from Freiburg and Geilweilerhof, Germany, and from Japan, in the New York breeding program (Table 3). In addition, the many grapevine

Table 3. Sources of germplasm to breed for disease resistance. (New York Grape Breeding Program)

READY TO USE (already selected for improved viticultural traits):

1. Black rot resistant hybrids from USDA, Beltsville, MD, Program no longer operative (J. McGrew)
2. Disease resistant hybrids from University of Illinois, Program no longer operative (H. Barrett)
3. Munson hybrids and other antique cultivars, a rich source of variation utilizing many native species
4. Some cultivars and selections - Products of breeders in Wisconsin (E. Swenson), Minnesota (J. Luby and P. Hemstad), South Dakota (R. Peterson, program no longer operative) and some French-American hybrids
5. New German selections from Freiburg and Geilweilerhof via pollen exchange

POTENTIAL INTEREST (long term solution):

1. Species and germplasm collection - USDA-ARS Germplasm Repository, Geneva
2. New varieties being developed abroad - Germany, France, Soviet Union
3. New collections of North American species

varieties and species that have been collected at Geneva over the past 100 years, as well as the new grapevine collections obtained by the USDA-ARS Germplasm Repository at Geneva, provide an excellent source of material for use as parents in the development of new disease resistant hybrids.

While there is a great deal of promise among the newest seedlings for types combining high levels of disease resistance with productivity and quality, it will take 10-15 years to determine which few perform best year after year. However, there are several older selections from the Geneva program which have shown promise in testing to date and merit further testing. Several of these are tolerant to one or more diseases: NY65.533.13, NY70.809.10, and NY 73.136.17 (Table 4). They have shown promise in testing to date but require further testing to define their tolerance to diseases and pests. Some of these selections are available for test purposes or will be available shortly from the NYS Fruit Testing Cooperative, Geneva, NY.

Among wine grapes common to the industry, several may already be suitable for situations requiring reduced input for disease control. Varieties such as 'Cayuga White', 'Melody', 'Marechal Foch' and 'Steuben' are all just slightly susceptible to several diseases especially when compared to 'Cabernet Sauvignon' (Table 5).

The development of hybrids with greater levels of resistance will become even more important in the future. Considerable effort is made to control pests through well timed spray programs of various fungicides. However, public concern over the use of pesticides may force restrictions on their future use. In addition, the loss of effective fungicides through the development of resistant strains of the fungus has already been documented with Benlate, and more recently, Bayleton. These developments cause us to recognize that continued use of pesticides cannot be assumed for the indefinite future. One important solution to this developing problem in viticulture is to increase the effort devoted to the development of varieties combining quality and productivity with high levels of pest resistance, obviating the need for chemical and other control measures. Through traditional hybridization and selection efforts, as well as advances in genetic engineering technology, we look forward to the development of varieties which will meet the future needs of the New York industry.

Table 4. Summary of best selections in New York State graoe variety trials – 1990.

Table grapes:

NY64.029.1 – white mid-season large berried seedless

NY65.482.1 – blue seedless, excellent texture and flavor

White wine grapes:

NY62.122.1 – hybrid with Muscat Ottonel, produces a top-ranked muscat wine. Grafting recommended to increase vine size.

NY65.467.1 – highly rated wine, with floral, citrus character. Growth and yield are excellent at Geneva, Fredonia and on Long Island.

NY 65.533.13 – Gewürztraminer hybrid, produces high quality wine. Vine is productive, and moderately resistant to powdery mildew.

Red wine grapes:

NY66.717.6 – wine ranked 1 out of 40 reds in 1990. Vine is moderately vigorous and productive at Fredonia.

NY70.809.10 – a vinous, *vinifera* type wine, Gamay-style. Vigorous and very productive at Geneva with good powdery mildew resistance.

NY73.136.17 – very productive, vigorous, moderately resistant to powdery mildew. Wine has black pepper character and good tannin levels.

Table 5. Disease susceptibility ratings of grape varieties – 1991.

Susceptible or Sensitive to:

Variety	BR	DM	PM	Bot	Phom	Eu	CG
Baco Noir	+++		++	+	+	++	+++
Cabernet Sauvignon	+++	+++	+++	+	+++	+++	+++
Canadice	+++	+	+	++	?	?	+
Cayuga White	+	++	+	+	+	+	?
Concord	+++	+	++	+	+++	+++	+
Elvira	+	++	++	+++	+	+	++
Ventura	++	++	+++	+	?	?	+
Foch	++	+	++	+	?	+++	?
Melody	+++	+	+	+	?	?	?
Steuben	++	+	+	+	?	?	?

reprinted from the "1991 Pest Management Recommendations for Grapes", Cornell University

+=slightly susceptible, ++=moderately susceptible, +++=highly susceptible
BR=black rot, DM=downy mildew, PM=powdery mildew, Bot=*Botrytis*,
Phom=*Phomopsis* cane and leaf spot, Eu=*Eutypa* dieback, CG=crown gall

BIOLOGICAL AND INTEGRATED CONTROL OF BUNCH ROT OF GRAPE

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Introduction

Biological control of plant pathogens is becoming an important component of plant disease management. Biological control potentially offers answers to many persistent problems in agriculture, including those concerning resource limitations, non-sustainable agricultural systems and over-reliance on chemicals.

Management of Botrytis bunch rot, incited by *Botrytis cinerea* Pers., has become complicated over the past few years due to the development of strains of the pathogen which are resistant to benzimidazole (e.g. Benlate) and/or dicarboximide (e.g. Rovral) fungicides in many grape growing areas worldwide (Gullino and Garibaldi, 1986; Lorenz, 1988). Moreover, as more chemicals are withdrawn from the market due to toxicological problems, and fewer new ones are developed, the need for alternative control strategies that may avoid exclusive use of chemicals is becoming more important.

Among the fungi which have been shown to control various plant pathogens, *Trichoderma* is one of the most investigated (Papavizas, 1985). Nevertheless, practical application of this antagonist is still very much limited. This is particularly true in the case of foliar pathogens (Elad, 1990).

Our work during the past few years has focused on control of Botrytis bunch rot using *Trichoderma*. The aim of the project is to select strains of the *Trichoderma* antagonist which can control bunch rot under practical conditions.

Results in Italy

Most strains of *Trichoderma* obtained by selection from nature offer partial and inconsistent disease control. Their efficacy, under practical conditions, ranges between 25 and 70%, with high variability among different trials (Bisiach, et al., 1985; Garibaldi, et al., 1989).

Selection of ultraviolet light-induced mutants of *Trichoderma* resistant to fungicides currently used against bunch rot and other grape pathogens permitted combined use of chemical and biological control measures (Gullino, et al., 1986). Strains resistant to benzimidazoles and dicarboximides, used in rotation with fungicides, permitted better control of grey mould than Trichoderma used alone (Tables 1 and 2). The cluster region of grapevines was sprayed with a mixture of 4–6 *Trichoderma* isolates, prepared as conidial suspensions (10^7 conidia/ml) in a 1% malt solution. The addition of malt should favor colonization of flower residues and berries by *Trichoderma*. Treatments were applied at bloom, end of bloom, berry touch, veraison, and 20–25 days before harvest. Fungicides were applied at normal rates.

The efficacy shown by *Trichoderma* when used alone in 4 or 5 applications was partial and variable in the different trials (Tables 1 and 2). *Trichoderma* performance is particularly poor in seasons with a severe disease, such as 1987 (Table 1). Under the best circumstances, control provided by *Trichoderma* is similar to that shown by conventional fungicides such as dichlofluanid (Euparen) and chlorothalonil (Bravo). Unfortunately, especially in the case of varieties very susceptible to bunch rot, such as 'Moscato', and during seasons with severe disease, partial control is inadequate. Alternating *Trichoderma* application with one chemical spray applied at veraison, improves control and reduces number of chemical sprays to just one.

Mechanism of action

The antagonistic activity of *Trichoderma* may be due to competition for nutrients, antibiotic production, or direct parasitic action, termed mycoparasitism (Chet,

Table 1. Effect of different treatments against bunch rot of grape, shown as the percent of infected berries relative to controls as 100%. The actual percent infection of control berries is given in parentheses.

		Percent Infected Berries (compared to Control)		
Treatment	Applied at:	'Barbera' 1986	'Moscato' 1986	'Moscato' 1987
Trichoderma IPV	End of bloom, berry touch, veraison, 20-25 days preharvest	83 c	52 b	75 ab
Trichoderma IPV [Plus one spray of Benomyl+vinclozolin (Ronilan)]	End of bloom, berry touch, 20-25 days preharvest. [Veraison]	18 a	33 a	not tested
Benomyl+vinclozolin	Berry touch, veraison	3 a	25 a	59 a
Benomyl+vinclozolin	Veraison	40 b	25 a	not tested
Control	--	100 c (11)	100 c (19)	100 b (38)

* Data within the same column followed by the same letter do not differ significantly, according to Duncan's Multiple Range Test (P = 0.05).

Table 2. Effect of different treatments against bunch rot of grape on cv. Moscato, shown as the percent of infected berries relative to controls as 100%. The actual percent infection of control berries is given in parentheses.

		Percent Infected Berries (compared to Control)			
Treatment	Applied at:	1988	1988	1989	1989
Trichoderma IPV	Bloom, end of bloom, berry touch, veraison, 20-25 days preharvest	35 a	25 a	72 bc	44 b
Trichoderma MTR	Bloom, end of bloom, berry touch, veraison, 20-25 days preharvest	35 a	35 a	67 bc	41 b
Trichoderma IPV [Plus one spray of procymidone+thiram]	Bloom, end of bloom, berry touch, 20-25 days preharvest. [Veraison]	not tested	21 a	32 a	20 a
Procymidone+thiram	Berry touch, veraison	8 a	5 a	18 a	19 a
Procymidone+thiram	Veraison	not tested	28 a	47 ab	22 a
Control	--	100 b (8)	100 b (13)	100 c (20)	100 c (28)

* Data within the same column followed by the same letter do not differ significantly, according to Duncan's Multiple Range Test (P = 0.05).

1987). In the case of grapevine, both competition and mycoparasitism have been demonstrated as occurring between *Trichoderma* and *Botrytis* (Dubos, 1987). Competition between *Trichoderma* and *Botrytis* occurs during bloom for colonization of floral debris. For this reason treatment with the antagonist at the end of bloom is important because prior colonization of flower parts by *Trichoderma* might prevent the saprophytic colonization of blossom debris by *B.cinerea*. Therefore, the application of *Trichoderma* at flowering may delay development of the first infections by *B.cinerea*.

The expression of competition and mycoparasitism in culture and under natural conditions between *Trichoderma* and *Botrytis* depends on temperature. The range of temperatures at which *Trichoderma* is active is narrow compared to *Botrytis*. Only a few of the tested *Trichoderma* strains exhibit good antagonistic activity below 59°F and above 82°F. Moreover, higher activity of *Trichoderma* was reported under moist conditions. Unfortunately, in many cases, *Trichoderma* is applied in vineyards during hot, dry weather (Gullino, et al., 1989). The choice of the isolate to be used in the field should, therefore, be oriented toward those better adapted to specific environmental conditions of the region and those able to compete with other local microorganisms on the surface of the fruit.

Considerations

It is obvious that a biological control agent will not persist and be active unless it is adapted to the plant environment. Moreover, to be successful in controlling foliar pathogens, it must compete with other microorganisms and establish an active population on the plant surface. This is one of the least understood aspects in the establishment of introduced microorganisms. This should be a primary consideration in the case of a typical soil inhabitant such as *Trichoderma*.

Unfortunately, in the case of *Botrytis* fruit rot control by*Trichoderma* research has been discontinued (e.g. France) because the results obtained were not considered good enough compared to those obtained with commonly used fungicides. However, development of resistant pathogen populations, increased awareness of the negative side-effects of fungicides on the ecosystem, and growing interest in pesticide-free agricultural products are now driving forces behind new investments in this area of research. Indeed, many chemical companies are also showing increasing interest in this field.

The performance of *Trichoderma* should not be expected to be like that of an excellent fungicide. A moderately effective, but consistent biocontrol agent might be sufficient, considering the general trend toward acceptance of fruit with some visual defects but free of chemicals. This is particularly applicable to wine grapes, while in the case of table grapes there is still a demand for a cosmetically perfect final product.

The successful use of *Trichoderma* as a biocontrol agent will be greatly enhanced if improved strains are developed. Biocontrol capability, as well as numerous other desirable or essential traits, is an attribute of specific strains, rather than of a particular species or genus, and is extremely variable among strains. For example, most currently available strains of *Trichoderma* are unable to grow at either high or low temperatures, only a few are able to compete with other microorganisms on the surface of the plant, and most control only a narrow range of plant pathogens.

Genetic recombination potentially is a much more powerful method for developing superior biocontrol strains than selection or mutagenesis (Papavizas, 1987). Strains expressing desirable attributes can be used as parents in crosses with other strains expressing other desirable traits. By so doing, progeny with a combination of traits could be developed. Protoplast fusion has been used as a tool to obtain new strains of *Trichoderma* active against soil-borne pathogens (Stasz, et al., 1988).

Future research priorities

Factors to be studied in future for commercialization of *Trichoderma* are fermentation and mass production technologies, as well as delivery and formulation of the product. When considering production and formulation, important features of the antagonist must be preserved, and even better performance of the formulated products, in terms of disease control and survival of the antagonist, should be a goal.

Some of the problems that *Trichoderma* (and we must remember that it is normally a soil inhabitant) encounters in a hostile environment, such as the leaf surface, may be overcome through appropriate formulations. Certain additives, such as nutrients, stickers, spreaders or carriers, can improve its performance (Gullino, et al., 1989). This fact must be taken into consideration during formulation of the antagonist.

The side effects and toxicology of *Trichoderma* must also be considered. Strains producing antibiotics or toxic metabolites are unacceptable and their use could represent a much higher risk than that posed by use of well known chemicals. In fact, among the isolates of *Trichoderma* selected in our laboratory, some have been discarded due to their toxicological risk. Initial screening for evaluation of potential toxicological risk is carried out by using *Artemia salina* as a test organism (Altomare, et al., 1990). The toxicological and ecotoxicological tests commonly required for the registration of fungicides, plus further studies on survival under different conditions, are required in Italy for registration of biocontrol agents. Registration of genetically modified organisms or strains is even more complicated.

The development of novel strains in future by means of biotechnology and molecular biology will probably supply more effective control agents. Such recombinant strains may have broader activity spectra, higher efficacy, and thus ability to survive under adverse environmental conditions. Regulatory concerns are likely to arise in response to products with some of the same disadvantages of today's fungicides (Elad, 1990).

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BIOLOGICAL CONTROL OF GRAPE POWDERY MILDEW

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Introduction

The fungus *Ampelomyces quisqualis* is a common parasite of powdery mildews in general, and in particular of the grape powdery mildew pathogen, *Uncinula necator*. A general term for fungi, such as *A. quisqualis*, that parasitize other fungi is mycoparasite. *A. quisqualis* is internal, grows within the hyphae of *Uncinula necator*, and forms a spindle-shaped pycnidium within conidiophores, hyphae and immature ascocarps of the powdery mildew pathogen. Within 10 day after infection, conidia of *A. quisqualis* are available for release. If the pycnidia are wet by rain, within a few minutes conidia are released in a cirrus and are then dispersed by splashing rain. Free water is required for infection of mildew colonies, and at temperatures between 10 and 25 C, infection takes place within 24 hours after inoculation.

Although a high proportion of mildew colonies are parasitized by *Ampelomyces* every year, this always occurs far too late in the year to hold powdery mildew at tolerable levels in commercial vineyards. There are four key processes in the concurrent development of grape powdery mildew and *A. quisqualis* in vineyards: at first, there is an increase in the incidence of foliar infection by *U. necator*; next, cleistothecia of *U. necator* begin to form as colonies of compatible mating types merge on the leaves; thirdly, the cleistothecia are dispersed in rain to the bark of the vine; and finally the senescing mildew colonies are infected by *Ampelomyces*. All in all, a very nicely evolved system in which *Uncinula* is allowed to colonize its host, reproduce, and then in turn serves as the host of the mycoparasite. Our objective in the present research project is to disrupt the timing in this system by introducing the mycoparasite in the early stages of a powdery mildew epidemic.

Selection of an isolate of *A. quisqualis* for vineyard trials

We isolated several strains of *Ampelomyces quisqualis* from infected mildew colonies on grape leaves. Based upon stability and sporulation in culture, and its pathogenicity towards a broad range of grape powdery mildew isolates, we selected an *Ampelomyces* isolate for vineyard trials that we named G273. Controlled inoculation of mildew colonies with G273 results in collapse of 90% or more of the colony with 48 hours, and pycnidia form in the parasitized areas within 10 days.

Deployment of the mycoparasite in vineyards

There are several considerations in trying to establish *Ampelomyces* in vineyards about three months before it is found naturally. You must be able to culture the mycoparasite in sufficient quantity for effective inoculations. You must have a means to deliver the mycoparasite to the mildew colonies. And finally, inoculations must be performed when conditions for infection by the mycoparasite are optimal. Raising an inoculum supply is quite easy with *Ampelomyces* because it produces sporulating pycnidia in 7-10 days on various agar media. However, delivering that inoculum in a vineyard and having it in a viable state when conditions are right for infection is more complicated. Of course, we could spray the vines with a conidial suspension just as we would a traditional fungicide, but this would have to be applied at the onset of rain or under sprinkler irrigation; neither of which is practical for commercial vineyards.

On the other hand, if we could establish pycnidia in the trellis, inoculation might be accomplished naturally by rain, under ideal conditions for infection of mildew colonies. We succeeded in growing *Ampelomyces* on cotton twine that had been soaked in diluted malt agar. Within 14 days after inoculation, pycnidia had formed on the surface of and within the twine. The twine was removed from the culture jars and dried in the greenhouse overnight.

Two-meter lengths of the twine were suspended in the trellis wire above Riesling grapevines when shoots were 6 inches in length only, at bloom only, or at 6 inches of shoot growth and again at bloom. The incidence of powdery mildew on fruit and foliage was assessed at weekly intervals and was compared to disease progress on control vines within the same vineyard. Release of conidia from the twine-cultures into rainwater was measured by funnel traps suspended beneath the trellis.

Large numbers of *Ampelomyces* conidia were released from twine-cultures in each rain event. We trapped from 250 to 4,500 conidia per square centimeter of funnel surface in each rain event. The actual numbers trapped were correlated with the amount and duration of rainfall in each event. *Ampelomyces* conidia were released from a single twine culture over a three month period in our vineyard trials.

All *Ampelomyces* treatments significantly reduced the number of mildewed leaves per shoot. The severity of infection on mildewed leaves was reduced below the level of the controls by single treatments at 6 inches of shoot growth and at bloom, but the greatest reduction occurred when twine cultures were installed in the trellis at 6 inches of shoot growth and again at bloom. Fruit infection was not reduced when treatment was delayed until bloom, nor did re-treatment at bloom provide additional suppression of fruit infection. Early establishment of the mycoparasite appeared to be the single most important factor in suppressing fruit infection.

Summary

To summarize the results of the study: we have selected an isolate of *Ampelomyces quisqualis* that is pathogenic towards many isolates of *Uncinula necator*. Secondly, we have demonstrated that establishment of the mycoparasite in the early phases of a powdery mildew epidemic results in a substantial reduction of disease. And finally, installation of the mycoparasite on a substrate over field plants can result in natural dispersal of inoculum in rainwater, and effective inoculation of the powdery mildew pathogen under ideal conditions for infection by the mycoparasite. The amount of disease that developed in treated vines was above what would be tolerated in commercial production of wine grapes. Therefore, in 1991 we plan to expand the vineyard trials to include grape cultivars with more resistance to powdery mildew, to determine the sensitivity of *Ampelomyces* to fungicides used in viticulture, and to investigate other substrates for the culture of *Ampelomyces*.

POTENTIAL FOR BIOLOGICAL CONTROL OF DISEASES OTHER THAN POWDERY MILDEW

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Botrytis bunch rot:

In cooperation with Dr. Gary Harman of the Department of Horticultural Sciences, we have begun studies using *Trichoderma* and other fungi for control of Botrytis bunch rot. During the 1990 season we applied spore suspensions of selected fungi in a spray at specific times in the growing season. In each application we included a Rovral spray as a comparison treatment. Treatments ranging from 1-5 applications were sprayed at 90% bloom, bunch closing, 5^{o} Brix, 10^{o} Brix, and 2 weeks before harvest. Most treatments, with the exception of the single sprays, provided significant control of bunch rot compared to the non-treated check (Table 1). The results are encouraging enough to continue the studies. In addition to screening isolates, future experiments will evaluate combination treatments and alternation of fungicide treatments with biocontrol treatments.

Downy mildew:

This past season we began searching for microorganisms that have potential for control of downy mildew. We collected leaves from the field that were infected with the downy mildew fungus and examined them in the laboratory. Fungi growing on the downy mildew colonies were isolated and grown on agar media. Preliminary tests in the laboratory indicate a couple of fungal isolates in particular have potential as eradicants. When water drops containing spores of these fungi were placed on 7-day-old colonies of downy mildew, they collapsed. If water was sprayed on the healthy downy mildew colonies, sporangia were dispersed over the leaf disc and new colonies began to grow across the surface of the leaf disc. However, if water containing spores of the biocontrol fungi was sprayed onto the leaf discs there was no secondary spread of the downy mildew fungus and the downy mildew colonies collapsed. These results are promising and further studies are planned, including studies to determine the potential for protection of healthy tissue.

Black rot:

There are no reports of biological control of black rot. However, Dr. Chris Becker is currently conducting studies on the potential for biocontrol of black rot. He has treated black rot mummies with various microorganisms to determine their effect on production of fruiting bodies of the black rot fungus. He will also be treating healthy foliage with microorganisms to see if they can protect the foliage from infection.

Eutypa dieback:

Studies in Australia in the early 1970s by Carter and Price indicated the fungus *Fusarium lateritium* had the ability to protect pruning wounds against infection by *Eutypa lata*. They applied high concentrations of *Fusarium* spores to fresh pruning cuts then challenge inoculated with *Eutypa* spores. This procedure protected the cut surface from subsequent infection by *Eutypa*. They also found that the combination of *Fusarium* and Benlate provided better control of *Eutypa* than either applied alone. This fungus was not developed for commercial use because the results were variable and costs involved in registration and production of the product were high.

Recently, a bacterium called *Bacillus subtilis* was reported by South Africans to protect grapevine pruning wounds from infection by *Eutypa*. The study indicated an antibiotic was produced by the bacterium that prevented germination of *Eutypa* ascospores. Further research is needed to determine if this bacterium has any commercial potential.

Phomopsis cane and leaf spot:

Scientists at Bordeaux, France in the 1970s showed *Trichoderma viride* (the same fungus that has been used

Table 1. Control of Botrytis Bunch Rot using traditional fungicides or fungi with biological control potential at Geneva, NY in 1990

Treatment	Application date[1] BL	BC	5B	10B	2W	Bunch Rot % clusters[2]	% cluster area[3]
Untreated						61.2 a[4]	8.1ab
Rovral 50W 1.75 lb/ac	X	X	X	X	X	2.3 g	<0.1 e
Rovral 50W 1.75 lb/ac		X	X	X	X	2.2 g	0.1 de
Rovral 50W 1.75 lb/ac			X	X	X	2.7 g	0.2 de
Rovral 50W 1.75 lb/ac				X	X	15.3 fg	1.8 cde
Rovral 50W 1.75 lb/ac					X	33.6 cde	4.4 bc
Tricoderma harzianum str.P1		X	X	X	X	14.5 fg	1.5 cde
T. harzianum str.P1			X	X	X	28.4 cdef	3.0 cde
T. harzianum str.P1				X	X	27.5 cdef	3.4 cde
T. harzianum str.P1					X	26.6 cdef	3.0 cde
T. harzianum str.1295-22	X	X	X	X	X	27.7 cdef	2.7 cde
T. harzianum str.1295-22		X	X	X	X	24.3 cdef	3.3 cde
T. harzianum str.1295-22			X	X	X	17.2 efg	1.8 cde
T. harzianum str.1295-22				X	X	18.2 efg	1.8 cde
T. harzianum str.1295-22					X	52.6 ab	10.1 a
Gliocladium virens str.31	X	X	X	X	X	34.0 cde	2.6 cde
G. virens str.31		X	X	X	X	20.5 def	2.8 cde
G. virens str.31			X	X	X	25.1 cdef	2.7 cde
G. virens str.31				X	X	40.2 bc	4.1 bcd
G. virens str.31					X	36.8 bcd	4.9 abc
minimum significant difference						17.2	4.1

1. Application dates: BL-90% bloom 6/20; BC-bunch closing 7/20; 5B-5° Brix 8/3; 10B-10° Brix 8/14; 2W- 2 weeks before harvest 8/24.
2. All clusters from 1- to 2-vine plots were rated for disease on 9/12/90.
3. Clusters were rated using the Barratt-Horsfall scale and converted to percent using Elanco conversion tables.
4. Treatment means followed by the same letters are not significantly different according to Waller-Duncan K-ratio t-test ($p \leq 0.05$).

to control *Botrytis*) had the ability to protect vines from infection by *Phomopsis*. They applied a very high concentration of spores of *T. viride* in a single spray to dormant buds prior to bud break and obtained 82% control compared to 94% control with two sprays of mancozeb applied when one and three leaves had unfolded, respectively. This biological treatment was not developed for commercial use because of difficulties in preparation and storage of viable *Trichoderma* inoculum and its high cost compared to traditional fungicides.

Summary:

So far there are no commercial products of biological control agents for control of grape diseases. Many show promise and we will continue to work in this area. However, you should realize that prior to the registration of a biocontrol organism it must go through the same stringent toxicological studies as would any synthetic fungicide. Many of these organisms produce very toxic metabolites and some are even human pathogens. Just because it is natural, doesn't make it safe!

SYMPOSIUM SUMMARY

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While this symposium has concentrated on integrated pest management of grape diseases, it is important to remember that integrated pest management, or IPM, involves more than just diseases. This is obvious if we look at the words which make up IPM. For the sake of clarity we will start with the word pest.

Pest – A pest is any living thing which has the ability to produce economic damage to the crop. When developing an IPM program for your vineyard you should consider all pests which need to be managed. For example, some of the pests found in a vineyard are weeds, insects, birds, mammals and diseases.

Management – This is probably the most important of the three words. You should be managing the pest populations in your vineyard. You will allow a small pest population to be present in the vineyard because it is not economically feasible to take the time or the money to try to completely eliminate it.

Integrated – The word integrated means just that. You take all the pest management options that are available to you and develop an IPM program for your vineyard. You can then apply each pest management practice at the correct stage of vine growth or pest development.

You have heard from researchers the results of studies on grape diseases which have been conducted in various areas of the United States and Italy. Several of the talks have centered on managing the same disease, with different types of "tools". With integrated pest management you have a wide variety of tools available to use. These "tools" include cultural practices (leaf removal for Botrytis bunch rot management), resistant varieties, natural enemies, and chemical control with approved pesticides, to name just a few. Oftentimes, two or more of these "tools" can be employed to better manage a pest. A good example of this is the management of Botrytis bunch rot. Removal of the leaves surrounding clusters will improve air circulation and help limit the period of time environmental conditions are suitable for infection of the berries. By removing the leaves, either by hand or with a machine, you have also provided an avenue for better fungicide distribution on the clusters.

The "take-home-message" of this summary is that you are the manager when it comes to making pest control decisions. Identify your pest problems, collect all the information you need about the "tools" available to you, and then integrate them to create an IPM strategy for your vineyard.

NELSON J. SHAULIS VITICULTURE SYMPOSIUM BANQUET ADDRESS

ALBANY PERSPECTIVES ON THE IPM PROGRAM

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I'd like to talk with you about what state government expects of the IPM program. The people of New York State have provided sustained support for the IPM program, based at Geneva, since 1986. Cumulative appropriations for this program totaled $3,530,000 over the five years since it was started. Funding in the current fiscal year, which ends this month, reached a peak of $1,080,000; and the Governor's budget proposal to the legislature for next year holds IPM at $900,000 — a reduction from this year of only 17%. This reflects an unusual commitment to the perceived value and importance of this program, considering the dire fiscal conditions facing the state, and the devastating budget cuts and layoffs levied against dozens of other programs supported by the state budget.

Why? The Governor, the legislature, and the Commissioner of Agriculture and Markets have long recognized the convergence of powerful and sustained public concern about the release of synthetic chemical pesticides to the environment; about the exposure of farmers and farm workers to the health hazards these chemicals represent; and about the safety of food containing residues of these toxic materials (be they ever so miniscule), with the established and long-standing dependence of growers upon these same synthetic materials for yield, quality and ultimately, their earnings.

As in other areas of our economic life where society has decided that the benefits of technology generate negative environmental and health effects that require some social control of their use, many of the signals suggest that public sentiment is calling for some change in the use of synthetic chemicals for pest control in agriculture. The difference here is that society recognizes that we are not dealing with large industrial firms like automobile makers, industrial chemical manufacturers, steel makers, or utilities, who have the capital and the ability to access or create technology to meet social demands for protecting public health and natural environmental systems from the effects of their production technology. IPM support for agriculture by government is really a societal offer of help to many small producers who cannot afford the capital investment to develop the new technology to respond to these social demands. This is not to say, parenthetically, that society expects no financial participation by agricultural producers in the effort to find better pest control technology.

How does this commitment to help New York's agricultural economy develop more acceptable pest control methods, while sustaining the yields and quality that are necessary to maintaining the economic viability of individual firms, translate into policy and operating goals for the IPM program? Since IPM work really consists of two distinctly different kinds of functions (1) research to develop new technology, and (2) processes for transferring that technology to growers and getting them to adopt it — it's convenient to discuss public expectations for each separately.

Let me talk about the research effort first. I believe the public expectation of the IPM program is that it will ultimately produce a set of technologies, systems, products, and strategies that will enable growers to move completely away from dependence on synthetic chemicals for pest control. This goal may sound implausible and impracticable to many of you, given where agriculture is today in pest control technology. But most of you know, also, that the knowledge, creativity, and capability, together with versatile new tools like recombinant DNA technology, are available to our research community to pursue such a goal with reasonable expectations that it can be achieved, albeit over a fairly long term and at considerable expense.

I do not mean to understate the importance of the significant advances in first-stage IPM technology that have been achieved by the program up to now. Nearly 300 projects have been funded since the inception of the program in 1986, and more than one-third of these have been implemented at the farm level. A number of these have addressed pest control problems in the grape area, including five that were funded initially in 1990. In addition, the 1990 contract provided support for a full-time grape entomologist (Tim Weigle) to conduct intensive effort to encourage IPM adoption by western New York grape growers.

Without denying the important contributions that first-stage IPM research results have made to reduced chemical releases by growers in the state, it is apparent to both Albany and Cornell that we must give greater emphasis to research that will produce non-chemical technologies and strategies for controlling the many pests that threaten significant impairment of New York's fruit, vegetable, field, and ornamental horticultural crops. All of the increased level of support for IPM by the state in the 1990-1991 appropriation was committed to bio-based research and technology transfer, about 1/3 of the current year's $1,000,000 financing of the entire program is devoted to non-chemical research and implementation.

To merely assert that the ultimate goal of the IPM program is to shift grower dependency away from synthetic chemicals for pest control, and to allocate more of our budget to develop non-chemical technologies and strategies, and to stop there, oversimplifies the challenge that lies before us in assuring that this effort meets grower needs on all fronts as those needs arise. Certainly research needs to continue, selectively, on least-chemical methods of pest control while we are awaiting the relatively longer periods it will take to produce effective bio-based controls for some pests. This means we must manage IPM research on at least two tracks.

There are a number of other very important considerations that should shape the composition of our research effort. They further complicate the management oversight, priority-setting, and operational direction of the IPM research program from year to year. They include, but are not limited to:

1. Anticipating the probable loss of pesticides critical to New York growers that may not be re-registered under the FIFRA '88 registration schedule. New York's pesticide-dependent agricultural economy is dominated by the minor crops. Given the high cost of re-registration and the relatively low level of sales for minor crop pesticides, many manufacturers may decide that it's not worthwhile to try to keep these products in the market. The IPM research program should be designed in part to time new research initiatives that will make alternative pest control techniques available to growers as minor crop pesticides disappear from the market within the next seven years.

2. Loss of pesticide availability caused by new EPA policies aimed at ground and surface water protection. When EPA issues its new pesticide policies designed to protect water quality, many pesticides with active ingredients that have significant toxic and leaching characteristics will be restricted or banned for use in watersheds or within the catchment zone of aquifers and wellheads where soil, slope, and other conditions tend to facilitate incorporation of these chemicals easily into the water body. IPM research needs to anticipate these restrictions and to develop strategies that will make alternative pest control methods available to growers in regions of the state that will be affected by restrictive pesticide water quality protection regulation.

3. Developing alternatives to those chemicals that are released in large quantities to the state's environment. One of the shortest routes to reducing total pesticide releases to the state's environment is to offer growers alternatives (either least chemical or bio-based) to those 10 or 15 pesticides which make up the largest proportion of the total released each year. This should be another set of priorities for the IPM research effort. Of course, this entails a periodic assessment of total pesticide use in the state, which is not done now.

4. Loss of probable carcinogens. Another predictable outcome of FIFRA '88 re-registration is the loss to growers of suspected or probable carcinogens for which EPA will have to refuse re-registration because of the impossibility of setting 0 residue tolerances for food crops as required by the Delaney Clause of the Food, Drug and Cosmetic Act. There is a long list of

more than 50 pesticides upon which many growers still depend for the control of a number of important pests. The IPM program should anticipate these losses and initiate research to try to produce substitute controls that will be available to growers as they are required.

These are a few of the important variables that need to be taken into consideration in deciding IPM research priorities from year to year while we simultaneously pursue the longer-term goal of developing bio-based technology and non-chemical systems for controlling pests.

In his 1991 State of the State message, the Governor asked for a long-range plan that will guide development and implementation of a statewide pest management strategy. We have been engaged in discussions with Jim Tette, Jim Hunter, the Dean, and his support staff about this plan and work has already started. Jim Tette is driving this initiative, and he will need a great deal of help in developing the information, analyses, and judgments that will be necessary to formulate such a strategy. We are expecting completion of this effort by the end of 1991.

One of the important changes in management of the IPM program that we have been discussing with Cornell is the formation of a Grower Advisory Committee, or several committees, to obtain grower judgment and advice both about research priorities, and for improving the policies and processes that influence the delivery to and adoption of research results by growers. I predict you will see this concept translated to action in the near future.

Let me mention another aspect of the IPM program that concerns us and that we believe should be taken into account in strengthening the program in the future. We are concerned that both the research and delivery components of the IPM program as it is now structured lack an economic dimension. This deficiency should be remedied.

Specific options for biological, chemical, and cultural technologies and methods of pest control generated as one component of the IPM research agenda are incomplete unless they are each accompanied by an explicit assessment of the benefits, costs, and risks attending their adoption by growers.

While I recognize that the economic aspects of alternative pest control methods are more relevant to a grower's decision to adopt a particular method than to the development of the pest control technology <u>per se</u>, economic information is critical to the ultimate transfer of research results to commercial use, and it must therefore be an integral part of the research effort.

Growers will be reluctant to try new methods of pest control, and to abandon proven methods, unless they have some clear sense of how recommended new control methods will affect their business condition.

The second part of the IPM program is to deliver the results of research to growers in ways that they understand how to use it, and to get them to adopt it.

The objective of this part of the program is, simply stated, to devise and execute a system that persuades growers to embrace the IPM research product. In the abstract, it's just technology transfer, but the public benefits associated with the adoptions of least-chemical or no-chemical methods of agricultural pest control require an aggressive program to induce growers to adopt them as quickly as they are proven effective. The marketplace has developed sophisticated processes for persuading producers and consumers alike to accept new technologies and products. We need to borrow from these marketplace experiences to improve the rate of growers acceptance of IPM research over what it has been up to now.

Reliance on farm demonstration methods and on private sector scouting services to effect IPM technology transfer has been the chief strategy of the IPM program up to now. After five years of effort, IPM has reached less than 5% of the farmland area of the state. We need to explore additional methods to accelerate grower acceptance.

Even if we succeed in developing a broad array of non-chemical and least-toxic pest control techniques and technologies, grower adoption of IPM practice will depend on their ability to control pests at a reasonable cost. Recommended IPM strategies must be economically competitive with prevailing chemical practices in terms of the cost of their use and the relative ease of application.

Up to now researchers have proven their capacity to successfully develop bio-based and least-chemical alternatives to chemical pesticides. Clearly, Tim Dennehy's grape berry moth pheromone tie is an example of what can be achieved.

However, the development costs of bio-based strategies can be prohibitive. While an environmentally minded public may desire bio-based controls that demonstrate species specificity, it is this very attribute that constrains its marketability. This characteristic (species specificity) may not be as attractive to growers accustomed to the use of broad-spectrum pesticides, which may incidentally control minor pest species in addition to the targeted pest.

The IPM program must identify incentives to sustain bio-based research. In 1990, approximately 26 bio-based projects were funded through a special allocation within the IPM appropriation. Equally important, we need to encourage and accelerate grower adoption of bio-based strategies as contrasted with least-chemical methods of control.

We will initiate discussions with representatives of the agricultural community to investigate and identify incentives to induce growers to adopt the more costly results of bio-based research.

These are some of the ingredients of the new dimensions in the publicly supported IPM program that will emerge in the coming months. I hope you will support them and join in their development.

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