An Abstract of the Thesis of

Tyrone W. Hall for the degree of Master of Science in Botany and Plant Pathology presented on February 07, 2000. Title: Epidemiology of Grape Powdery Mildew, *Uncinula necator*, in the Willamette Valley.

Abstract approved: _____

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An important disease of *Vitis vinifera* production in Oregon and all other commercial growing regions is powdery mildew of grape, caused by the obligate fungal pathogen *Uncinula necator* (Schwein.) Burril. Grape production can be characterized as a long-term investment in the establishment and maintenance of the vineyard. Establishment times have been reduced with the use of plastic vine shelters, but powdery mildew disease pressure within vine shelters had been an unaddressed issue. Control of the pathogen requires frequent spray applications and costly cultural management of the grape canopy. Industry interest in forecasting programs have shown promise in regulating spray applications to times when they are most effective, or needed. The timing of when to begin spray programs is believed to be a point of weakness in the forecasting programs currently available for grape powdery mildew.

The influence of vine shelter use on the development of powdery mildew was investigated in the field during the 1998 and 1999 growing season. Industry standard installations of various brands of vine shelters were tested against modified installations for both incidence and severity of *Uncinula necator* infection. The industry standard

installation of 76 cm high tubes hilled with 8 cm of soil at the bottom to prevent airflow, were effective in reducing the incidence of powdery mildew in both field seasons. Disease reduction was associated with prolonged temperatures above 36° C and the exclusion of infective spores by the artificial barrier created by the vine shelters.

The effectiveness of three forecasting programs for predicting the initial spray application was investigated for three seasons. Actual disease onset dates were determined by using trap leaves or plants. The forecasting programs consistently predicted initial spray dates between 31 and 44 days prior to the detection of powdery mildew with the trapping system. Modifications to the existing forecasting programs were attempted to adjust the forecasting programs to more closely predict the actual detected disease onset dates. The UC – Davis program performed the best over the three years of the study, but improvements will be necessary for an adequate forecasting program in the region. Flag shoots were reported for the first time in Oregon.

Epidemiology of Grape Powdery Mildew, *Uncinula necator,* in the Willamette Valley.

by

Tyrone W. Hall

A Thesis
Submitted to
Oregon State University

in partial fulfillment of
the requirements for the
degree of

Master of Science

Completed February 07, 2000
Commencement June 2000

Master of Science thesis of Tyrone W. Hall presented on February 07, 2000

Approved:

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Epidemiology of Grape Powdery Mildew, *Uncinula necator*, in the Willamette Valley.

1. Introduction

The grape industry of Oregon is a thriving and expanding industry, which is gaining market acceptance throughout regional and global economies. The region is characterized as a cool climate region producing high quality cool climate *Vitis vinifera* wines (52). Oregon is ranked fourth in the nation for wine grape production based on total crop harvested in 1996 (1). In 1998, wine grape production for Oregon totaled 14,700 tons of product harvested from 7,100 acres (3). New vineyard plantings in Oregon have steadily increased with 507 and 1,152 acres planted in 1997 and 1998, respectively (2,3).

Powdery mildew is an important disease of grape production in Oregon and all other commercial growing regions. Powdery mildew of grape caused by the obligate fungal pathogen *Uncinula necator* (Schwein.) Burril. (5). Control of *U. necator* is critical since as little as 3.0 % infection of fruit clusters has been shown to produce wine with a detectable off-flavor (50,59). Initial infections of powdery mildew are usually detected between bud break and fruit set on young green tissue (35,53) appearing as discreet superficial gray-white (hyaline) spider-web like colonies.

The grape industry has expressed interest for improvements in the management of powdery mildew in Oregon. Improvements are required in the timing and efficacy of both chemical and cultural control measures. Both the cultural control and improved timing of the initial fungicide application have been investigated in the following research. A cultural practice gaining acceptance in vineyard establishment has been the

use of plastic vine shelters in the first and second years of establishment. The influence of vine shelter use on powdery mildew pressure was investigated to determine whether the disease is exacerbated, or suppressed, by this cultural practice. A method for detecting the period of disease onset was combined with the monitoring of disease and environmental parameters to evaluate the effectiveness of three forecasting programs. This research will also be used to build the foundation of a powdery mildew forecasting program for Oregon grape growing regions.

2. Epidemiology and Forecasting of Powdery Mildew of Grape

2.1 Introduction

All members of Vitaceae are susceptible to the fungal obligate parasite, *Uncinula necator* (Schwein.) Burril, in varying degrees including *Ampelopsis*, *Parthenocissus*, and *Vitis* (24). *U. necator* infections consist of superficial hyaline spider web-like mycelia that turn white with age. Conidia, produced in chains on distinct conidiophores, form abundantly from the mycelia. Visible symptoms include oily looking chlorotic lesions and mottled patterns on infected tissues. Symptoms are not used for detection due to their inconsistent appearance. *U. necator* infects epidermal tissue throughout the growing season (53), but plant tissues become less susceptible with age (17). Berries have been reported as being susceptible to *U. necator* infection at less than 4-5% Brix and colony development on previously infected berries ceases at 8-10% Brix (26). Initial infections of powdery mildew can usually be detected between bud break and fruit set on young green tissue (35,53).

U. necator infections have been shown to reduce vine photosynthetic efficiency (43), short and long-term yield (59), and winter hardiness (5,59). Berry infections of 3% or greater have been associated with reduced wine quality (50,59). Infections of *U. necator* on immature fruit have also been associated with the cracking of berries, which become unmarketable and increase the occurrence of Botrytis Bunch Rot, caused by *Botrytis cinerea* Pers. (35,54). Although there are no figures on the economic impact of *U. necator* on grape production, crop loss can be complete without proper control

measures. Control nearly always involves frequent applications of fungicides applied at regular intervals.

2.2 Control

Elemental sulfur is the primary fungicidal material used in the control of *U. necator* (5). Sulfur applications are effective for 7-14 days depending on temperature and rainfall (65) and are relatively inexpensive, effective, and easy to apply. Factors limiting the utility of sulfur include short application intervals, and phytotoxicity when applied during temperatures in excess of 35° C. Adequate coverage is also important in sulfur application due to the non-systemic nature of the fungicide. The efficacy of sulfur is attributed to its vapor phase, but its mode of action is essentially unknown. Temperatures supporting the vapor phase of sulfur are between 18 and 30° C with optimum efficacy at higher temperatures (5).

Other chemical fungicides are used to control *U. necator* including benomyl, sterol demethylation-inhibiting (DMI) fungicides, and strobilurins (56). These compounds potentially allow for longer spray intervals and do not have the temperature restrictions of sulfur. Resistance has been documented for benomyl in New York (58) and DMI fungicides in California (37,85) and New York (79). Resistance to triadimenol, a DMI, was found to result from a single point mutation in the *U. necator* 14α-demethylase gene (15). Populations resistant to triadimenol were shown to overwinter and remain resistant in subsequent seasons, allowing the rapid build up of resistant populations in regions with optimal conditions for *U. necator* (37,84). As a result, these

chemical fungicides are typically used in rotation with sulfur and other chemicals with different modes of action.

Mineral oils and glyceridic plant oils have been shown to also effectively control disease development (48). Application of lime sulfur to dormant grapevines has been shown to delay the development of powdery mildew epidemics (31). Research into chemical products used in controlling *U. necator* epidemics has been extensive, resulting in new chemical fungicide products on a regular basis. Alternatives to chemical controls have been less forthcoming, but warrant further investigation.

Cultural and biological control have seen limited application, due to the low tolerance for disease on the fruit. Leaf removal has been shown to reduce the severity of powdery mildew on clusters by 54.4 – 72.5% during a two-year investigation in California (10). Interestingly, a significant interaction between leaf removal and fungicide application was not observed, indicating that the effect of leaf removal could be independent of improved fungicide coverage. Trellising systems that increase airflow, position shoots, and support thin canopies are also used to improve the microclimate of the canopy and improve fungicide coverage (5,62).

The most promising biological control agent is the commercially available mycoparasite, *Ampelomyces quisqualis,* (AQ-10, Ecogen, Inc.). *A. quisqualis* was shown to reduce the amount of overwintering cleistothecia of *U. necator* by 50 - 60%, when applied throughout the growing season (22). Also, no *U. necator* isolates were found to be resistant to *A. quisqualis* parasitism (23). Whether the reduction in powdery mildew initial inoculum is effective in delaying the epidemic in subsequent seasons is questionable due to the polycyclic nature of *U. necator*. Another biological control agent

is the mycophagous mite, *Orthotydeus lambi* (Baker). A 42% reduction in powdery mildew infected leaf area and 64% fewer cleistothecia were detected in plots where large populations of *O. lambi* were released (20). Sole reliance of biological control agents or cultural controls would not be sufficient to control powdery mildew epidemics, but they can be used to supplement traditional control programs.

The variety and number of tools to control powdery mildew of grape potentially allows for effective control of the disease in most situations. Proper selection and timing of control measures are the most critical factors in adequately controlling *U. necator* infections. Epidemiological parameters influencing the initiation and growth rate of *U. necator* are of primary concern in estimating proper timing of fungicide applications.

2.3 Epidemiology of *Uncinula necator*

Epidemiological studies of *U. necator* have focused on mechanisms of overwintering and conidial spread during the growing season. While the existence of *U. necator* was documented as early as 1834, there are still gaps in our understanding of processes that facilitate overwintering of the pathogen and subsequent spread through asexual propagation. *U. necator* is an obligate parasite that becomes quiescent during grape dormancy by two known mechanisms of overwintering. The fungus can form resistant sexually produced cleistothecia, or survive as vegetative hyphae in the prophylls of grape buds. Both overwintering forms of *U. necator* have different requirements for formation, and the epidemiological significance of each form depends on the environmental conditions in the region of grape cultivation. Once initial infection has

occurred, disease progress during the growing season is thought to be primarily due to vegetative proliferation and asexual propagation.

2.3.1 Cleistothecial Overwintering

The formation of cleistothecia was described along with the discovery of *U. necator* by Schweinitz in 1834 (as reviewed by(66)), but their relative importance in all growing regions has been a point of debate. Early speculation inferred that cleistothecia had relatively little importance in powdery mildew epidemics until 1985 when cleistothecia were determined to be the primary source of initial inoculum in New York vineyards (55). Cleistothecia have subsequently been reported to contribute to initial inoculum in California (73), Washington (33), Austria (74), Italy (12), Australia (Magarey, in print), Germany (67), and are believed to be the primary source of initial inoculum in Oregon. Determining the role of cleistothecia has stimulated an increase in research efforts focused on the biological and epidemiological parameters of cleistothecial supported proliferation.

2.3.1.1 Development

U. necator is a heterothallic fungus requiring at least two different mating types for sexual recombination and cleistothecial formation (21,30,71). Cleistothecial formation begins when hyphal contact is made between two different mating types (27,71). The precise mechanism of recognition between mating types is not known for *U. necator*. Touching cells proceed through plasmogamy after recognition, and a single

hyaline cleistothecial initial forms directly from the united cells. Lipid bodies (unidentified composition) accumulate within cleistothecia, giving them a yellow appearance as they develop (27). Anchorage hyphae develop from epidermal cells of the cleistocarp and become intertwined with vegetative hyphae of the surrounding colonies (27). Asci formation occurs during lipid body accumulation and continues while the cleistocarp undergoes melanization. Four to six subglobose to ovate asci measuring 50-60 X 25-40 μm can be contained within a single cleistothecium (41). Four to seven hyaline globose to ovate ascospores measuring 23-28 X 14-16 μm are fully developed by the time the cleistocarp has become fully melanized. Multiseptate, uncinate (hook shaped) appendages one to six times as long as a mature cleistothecium form during the melanization of the cleistocarp. These appendages are directed away from parent colonies and the leaf surface (41). A basal concavity forms upon cleistothecium maturation (27). When mature, the cleistothecium is dark brown to black in appearance, spherical, and 84-105 μm in diameter (27,56). Parent and anchorage hyphae necrose, releasing the cleistothecium from the parent colony upon maturation (27).

The number of cleistothecia that can form in a given population of isolates is dependent upon the number of hyphal contacts between opposing mating types, which is regulated by the growth rate of hyphal elongation (27). Development of cleistothecia after initiation was determined to take 500 to 650 degree-days (base = 0°C) for complete maturation using inoculated plants in a controlled environment (27).

2.3.1.2 Dispersal

Cleistothecial dispersal has been correlated with rain events by the use of collection funnels placed under the canopy (12,27). Dispersal from wind events has been reported in Washington State by the use of coated glass slides placed around the vineyard perimeter (Grove, unpublished). Dispersed cleistothecia have been detected on dormant cane wood, rachis left on canes, leaf litter, trunk and cordon bark, and the vineyard floor, but only cleistothecia isolated from trunks and cordons were found to remain viable after overwintering in New York vineyards (27). Since this discovery, viable cleistothecia have also been detected on grape bark in Europe (12), California (34), and Washington (33). The hooked appendages of *U. necator* secure tightly to grape bark and a single appendage has been reported to suspend up to three grams of grape bark (27). Viability of cleistothecia during the dormant season could be affected by temperature and moisture conditions. Field collected cleistothecia stored at -5°C and -20°C for 14 days displayed dehiscence (rupturing event releasing ascospores) of 20.5% and 10.8% respectively, while dehiscence decreased to zero after six months (16). Viability of ascospores decreases to around 1.0 % during the dormant season (33). Unfortunately, no studies have been comprehensive enough to form any conclusions about the effect of other environmental conditions during overwintering on cleistothecia viability.

2.3.1.3 Dehiscence

Understanding the conditions associated with ascospore release is an important parameter in determining when infection periods are most likely to begin. Ascospores

have been reported to release typically during a six-week period in early spring that corresponds to the availability of susceptible tissue and to rainfall in excess of 2.5 mm with temperatures above 4°C (55). Cleistothecial dehiscence appears to be associated with ascocarp degradation during overwintering and a decrease in water potential resulting in increased internal pressure (28). Also, increased dehiscence has been associated with cyclical wetting and drying causing a weakening of the cleistothecia (28,39). A lack of moisture during storage also was found to inhibit dehiscence (16). Dehiscence was found to increase as temperature increased from 4°C to 32°C during the first four hours of wetting (28). It is unknown if conditions for dehiscence vary in different regions of grape production. All studies have been conducted with field collected cleistothecia in New York and France, with no correlation made to environmental conditions during the time of formation. The lack in knowledge of the relationship between environmental condition and dehiscence has made accurate initial disease forecasting difficult.

2.3.1.4 Germination and Infection

Cleistothecial dehiscence results in the release of ascospores. Ascospores germinate within 12 hours, which includes germ tube and appressorium formation on susceptible tissue (55), at an optimal germination temperature of 20°C (29). Free moisture or 100% relative humidity increases the likelihood of ascospore germination and formation of appressoria (29). Infection and pathogenesis beyond appressorium formation is thought to be similar to conidial infection and pathogenesis, with the formation of branched hyphae, lobate haustoria, conidiophores, and conidia produced in

chains. Infection of susceptible tissue occurs between 10 - 25°C (29). Optimum infection has been documented between 20 - 25°C with 89 to 94% of viable ascospores resulting in infections (29).

2.3.2 Bud Perennation: Overwintering and Initial Inoculum

Infection of *Vitis* spp. has been observed to occur in the past without the presence of overwintering cleistothecia in Europe (5,32,57,64), Australia(77), and South Africa (76). This mode of infection was hypothesized to be due to overwintering mycelia within dormant buds as early as 1969, but fungal hyphae within the buds were not detected at that time (72). Later investigations isolated surface disinfested dormant vines in growth chambers to limit other sources of infection. Infections on emerging shoots, termed flag shoots, were detected, thus further strengthening evidence for bud infection (perennation) as a source of initial inoculum (76). The presence of *U. necator* on the adaxial surfaces of prophylls (bud scales) was finally observed using a scanning electron microscope (57). This initial observation was based on morphological traits implying some doubt to the positive identification of *U. necator* as the bud inhabitant. Verification was later achieved with the use of a polyclonal immunofluorescent antibody derived from conidial cell walls of *U. necator*. This staining procedure was successful in differentiating *U. necator* mycelia from mycelia of other common molds including *Botrytis, Penicillium*, and *Alternaria* (32).

Infected buds have been observed to break dormancy later than non-infected buds, and occur primarily between the third and fifth buds of second year cane wood (57,64). The location of infected buds has been hypothesized to be the result of infection during

bud formation. Infection of buds can not occur after buds have formed suberized prophylls. Pearson and Gartel (57) hypothesized that early conidial stem infection, as a result of spore release from flag shoots, occurs after the first and second buds have become immune to infection. However, data to support this hypothesis has not been presented due to unsuccessful attempts to initiate bud perennation in the laboratory.

Despite the potential epidemiological significance of bud perennation in initiating a powdery mildew epidemic, our understanding is limited due to difficulty in obtaining infected buds from the field, inability to culture infections under controlled conditions, and the presence of cleistothecia in all reported growing regions. Presently, all investigations have related the source of epidemic onset to the timing of infection in the field, requiring intensive field evaluation to detect the presence of flag shoots and cleistothecia production (4,55). Epidemiological principles involving the dynamics of *U. necator* dispersal and overwintering in dormant buds could be reasonably determined if cleistothecial formation could be isolated from the research vineyard through exclusion of wild *U. necator* populations. Geographic, or field plot, isolation could be utilized for wild population exclusion, but the techniques would require a long startup time with a high risk of contamination from conidial spread.

2.3.3 Conidial Germination, Infection, and Growth

Conidia are produced by *U. necator* colonies resulting from ascospore infection or from overwintering mycelia on bud scales of grape. Formation of conidia is an asexual reproductive event occurring in all known isolates of *U. necator.* Conidial production and subsequent spread are of primary concern in controlling the fungus. Epidemiological parameters of conidia include germination, infection, colony development, and conidial spread.

2.3.3.1 Germination

Disseminated conidia land and proceed to germinate by the formation of a single germ tube and appressorium similar to that of ascospores. Germination begins within 1.5 hours and is complete by 12 hours at 24 - 25°C (14,17). Appressorium formation is a thigmotropic response initiated when the germ tube touches a surface, and its formation is complete within 4 hours of initiation under optimum environmental conditions (14). The percentage of conidia germinating and the time required for germination was found to be influenced primarily by temperature in studies conducted on leaf surfaces in growth chambers. Only 9, 6, and 3% germination was detected for conidia tested at 15, 12, and 6°C respectively, and no germination was detected above 34°C (14). Exposure to temperatures between 35 - 36°C and 40°C resulted in thermal inhibition of germination and conidial death within 10 and 4 hours respectively (14). Another temperature related condition is the effect of ultraviolet B (UV B) irradiation on germination. UV B inhibits germination of conidia in controlled laboratory conditions, but the inhibition of germination in the field was related to higher temperatures associated with direct UV B irradiation (sunlight) (82). *U. necator* is considered to be a dry land tolerant, or

xenophytic, fungus due to its low requirements for free moisture, although free moisture is believed to be required for initial release and infection of its ascospores (29,83). The influence of humidity at the leaf surface has been shown to be negligible in growth chamber studies (14), but humidity measurements at the level of conidial spore height and the leaf surface have not been measured. Transpiration at the leaf surface could provide low levels of adequate humidity for efficient germination during times of low relative humidity and high temperatures in the field. Even though humidity has a limited association with germination, free moisture has been shown to reduce spore germination by 31.3% when conidia were suspended above a water surface and 39.2% when conidia were submerged (70). Germ tube deformation and stunting have also been associated with free moisture contact (14).

2.3.3.2 Infection

Primary infection is through the protrusion of an infection peg at the interface between the appressorium and leaf surface. The infection peg penetrates the epidermal cell wall but not the plasma membrane. A lobate haustorium, believed to be similar to the haustoria of ascospores, forms within the host cell. Infected cells provide the only source of nutrients and anchorage for the fungus (5). Conditions required for infection are typically not different from those required for germination except for a slight change in optimum temperature. Optimum infection temperature was found to be 27°C, and infection could occur between 7 and 32°C (14).

2.3.3.3 Colony and Conidia Development

Single thin hyaline filamentous hyphae grow from the infective conidia shortly after appressorium and haustorium formation. All subsequent hyphae are 4 - 5μm in diameter, slightly septate, and thin walled (5). Hyphae branch profusely at right angles and grow prostrate to the hosts' epidermis. The resulting mycelial network produces additional infection sites. Conidiophores, 10 - 400μm long, develop from hyphal cells as prostrate flexuous filaments with a swollen distal end. Conidia are produced from septations of the distal end of the conidiophores. Conidia swell, become highly vacuolated, and are cylindro-ovoid in shape measuring 28 - 40μm x 14 - 16μm (5). Sporulation rates were found to be highest at optimum temperatures for colony growth (see below)(8).

Optimum temperature for growth, determined by calculating the number of days from inoculation to sporulation, was 26°C with sporulation in five days (14). Temperature was also reported to influence the effect of free moisture on conidiation of *U. necator*. Water application to colonies grown at 19 and 30°C resulted in significant reductions in sporulation when compared to similar applications to colonies grown at 22 and 26°C (9). Conidia produced at slightly different temperatures have slightly different temperature ranges for germination and optimum growth (25). For example, conidia produced at 31°C day and 21°C night conditions had an optimum germination temperature of 26°C, while conidia produced at 24°C day and 18°C night conditions had a lower optimum germination temperature of 22°C. The ability of *U. necator* to adapt to regional environmental conditions could impact the development and implementation of predictive models, thus reducing their utility across regions.

2.3.3.4 Conidial Dissemination

Conidia are generally believed to be distributed by wind, but recent studies have included rain tap and spray applications as being substantial promoters of conidial distribution (80,81). Release has been shown to be diurnal with higher release during daytime hours (51,81). Long distance dispersal has not been documented. Dispersal within a field, or between neighboring fields, is believed to contribute to a high infection potential, making adequate control during the season very important. Forecasting programs (42,46,49,65,65,75) and growth models (11,63) have improved the timing of control applications and shown promise as useful tools in controlling *U. necator.*

2.4 Trends in modeling and forecasting

With the consequences of improper or ineffective powdery mildew control being so extreme, growers have been reluctant to stray from tried and tested spray schedules. These schedules are usually based on phenological stages of grape growth and are adequate in most growing years. A typical spray schedule would begin at, or shortly after, bud break and continue at regular intervals through veraison (7). Advances in knowledge of the effects of environmental conditions on the development of *U. necator* have lead to an understanding of the conditions that promote or inhibit the growth of the organism. The use of fungicides can be tailored to the conditions governing effectiveness and development of powdery mildew epidemics. Conditions favorable for disease development require more frequent applications of control treatments, while unfavorable

conditions require less frequent applications for adequate control. This knowledge has lead to the creation of disease growth and control application forecasting programs. Interest in the development of forecasting systems has increased due to public concern about the overuse of chemicals in agriculture, increased regulatory restrictions on chemical use, and cost of control applications.

2.4.1 Growth Models

An early attempt to model *U. necator* growth was based on the influence of temperature discovered by Delp (1954) (14), and subsequent growth chamber experiments (63). The growth model included regressions for conidial germination and infection, colony expansion, and growth of susceptible plant material. The presence of free moisture was assumed to reduce conidia germination by 60%. The result of the model was presented as percent colonization of fruit and leaf surfaces, and the model was run repeatedly for different spring and summer conditions. Warm spring conditions resulted in the greatest amount of infection, which was validated in 1978 when early spring temperatures were ~2.2°C above normal and disease levels were high. The model also predicted that a delay in initial infection resulted in a decrease in overall infections. Another growth model of *U. necator* was later developed that included the influence of sporulation rates in relation to colony age and free moisture (11). This model yielded similar predictions as above, but was not validated with actual field results.

Growth models have reinforced our understanding of the response of the fungus to different environmental conditions. Once validated against actual field responses,

these growth models could be incorporated into forecasting systems to aid the timing of control applications.

2.4.2 Forecasting Programs

A simple model for predicting sulfur efficacy in relation to temperature was the first forecasting program developed for the control of *U. necator*. The growth model developed by Sall (63) was used to predict the rate of *U. necator* development in conjunction with sulfur efficacy to aid in the timing of sulfur applications (65). Validation of the sulfur application model resulted in comparable control to standard phenology based control schemes used at the time. The Sall-sulfur model showed the potential for timing sulfur applications when most effective, but the timing of the initial fungicide application was not included in the model.

Improved communication through computers, the Internet, and the use of remote weather sensing has increased accessibility and interest in the development of disease forecasting programs worldwide. These programs relay simplified disease warning information in a timely manner to extension specialists and growers. Warnings for multiple diseases, critical weather information, and spray recommendations are often included in the systems. As a result, forecasting programs have been developed and implemented in Australia and New Zealand (46), Germany (42), Italy (49), California (65,75), and New York (Gadoury, as tested by Pscheidt (60,61))

Limitations in forecasting models have been observed in their usefulness across broad geographical regions indicating the necessity for refinement of a model to a particular region (60). Of particular interest is the timing of the first control treatment.

The proper timing of control treatments during the initial phase of disease development is critical for effective control of *U. necator*. Early control treatments are wasted, while late control treatments could be inadequate in controlling the established infections. There is a lack of evidence that a majority of the currently used models accurately predict initial release and germination conditions. A study conducted in the Willamette Valley of Oregon, observed that three prominent forecasting programs predicted conservative initial control treatments (60,61). In all cases, one to three control applications appear to have been unnecessary. Being conservative is understandable, but increased regulations and the desire of growers and the public to reduce farm inputs should provide the necessary incentive to improve powdery mildew forecasting.

It is possible that current programs could be refined to work in other geographic regions with a better understanding of the basic epidemiological principles underlying overwintering, initial infection, and conidial production and spread in a variety of environmental conditions. Limitations in forecasting program flexibility and accuracy results from a lack of understanding in the basic epidemiological parameters controlling the initiation and subsequent spread of the disease. For example, rainfall resulting in substantial leaf wetness during marginal growth conditions for *U. necator* could have a significant negative influence on the rate of expansion of the disease in the field. Rainfall is typically not included as a parameter in forecasting programs of *U. necator*. The refinement of the deleterious influence of rainfall on ascospore infection, conidiation, and conidial dispersal should be investigated and incorporated into forecasting programs to aid in the timing of control measures. Also, the development of infections resulting from ascospore release warrants further investigation. Time requirements for ascospore

infection in relation to temperature, leaf wetness, rainfall, and relative humidity would aid in better predictions of initial infection periods.

Finally, the term "forecasting program" has been used too loosely with regard to true forecasting. The forecasting programs developed to date all relay disease information after, or at best during, the period of interest. The programs are reactive to conditions warranting action and not predictive. True forecasting programs should incorporate a "forecast" of useful duration (2-3 days) to predict when control should be applied before severe disease conditions are encountered. Currently, increased accuracy of weather forecasting could facilitate the creation of an accurate and timely forecasting program.

2.5 Conclusion

It is surprising that current forecasting programs are based summarily on identified epidemiological parameters of *U. necator*. The obligate nature of the disease lends to this lack of supporting structure in the programs. Also, the number of tools used to control *U. necator* is high and relative expense of control has remained low. Currently, growers are somewhat content to apply additional control applications for insurance against the potential economic loss of low levels of infection. This prevailing attitude will likely change as agriculture slowly shifts from a high off farm input industry to a more environmentally conscious and efficient system.

The future of powdery mildew control will be that of a more refined regionally based control system. Already, programs are being developed to improve grape cultivation at a regional level through voluntary compliance to approved management

practices at the vineyard level (6,40,44). These programs have been designed with the vision of reducing unnecessary farm inputs, while still producing a superior product. Compliance has been generally voluntary with the use of market recognition incentives. Regulations limiting the numbers of control sprays and limiting the types of chemical controls that can be used without penalties, are just one aspect of the production programs. The Oregon production program, Low Input Viticulture and Enology (LIVE) (44), provides point incentives for using forecasting programs that may reduce spray applications. Improvements in the forecasting programs will be necessary, but a better understanding of the underlying biology of *U. necator* will be required. Long term monitoring of environmental parameters in the region, and investigations on the development of the disease can produce the necessary body of knowledge to create regional forecasting and improved control of *U. necator*.

3. The Impact of Vine Shelter Use on the Development of Grape Powdery Mildew

3.1 Introduction

The use of plastic vine shelters in the first year of vineyard establishment has gained popularity in recent years. Vine shelter use has been shown to increase grapevine vigor (18,19,38,45,69), protect plants from wind (69), reduce small mammal (38,45) and insect damage (18,38), and reduce the need for irrigation (18,19,69). Vineyard establishment times have been reduced by a growing season (38,45), resulting in a small crop in the second or third year after planting. In addition, vine shelters promote vertical growth without training on a fixed trellis system, which reduces labor costs and initial trellising expenses (18,19,38,45).

Powdery mildew of grape caused by the obligate fungal pathogen, *Uncinula necator*, is found in most regions where grapes are cultivated (56). Severe powdery mildew infections can reduce vigor, vine health, and in extreme cases lead to plant death (5,43,59). Powdery mildew epidemics are typically controlled by the regular application of protectant fungicides throughout the growing season. Fungicides are typically not applied to young vines, especially when in vine shelters, due to the difficulty of application, expense, and phytotoxicity concerns. Of primary concern with vine shelter use is severe cane infection on the main shoots, which could lead to brittle (56) and possibly weakened young trunks. Severe foliar infection can also contribute to a weak and less vigorous plant, thus negating the positive effects of vine shelter use.

Reports have indicated that significant *U. necator* infection has not been observed with vine shelter use in Australia (18,19). Altered environmental conditions within vine shelters are thought to have the greatest influence on the establishment and severity of powdery mildew infections (18). *U. necator* conidia will germinate and infect between the temperatures of 7 - 32°C with optimum growth and sporulation at 26°C (14). Thermal inhibition of *U. necator* occurs when exposed to prolonged temperatures above 36° (14). Vine shelters have been reported to provide high relative humidity and temperatures in Eastern Washington (69) and Australia (18). High temperatures during mid-summer months could reduce the severity of infections and even eliminate the need to control the disease. However, vine sheltered plantings have been observed with severe powdery mildew infections in the Willamette Valley (personal observation). The Willamette Valley is characterized as a cool climate growing region and the high temperatures required to inhibit *U. necator* infections within vine shelters may not occur. The objective of this study was to determine the influence of vine shelters on disease development within vine shelters in the Willamette Valley.

3.2 Materials and Methods

3.2.1 Plant Material and Field Design

Self-rooted cane cuttings of Cabernet Sauvignon and Chardonnay were used in 1998, and only Chardonnay was used in 1999. Dormant one year-old canes were collected from pruned dormant laterals within one month of removal from mature parent plants. Three bud cane pieces were placed vertically in moist Perlite and held in mist

chambers until root formation was observed. Rooted cane pieces were planted into 500 mL containers with a yard-compost/sandy-loam mixture (#1 Fertile Mix, Shamrock, Corvallis, OR) and held in a non-heated greenhouse. One application of an oil-based fungicide (JMS Flower Farms Inc., Vero Beach, FL) was applied in early April to protect plants against premature powdery mildew infection in the greenhouse. Plants were held in the shade at ambient temperatures outside for one to two weeks before being planted in the test vineyard. Vines were planted on June 2, 1998 and May 19, 1999 with 1 m spacing between plants. Natural infections of powdery mildew in an adjacent field were detected on May 4, 1998, and June 14, 1999 (Chapter 4). Rows spacing was 2 m in both years. Plantex 20-20-20 (29 g, Plantco, Inc., Brampton, Ontario, Canada) and Osmocote 14-14-14 (53 g, Scotts-Sierra Horticultural Products Co., Marysville, OH) were applied to each plant at planting in 1998 and 1999, respectively. Shoots were thinned to one main shoot at planting in both years. Plants were drip irrigated as need throughout each season.

3.2.2 Vine Shelter Treatments

Four vine shelters were tested in 1998 including the Green-Gro (Jim's Supply Co., Bakersfield CA), Remay (International Reforesters, Eugene, OR), Gro Tube (Curtis Wagner Plastics Corp., League City, TX), and Blue-X (Glunt Enterprises, Rancho Cordova, CA). In 1999, the Clipper Grow (Treessentials, Mendota Heights, MN) was added. Shelter diameter, material, and color varied with each product. The Green-Gro tube was a green polypropylene single walled tube that came with a variable diameter of 7.6 to 8.9 cm. Remay was a white spun polyester fabric that was sown into a 12.7 cm

diameter tube. The Gro Tube was a blue polyvinyl chloride (PVC) sheet with tab and slot construction making a 7.6 cm diameter tube after assembly. The Blue-X shelter was a transparent blue polyester sheet rolled inside a blue polytube (unspecified material) to produce a 7.6 cm diameter tube. Finally, the Clipper Grow was a natural pink ridged polypropylene 7.6 cm diameter tube.

For each vine shelter brand, four installation types were used in both years of the experiment. Installation types were based on variations of the industry recommended installation. The recommended installation was vine shelters of 76.4 cm in length (standard height) that are hilled at the bottom with ~7.6 cm of soil. Two variations of the standard height installation type were vine shelters of 76.4 cm in length with four 2.5 cm vents (vented) and hilled as above, and vine shelters of 76.4 cm in length installed with bases 5.1 cm above ground level (raised). The final variation of the standard height installation type was vine shelters of 38.2 cm in length (half height) and hilled as above. In 1998, a total of 13 treatments (4 shelter types x 4 shelter treatments = 12 treatments + 1 no-tube control plant = 13 total treatments) replicated six times for each of the two grape varieties were applied within 24 hours of planting. Five vine shelter brands were used in 1999 (described above) with the same four installation types, excluding the Clipper Grow vine shelter with raised installation type. In 1999, a total of 20 treatments (5 shelter types x 4 shelter treatments – (Clipper Grow - Raised) = 19 treatments + 1 no-tube control plant = 20 total treatments) replicated eight times were applied six days after planting. Treatments were arranged in randomized complete blocks for both years.

3.2.3 Disease Development

Incidence and severity of powdery mildew were assessed throughout each growing season. Entire plants were assessed in 1998 by removal of the vine shelter and examination of all leaf surfaces. Cabernet Sauvignon was assessed on 16 and 30 June, 7, 14 and 27 July, and 11 and 25 August. Chardonnay was assessed on 16 and 30 June, 7 and 21 July, and 4 and 19 August. Measurements of incidence and severity were standardized against an average-sized grape leaf with a leaf index area of approximately 79 cm^2. Incidence was determined as the percentage of leaves infected per plant. Severity measurements were determined by summing the amount of infected leaf area for the entire plant as a percentage of an average-sized leaf, and then divided by twice the number of estimated average-sized. The resultant severity is a percentage of infected area per average-sized leaf (abaxial and adaxial surface) for each plant. No distinction was made between plant material within vine shelters and plant material that grow out the top of vine shelters except during the last assessment date.

In 1999, every fifth node beginning from the fifth node above the basal node and proceeding up every five nodes of each plant was assessed. This assessment method was compared to entire plant assessments in 1998 (data not shown) and was determined to provide similar disease progress results. Assessments were performed on 7 June, 8 and 20 August, and 7 and 23 September. Also, in-shelter and out-of-shelter plant incidence and severity were assessed during the entire growing season. Finally, cane severity was determined at the end of the experiment by estimating the percentage of powdery mildew infection per cane. Assessment of cane severity was collected for the total cane and the portion of cane located within the vine shelter treatments.

3.2.4 Plant Growth

In 1998, plants were assessed by measuring the growth differential of trunk diameter at ground level during the growing season, the final shoot diameter at basal node and 50 cm above ground level, and final shoot length from basal node to shoot tip. Measurements in 1999 included final shoot diameter at basal node and 50 cm above ground level, final shoot length from basal node to shoot tip, and the average final internode length of the main shoot.

3.2.5 Environmental Data

Miniature temperature/relative humidity data loggers (Spectrum Technologies, IL) were prepared with custom-made rain covers and suspended at mid-height in a subset of nine vine shelters in each year. In 1998, data loggers were placed in the Blue X and Green-Gro - standard height, raised, and vented treatments, the Remay standard height treatment, and Gro Tube vented treatment. The data logger monitored treatments were all in one block of the Chardonnay cultivar. In 1999, data loggers were placed in all standard height treatments, Blue X raised and vented treatments, and Clipper Grow vented treatment. Ambient temperature and humidity were collected adjacent to the unsheltered control plant in a specially designed data logger enclosure (Spectrum Technologies, IL) in both years. Variability in recorded temperature and relative humidity between the custom made rain covers and the data logger enclosure was found to be within the precision of the data loggers (data not shown). Data loggers were

calibrated by the manufacturer prior to installation in both years. Temperature and relative humidity were collected hourly for the duration of each season.

3.2.6 Data Analysis

Total plant disease severity and incidence measurements were compared using area under the disease progress curve (AUDPC) determined for each plant using mid-point approximation of the sample data. Three-way analysis of variance using the GLM procedure and Type III sums of squares in SAS (v.6.12, Casy, NC) was used to test for independence between factors. The factors were block, vine shelter brand, installation type, and the interaction between vine shelter brand and installation type. Comparisons among treatment means and the treatment means to the no-tube control were performed with Tukey's Honest Significant Difference and Dunnett's tests, respectively. Additionally, in vine shelter and out of vine shelter AUDPC data was compared as above for data collected in 1999. Paired comparison t-test was also used to examine AUDPC results between in shelter and out of shelter disease assessments.

A degree hour calculation was performed on temperature data (base = 36°C) to quantify the inhibitory affect of high temperature on *U. necator* growth. Exponential regression between AUDPC incidence and the degree hour calculations were used to investigate the relationship between the inhibitory affect of high temperature and disease development using Statgraphics (v. 4.0, Manugistics, Inc. Rockville, MD).

3.3 Results

3.3.1 Disease Development

Powdery mildew was detected within vine shelters beginning July 27, 1998 and June 7, 1999. Disease pressure from powdery mildew was considered light during both years of the study, but significant disease did develop on plants within various vine shelters. A significant vine shelter brand by installation type interaction was not detected in either year or variety tested. Powdery mildew incidence and severity measurements for entire plants were not consistently affected by vine shelter brand across both years. Total plant powdery mildew incidence and severity were consistently affected by installation type, but severity was not significantly different from the no-tube control vines across both years and varieties tested.

In 1998 (Table 1), results for vine shelter brands were similar for both Cabernet Sauvignon and Chardonnay. Incidence of powdery mildew was significantly lower on vines with the Green-Gro and Remay vine shelter brands when compared to the no-tube control vines. The Blue X vine shelter brand had vines with significantly reduced incidence on Chardonnay when compared to the no-tube control vines. No consistent significant differences in severity of vines between vine shelter brands and the no-tube control vines were observed. In 1999 (Table 2), vine shelter brand did not significantly affect disease levels on leaves. However, the Blue X, Gro Tube, and Clipper Grow vine shelter brands had vines with significantly lower cane infection severity than the no-tube control vines.

Table 1: Comparison of total incidence, total severity, and shoot length for plants treated with various vine shelters in 1998.

	Cabernet Sauvignon			Chardonnay		
Vine Shelter	**Total Incidence[v]**	**Total Severity[w]**	**Shoot Length[x]**	**Total Incidence**	**Total Severity**	**Shoot Length**
Blue X	8.5 bc[z]	0.4 bc	111 * a	5.7 * ab	0.24 a	108 * a
Green-Gro	2.7 * a	0.1 * a	94 ab	2.8 * a	0.05 a	101 ab
Gro Tube	5.9 abc	0.2 * ab	111 * a	6.3 bc	0.17 a	114 * a
Remay	4.0 * ab	0.1 * a	106 * a	4.3 * ab	0.12 a	110 * a
No Tube Control	12.2 c	0.4 c	74 b	11.2 c	0.30 a	73 b
Installation						
Half Height	4.5 * ab	0.1 * b	94 ab	5.5 * ab	0.11 ab	94 bc
Raised	9.0 c	0.4 bc	102 ab	6.8 bc	0.33 b	106 ab
Standard Height	1.4 * a	0.0 * a	114 * a	2.3 * a	0.03 a	115 * a
Vented	6.2 bc	0.2 * b	112 * a	4.4 * ab	0.11 ab	118 * a
No Tube Control	12.2 c	0.4 c	74 b	11.2 c	0.30 ab	73 c

[v]Mean area under the disease progress curve (AUDPC) for incidence of powdery mildew recorded for entire plants. Incidence was assessed for Cabernet Sauvignon eight times between 6/2/98 and 8/25/98. Incidence was assessed for Chardonnay seven times betwe

[w]Mean AUDPC for severity of powdery mildew infection on entire plants. Severity was assessed on the same dates as incidence for each corresponding cultivar.

[x]Mean shoot length of main shoot (cm).

[y]Mean diameter of main shoot taken 50 cm above ground level (mm).

[z]Numbers followed by the same letter are not significantly different (P=0.05) according to Tukey (HSD) test.

*Statisticaly significant from Untreated Control indicated by Dunnett's test (p = 0.05)

Table 2: Comparison of total incidence, total severity, cane severity, shoot length, mid-shoot diameter, and internode length for Cabernet Sauvignon treated with various vine shelters in 1999.

Vine Shelter	Total Incidence[t]	Total Severity[u]	Cane Severity[v]	Shoot Length[w]	Mid-Shoot Dia[x]	Internode Length[y]
Blue X	35.8 a[z]	6.1 a	0.04 * a	97 * ab	4.4 ab	3.1 * abc
Clipper Grow	27.4 a	2.6 a	0.04 * a	110 * a	4.6 * ab	3.5 * a
Green-Gro	36.5 a	3.9 a	0.06 ab	104 * a	4.9 * a	3.2 * ab
Gro Tube	28.0 a	3.5 a	0.04 * a	100 * a	4.4 ab	3.1 * ab
Remay	34.3 a	3.0 a	0.07 ab	88 ab	4.2 ab	2.8 bc
No Tube Control	39.8 a	4.0 a	0.14 b	64 b	3.0 b	2.4 c
Installation						
Half Height	25.6 ab	1.4 a	0.01 * a	86 bc	4.6 * a	2.8 bc
Raised	51.6 c	8.1 b	0.09 b	101 * ab	4.5 * ab	3.2 * ab
Standard Height	15.5 * a	0.8 a	0.02 * a	108 * a	4.4 * ab	3.2 * a
Vented	42.3 c	6.2 b	0.09 b	103 * ab	4.5 * ab	3.3 * a
No Tube Control	39.8 bc	4.0 ab	0.14 b	64 c	3.0 b	2.4 c

[t]Mean area under the disease progress curve (AUDPC) for incidence powdery mildew infection on entire plants. Incidence was assessed six times between 5/19/99 and 9/23/99. AUDPC was calculated using the mid-point approximation.

[u]Mean AUDPC for severity of powdery mildew infection on entire plants. Severity was assessed on the same dates as incidence.

[v]Mean severity of the segment of dormant cane located within the vine shelter. Assessed on 11/11/99.

[w]Mean shoot length of main shoot (cm).

[x]Mean diameter of main shoot taken 50 cm above ground level (mm).

[y]Mean internode length of main shoot (cm).

[z]Numbers followed by the same letter are not significantly different (P=0.05) according to Tukey (HSD) test.

*Statisticaly significant from Untreated Control indicated by Dunnett's test (p = 0.05)

In 1998, standard and half height installations resulted in significantly less incidence of powdery mildew on both varieties tested compared to the no-tube control vines and vines with the raised installation type. No consistent significant differences in disease severity was found for vines with different installation types when compared to the no-tube control vines, but consistent differences between installation types were observed. The standard height installation type had vines with significantly lower severity when compared to vines with the raised installation for both varieties tested. In 1999, vines with the standard height installation type were the only vines that had significantly lower incidence than vines with the raised and vented installation types, and no-tube control vines. Standard and half height installation types had vines with significantly lower severity when compared to vines with the raised and vented installation types. Also, standard and half height installation types had vines with significantly lower cane infection severity by 93 and 86% when compared to the no-tube control vines, respectively.

Differentiating individual vines for disease development within and external of vine shelter treatments in 1999 (Table 3) indicated that vine shelter brands had no impact on the development of powdery mildew incidence or severity. Vines with standard and half height installation types did have significantly lower incidence when compared to the no-tube control vines and vines in other installation types. The severity on vines within tubes was found to be significantly lower in the standard and half installation types when compared to vines in the other installation types, but no installation type vines were significantly different from the no-tube control vines.

Table 3: Comparison of incidence and severity inside and outside of various vine shelters in 1999

	Incidence[u]			Severity[v]		
Vine Shelter	**In Shelter[w]**	**Out Shelter[x]**	**In - Out[y]**	**In Shelter**	**Out Shelter**	**In - Out**
Blue X	29.1 a[z]	24.2 ab	No	6.31 a	1.92 ab	No
Clipper Grow	13.0 a	31.7 b	Significant Diff	1.74 a	1.87 ab	Significant Diff
Green-Gro	29.3 a	24.7 ab	No	4.21 a	1.24 * a	No
Gro Tube	21.5 a	16.1 * a	No	3.33 a	1.07 * a	No
Remay	30.2 a	16.3 * a	No	3.11 a	0.61 * a	Significant Diff
No Tube Control	39.8 a	39.8 b	-	4.01 a	4.01 b	-
Installation						
Half Height	7.9 * a	31.8 b	Significant Diff	0.52 a	1.56 * a	Significant Diff
Raised	50.4 b	15.7 * a	Significant Diff	8.59 b	1.54 * ab	Significant Diff
Standard Height	9.6 * a	17.5 * a	No	0.56 a	0.73 * a	Significant Diff
Vented	38.7 b	22.2 * ab	Significant Diff	6.80 b	1.49 * a	Significant Diff
No Tube Control	39.8 b	39.8 b	-	4.01 ab	4.01 b	-

[u]Mean area under the disease progress curve (AUDPC) for incidence. Incidence was assessed six times between 5/19/99 and 9/23/99. AUDPC was calculated using the mid-point approximation technique.

[v]Mean AUDPC for severity. Severity was assessed on the same dates as incidence.

[w]In shelter is defined as all plant material within the vine shelter.

[x]Out shelter is defined as all plant material extending beyond the top of the vine shelter.

[y]Paired comparison between individual in vine shelter and out of vine shelter AUDPC for each vine shelter and installation type. "Significant Diff" indicates a significant difference (p = 0.05).

[z]Numbers followed by the same letter are not significantly different (P=0.05) according to Tukey (HSD) test.

*Statisticaly significant from Untreated Control indicated by Dunnett's test (p = 0.05)

Incidence measurements for vine leaves external of vine shelter treatments resulted in significant differences observed between vine shelter brands and installation types. The Clipper Grow vine shelter brand was found to have vines with significantly higher external incidence than vines with the Gro Tube and Remay vine shelter brands, but no differences in severity between vine shelter brand vines were observed. Standard height and raised installation type vines had significantly less external incidence than vines with the half height installation type, but as with vine shelter brand, no significant differences between severity on vines external to the vine shelter treatments were observed.

Paired comparison vine leaves internal and external of the vine shelter treatments indicated a significant reduction of incidence and severity on vine leaves internal of the Clipper Grow vine shelter brand (Table 3). Vine leaves within the Remay vine shelter brand had significantly higher severity than vine leaves external of the vine shelter. Half height installation type had significantly higher incidence and severity on vine leaves external to the installation, while the raised and vented installations had vine leaves with significantly higher incidence and severity within the vine shelters. Standard installation type did not have a significant difference of incidence between vine leaves internal and external of the installation treatments, but the severity on internal vine leaves was significantly less.

3.3.2 Plant Growth

In 1998 (Table 1), vines with the Blue X, Gro Tube, and Remay vine shelter brands had significantly longer shoots when compared to the no-tube control vines for

both Cabernet Sauvignon and Chardonnay. Shoot length was significantly longer for vines in the standard height and vented installation types compared to the no-tube control vines for both Cabernet Sauvignon and Chardonnay. The only significant difference in the mid-shoot diameter was observed in Cabernet Sauvignon between vines in the Blue X and Green-Gro vine shelter brands. Vines in the Blue X vine shelter brand had an average mid-shoot diameter 1.1 mm larger than vines with the Green-Gro vine shelter brand. No significant growth differences were observed for any other growth measurement.

In 1999 (Table 2), shoot length for vines with the Blue X, Gro Tube, Clipper Grow, and Green-Gro vine shelter brands were significantly longer when compared to the no-tube control vines. Clipper Grow and Green-Gro vine shelter brands had vines with significantly larger mid-shoot diameters than the no-tube control. Standard height, raised, and vented installation types resulted in vines with 37.7 to 44.1 cm longer shoots compared to the no-tube control vines. Significant increases in internode length were observed between vines with the Blue X, Gro Tube, Clipper Grow, and Green-Gro vine shelter brands, and vines with the standard height, raised, and vented installation types when compared to the no-tube control vines.

3.3.3 Environmental Data

Temperatures within the monitored vine shelter treatments were on average 2.5°C to 4.3°C higher than ambient temperatures in 1998 and 1999, respectively. In 1998, temperature within the Green-Gro raised treatment type resulted in the highest and lowest recorded temperature of 14.9°C above ambient to 2.9°C below ambient. An exponential

regression of incidence and degree hours of thermal inhibition of powdery mildew (base = 36°C) (Figure 1-A) indicates a significant negative relationship. In 1999, the Green-Gro standard height installation produced the highest recorded temperature of 17.9°C above ambient. The lowest recorded temperature of –3.4°C below ambient was recorded within the Clipper Grow standard height installation. A linear regression of incidence AUDPC and degree hours of thermal inhibition of powdery mildew (base = 36°C) (Figure 1-B) indicates a significant negative relationship.

Relative humidities within the monitored vine shelter treatments were on average 6.0 to 3.6% higher than ambient relative humidity in 1998 and 1999, respectively. There was no significant relationship observed between relative humidity within vine shelter treatments and levels of recorded disease incidence or severity.

3.4 Discussion

Powdery mildew development was inhibited by the standard height installation of vine shelter brands tested in both years of this study. Modified installations of vine shelters were performed to lower internal relative humidity with the intent of creating an environment less suitable for powdery mildew development. These modifications appear to have allowed increased airflow within the shelter, which reduced internal temperature and relative humidity, but increased disease pressure. The reduction in air movement associated with the standard height installation is believed to be a major contributing factor to the increased internal temperature observed in the vine shelters. On numerous occasions, standard height installation of vine shelters resulted in temperatures above 36°C for long enough to inhibit powdery mildew development. However, comparisons

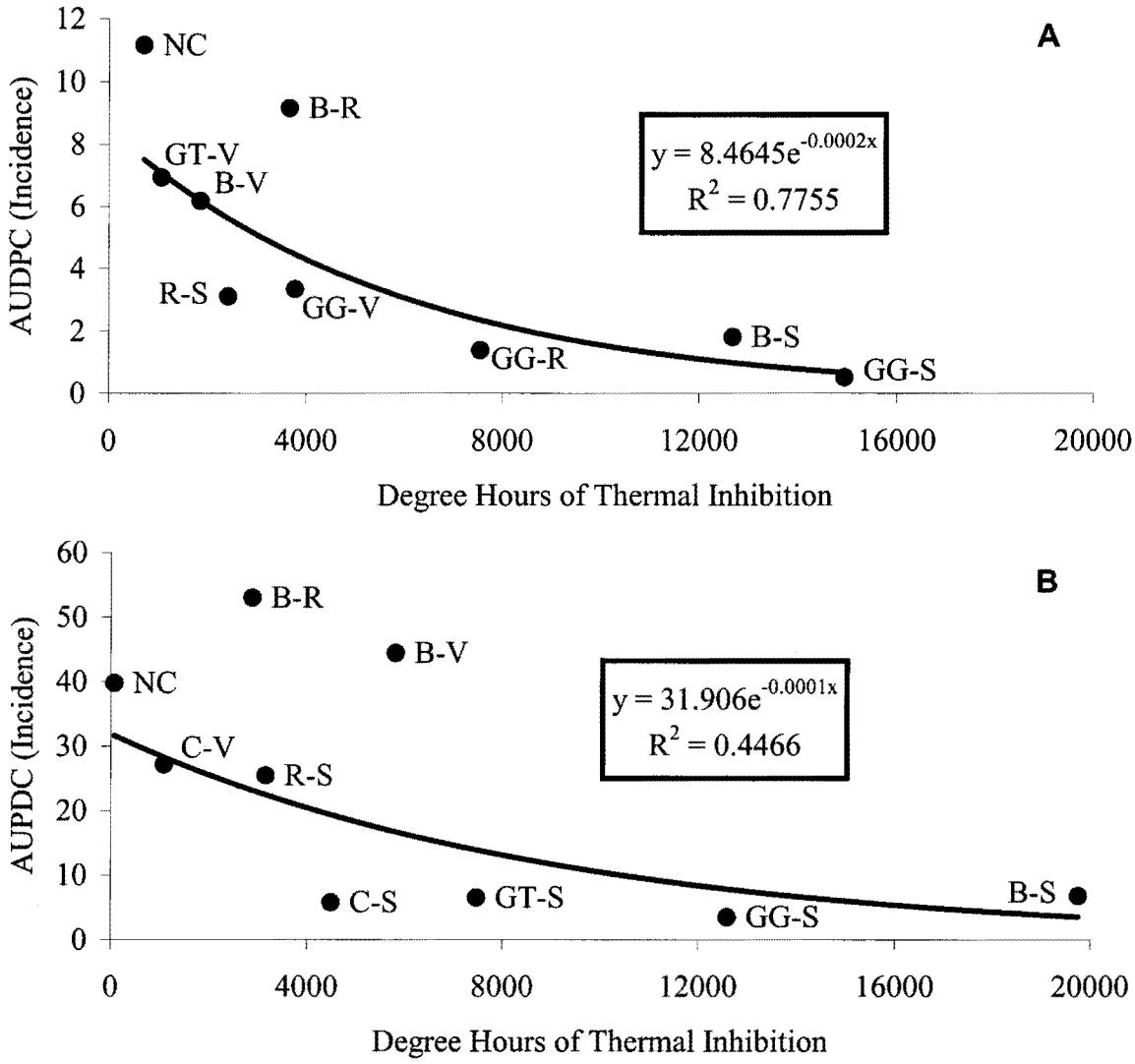

Figure 1. Relationship between incidence of powdery mildew on grape plants in vine shelters and degree hours of powdery mildew inhibition within vine shelters in 1998 (A) and 1999 (B). AUDPC is based on incidence, which is defined as the proportion of infected leaves to total leaves. Degree hours of thermal inhibition for powdery mildew were calculated with a base of 36°C. Date point labels represent the treatment: untreated control (NC), Green-Gro – vented (GG-V), Green-Gro – raised (GG-R), Green-Gro – standard height (GG-S), Blue X – vented (B-V), Blue X – raised (B-R), Blue X – standard height (B-S), Remay – standard height (R-S), Clipper Grow – vented (C-V), Clipper Grow – standard height (C-S), Gro Tube – vented (GT-V), and Gro Tube – standard height (GT-S). The fitted model is significant ($p < 0.05$).

between incidence and inhibitory temperatures do not result in sufficient correlation to indicate temperature as the only important factor.

Vine shelters could provide protection to the plant by conidial spread between infected individuals and within individual vine shelters. *U. necator* is believed to be primarily wind distributed with some evidence for rain tap, rain puff, and splash distribution (80,81). The severity of powdery mildew infection remained low with respect to incidence in both years of the study. This is a characteristic of wind dispersed polycyclic diseases, which produces enough inoculum from a small initial severity to infect a large number of plants (68). Installations allowing increased air movement through the vine shelter could increase the likelihood of conidial spores entering the confines of the shelter. Cane infections were reduced with standard height installation types, which also indicate a reduction in spore movement into and within the vine shelters. Although the impact of cane infections on young plant establishment is not known, clearly the reduction in powdery mildew infection on the cane should produce a stronger and healthier trunk.

Goals of vine shelter use are to provide protection from certain management practices, pests, and to create an environment which promotes rapid growth in the early establishment years. In Washington, increased shoot length has been related to high internal relative humidity allowing improved water potential for the portion of the plant inside the vine shelter (69). Significant increases in shoot length were observed with standard height and vented installation types. Vented vine shelters do not retain a high level of humidity as standard vine shelters. The observed difference could be related to a phototropic response in conjunction with improved water potential. A vented vine shelter

allows additional light to enter the tube, while water potential remains higher in a vine sheltered plant compared to than of a plant in ambient conditions.

The observation of heavily infected plants within vine shelters in the Willamette Valley remains unexplained. Improper vine shelter installations in newly established plantings have been observed in the region since the original observation of heavily infected installations. Problems have consisted of inadequate anchorage of vine shelters to a fixed support or improper hilling of vine shelter bases. Vine shelters installations with weak anchorage systems have been observed to not withstand heavy winds or certain cultural practices (Personal observation). Occasionally, incorrect installation can result in the loss of plants within vine shelters due to physical injury and breakage. This study substantiated the potential of increased benefits associated with vine shelter use, and emphasizes the need for proper installation of the vine shelters.

Powdery mildew reduction is an additional benefit to the already substantial improvements possible with proper vine shelter use. The observed reduction in powdery mildew could reduce the need to apply fungicides for the control of powdery mildew during the first year of vineyard establishment. Improvements of increased growth, protection from adverse environmental conditions and cultural practices, and reduced powdery mildew pressure should compensate for the additional expense of vine shelter installation and maintenance.

4. Evaluation of Disease Forecasting Programs and Detection of Disease Onset for *Uncinula necator* in the Willamette Valley.

4.1 Introduction

Oregon is currently the fourth largest producer of wine grapes in the nation (1). The Willamette Valley of Oregon is characterized as a cool climate region producing high quality cool climate *Vitis vinifera* wines (52). An important disease of grape production in Oregon and all other commercial regions is powdery mildew, caused by the obligate fungal pathogen *Uncinula necator* (Schwein.) Burril. (5). Control of *U. necator* is critical since as little as 3.0 % infection of fruit clusters has been shown to produce wine with a detectable off-flavor (50,59). In Oregon, *U. necator* has been assumed to overwinter primarily via cleistothecia, the sexual resting structure of the pathogen.

U. necator is controlled principally with the repeated use of protective fungicides applied every 7 – 21 days between bud break and veraison (onset of fruit maturation). A standard phenology based control program has been developed for Oregon (7), but interest in a more accurate and effective program has been expressed by the industry. Forecasting programs based on environmental conditions have been developed to predict the timing of control applications in regions other than Oregon. A study conducted from 1996 to 1997 compared the effectiveness of three forecasting programs in the Willamette Valley of Oregon (60,61). The study showed that the forecasting programs called for 1 – 2 control applications prior to the detection of the disease on water treated or untreated plants in the vineyard. These data indicated that the forecasting programs need to be

refined, or a new forecasting program needs to be created, for the regional environment. The objectives of this study were to evaluate the adequacy of three forecasting models in predicting disease onset in the Willamette Valley of Oregon and to collect environmental and disease onset data for refining a disease forecasting program.

4.2 Materials and Methods

4.2.1 Trapping of Initial Inoculum

In 1997, powdery mildew free, self-rooted, potted Cabernet Sauvignon plants were trained on bamboo stakes. Four, 80 cm high plants were placed daily (excluding weekends) next to untreated control blocks of Chardonnay beginning on 8 May. The height of the plants allowed for susceptible tissue to be placed immediately above and below mature grape cordons. Exposed plants were returned to a greenhouse with optimal conditions for powdery mildew development after approximately 24 hours of exposure in the field. Returned plants were periodically assessed for signs of powdery mildew infection.

In 1998 and 1999, detached leaves were used instead of entire plants. This method was validated during the 1997-growing season by testing the durability of leaves from different cultivars in different environmental conditions (data not shown). Detached leaves from Cabernet Sauvignon were determined to be suitable for trapping *U. necator* conidia in the vineyard. Trap leaves were produced from self-rooted Cabernet Sauvignon potted plants grown in a greenhouse. The plants were kept free from powdery mildew infection by volatilization of elemental sulfur by four electric sulfur pots for 4 – 6 hours

nightly. Two to three week-old leaves were removed from the plants by cutting the basal end of the petioles just adjacent the node. Removed leaves were immediately placed in water to prevent wilting. The ends of the petioles, were removed with a clean scalpel, while submerged in water. The leaves were then placed in plastic florist tubes (Syndicate Sales, Inc., Kokomo, IN.) and held for 24 hours in the powdery mildew free greenhouse to harden off. In 1999, leaves were placed in plastic bins and held in a 4°C cold room for 24 hours before use, which reduced leaf wilting and collapse in the field.

Leaves were transported to and from the field every 24 hours in plastic containers to reduce the possibility of infection during transportation. In 1998, six leaves were placed in each of four untreated blocks of *Vitis vinifera*. The untreated blocks consisted of three mature Pinot Noir blocks and one block of abandoned *V. vinifera* of unknown cultivar. In 1999, eight leaves were placed in each of three blocks of untreated Chardonnay. Leaf placement in each block was in pairs with one leaf above and one below mature cordons. A negative control leaf remained in the greenhouse for the 24-hour period while the treatment leaves were in the field. The negative control leaves were then placed with the returning leaves from the field. Returning leaves were placed in a custom made incubator and held at 25°C, relative humidity >50%, and 8-16 day/night light pattern. The incubator design provided isolation of samples between sample days and limited air movement around samples to reduce the possibility of cross contamination between samples and sample days. Leaves were assessed by visual inspection for signs of powdery mildew every 24 to 72 hours.

The untreated mature grape field blocks were regularly monitored for the presence of *U. necator* infections adjacent to the trap plant and trap leaf sampling sites.

Abaxial and adaxial leaf surfaces and young green tissues were randomly inspected every 2 to 3 days.

4.2.2 Ascospore Release Validation

Cordons and trunks were collected from an abandoned vineyard, cut into 30 cm segments, and attached to 90 cm wooden stakes in the spring of 1998. The cordon pieces where then stored dry at ambient outdoor temperatures. Three cordon pieces were placed in an untreated block of Chardonnay on August 3rd, 1998. Cordon pieces were placed as close as possible to the mature Chardonnay cordons and remained in the field until 23 November (90% leaf fall). The cordon pieces were then removed from the field and stored exposed to fall, winter, and spring conditions away from other *Vitis* species. A negative control cordon consisted of a cordon piece that was not exposed to the field.

A positive control cordon was created by applying harvested cleistothecia to a cordon piece. To accomplish this, dry leaves were collected in the fall of 1998, placed in plastic bags, and stored at 4°C until needed. Cleistothecia were harvested from the stored leaves by a modification of a wet sieving procedure (55). Approximately 25 leaves were shaken in 400 ml of 4°C water for 3 min. The resulting washate was strained through a #60 mesh and #170 mesh stacked sieve. The procedure was repeated two more times with the same leaves, but the shaking time was reduced to 1 min. Filtrate in the #170 mesh sieve was retained and the entire procedure was repeated 12 times with fresh leaf aliquots. The filtrate was re-sieved and suspended in 15 ml of 4°C water. The number of cleistothecia was determined using a stereo microscope at 40x (13). Viability of ascospores within the cleistothecia was determined using a compound microscope at

200x and a 0.001% FDA staining technique (78). The filtrate, consisting of 6300 cleistothecia with 10% viability, was poured over a pre-wetted cordon piece, which was placed outside with the other cordon pieces.

Four leaves prepared in plastic florist tubes (as above) were placed such that two were located above and below each cordon piece. Leaves were replaced with fresh leaves every 24 hours beginning on May 12, 1999. Exposed leaves were incubated in clear plastic bins stored in a shaded greenhouse to produce optimal infection conditions. The clear plastic containers facilitated the isolation of leaf samples by day. Leaves were inspected every 24 to 72 hours for sign of infection.

4.2.3 Cleistothecia Dispersal

Cleistothecia collection cones (13) were pinned to mature cordon wood among the three cordon pieces (above) in the untreated Chardonnay block during the fall of 1998. Collection cones were made from 9.0 cm filter paper disks (Whatman #1, Whatman International LTD, Maidstone, England) folded in fourths. Collection cones were replaced every two weeks until 90% leaf fall. Collection cones were also pinned to mature cordon wood at random spacing in a treated Chardonnay block and were collected at 90% leaf fall. Returned collection cones were stored at 4°C in individual plastic bags until processed. The collection cones were unfolded and viewed with a stereo microscope at 40X to determine the number of cleistothecia dispersed into each cone within each two week interval. A sub-sample of melanized cleistothecia was randomly selected from each two week set of collection cones. The sub-sampled cleistothecia were

stored in water at 4°C until bud break of 1999. Viability of the ascospores within the sub-sampled cleistothecia was determined as above.

Cleistothecia dispersal away from the canopy was investigated with the use of collection cones placed within the rows of a mature untreated block of Chardonnay. Collection cones were made from 15.0 cm filter paper disks (Whatman #113, Whatman International LTD, Maidstone, England) folded in fourths. Collection cones were stapled to 1.0 m bamboo stakes and placed in the field at the height of the mature grape cordons. Collection cones were placed in 30.0 cm intervals (30, 60, 90, 120, 150, 180, 210, 240, and 270 cm from cordon) extending laterally from the canopy in the windward (west) and leeward (east) direction. Three complete sets of collection cones were arranged in this manner on August 29, 1998, and remained until October 12, 1998. Collection cones were stored at 4°C and the cleistothecia contained in each collection cone were enumerated as above.

4.2.4 Environmental Data

The environmental parameters of temperature, relative humidity, rainfall, and leaf wetness were collected in all three years of the study. Data were collected in 1997 and 1998 from a Luft weather system (Luft, Abbeon, Germany) that recorded hourly data and was located approximately 100 m from the sampled grape blocks. In 1998 and 1999, an Adcon radio telemetry weather system (Western Farm Service, Tangent, OR) was placed in one of the sampled blocks. Environmental parameters were collected on 15 minute intervals from this system with sensors located within the grape canopy.

4.2.5 Bark Wetness Data

Campbell 21X data loggers (Campbell Scientific, Inc., Logan, UT) were used in 1999 to support custom-made bark wetness sensors. Grape cordon pieces were wrapped with two pairs of copper wire to produce two sensors on each cordon piece. The Campbell data loggers were also fitted with a temperature and relative humidity probe, tipping bucket rain gauge, and three in-canopy leaf wetness sensors. One data logger was placed in a mature Cabernet Sauvignon block adjacent to the untreated Chardonnay block containing the cordon pieces, while the other was placed with the ascospore release validation shelter.

4.2.6 Disease Onset Adjustments

Adjusting dates of observed disease onset were also investigated in attempts to account for the possibility that the observed dates of disease onset were not the first, but the second or third round of secondary spread by infection from asexually produced conidia. Based on a previous study of the time to sporulation of conidia after inoculation by Delp (1954) (14) and observed temperature data, earlier disease onset dates could be estimated.

4.2.7 Forecasting Programs

Three powdery mildew forecasting programs were evaluated for their accuracy in predicting the required initial spray application with respect to disease onset for the three years of the study. The evaluated forecasting models were the German Oi Diag program

(42), the UC – Davis program (36,75), and the New York program (Gadoury, as implemented by Jay Pscheidt, (60,61)). Environmental data collected above were used to calculate the date that each model would call for the initial spray application.

The Oi Diag program predicts the initial spray application date based on parameters predictive of an initial infection from the perennation of grape buds. The model uses a subjective assessment of the previous years powdery mildew intensity (disease rating [0 – 5] with 0 = no damage and 5 = severe damage) and the coldest recorded temperature of the previous winter (low temp). The prediction is represented by the equation (184 – (11 X disease rating) + (2.6 X low temp)) and represents the day that the first colony can be expected. A disease rating of four was assigned for each year as an estimate of the disease pressure in the untreated vineyard blocks.

The UC – Davis program calculates ascospore infection risk periods based on a 2/3 Mills table developed for apple scab ascospore infection. The adequate release of ascospores is assumed to occur between bud break and fruit set. The 2/3 Mills table is a composition of the hourly temperature and duration of leaf wetness required for ascospore infection (47). The table is catagorized into three columns of risk including: light risk, moderate risk, and severe risk. Typically, long periods of warm weather combined with a long duration of leaf wetness equate into a severe risk period for ascospore infection. The initial application of fungicides is to occur when the risk of ascospore infection becomes severe.

The New York program uses rainfall and temperature to predict ascospore release. The first fungicide treatment is applied after the occurrence of 2.5 mm of rainfall and temperatures above 10° C within 96 hours of the rainfall event.

Simple modifications in the parameters of the UC – Davis forecasting program were performed in an attempt to modify the program for use in the Willamette Valley. Modifications included adding additional temperature and rainfall restrictions to the program to delay the initial spray prediction. The Oi Diag program was not modified because the subjective nature of estimating the previous year's disease pressure was thought to limit the versatility and accuracy in forecasting over large and varied geographic areas. The New York program was though to be too simple for modification, but was used in combination with the UC – Davis program to predict ascospore release (New York program) and subsequent infection periods (UC – Davis program). Additionally, bark wetness duration was used in place of leaf wetness duration in the UC – Davis program. Bark wetness duration measurements were assumed to be less variable than leaf wetness measurements and more consistent in representing the microclimate of the leaves immediately near the cordons.

4.3 Results

4.3.1 Trapping of Initial Inoculum

Infections were detected using trap plants or leaves in every year of the study. No infections were observed in the field before the dates of detected infections with trap plants or leaves. Once infection was detected in the trap system, intense scouting in the vineyard around the area of the detected infection revealed infections near the sample site. In 1997 and 1999, infections discovered in the mature vineyard were located on green tissue that was close in proximity to the cordon, indicating that the infections were

probably from ascospores released by cleistothecia overwintering on the cordon. In 1998, infections were discovered on new shoots and surrounding leaves in the abandoned block of grape that were likely from conidia dispersed from the infected shoots, called flag shoots, which were observed in this field.

In 1997, infections were detected on a trap plant returned from the field on June 5th (Figure 2). Multiple infections were located on the trap plant approximately at the same height as the cordon on the mature vine. Additional infections were detected on trap plants returned after June 5th.

In 1998, infections were detected on trap leaves returned from the abandoned block of grape on 5 May (Figure 3). Two flag shoots were discovered near the location where the trap leaves were exposed (Figure 4). A single trap leaf from the mature block was found with an infection on May 8th. This infected trap leaf was considered to be contaminated from the abandoned vine trap leaves in transport to the laboratory due to the collection method being used. Infection were located in the margins of the leaf exposed in the mature block, which was though to have come in contact with a heavily infection leaf exposed to the abandoned vines. Collection of the trap leaves was then modified to reduce the possibility of cross contamination. Infections were not observed in the mature blocks or from trap leaves from the mature blocks until June 15th.

In 1999, infections were detected on trap leaves returned from the field on June 14th (Figure 5). No flag shoots were discovered on any scouted vine.

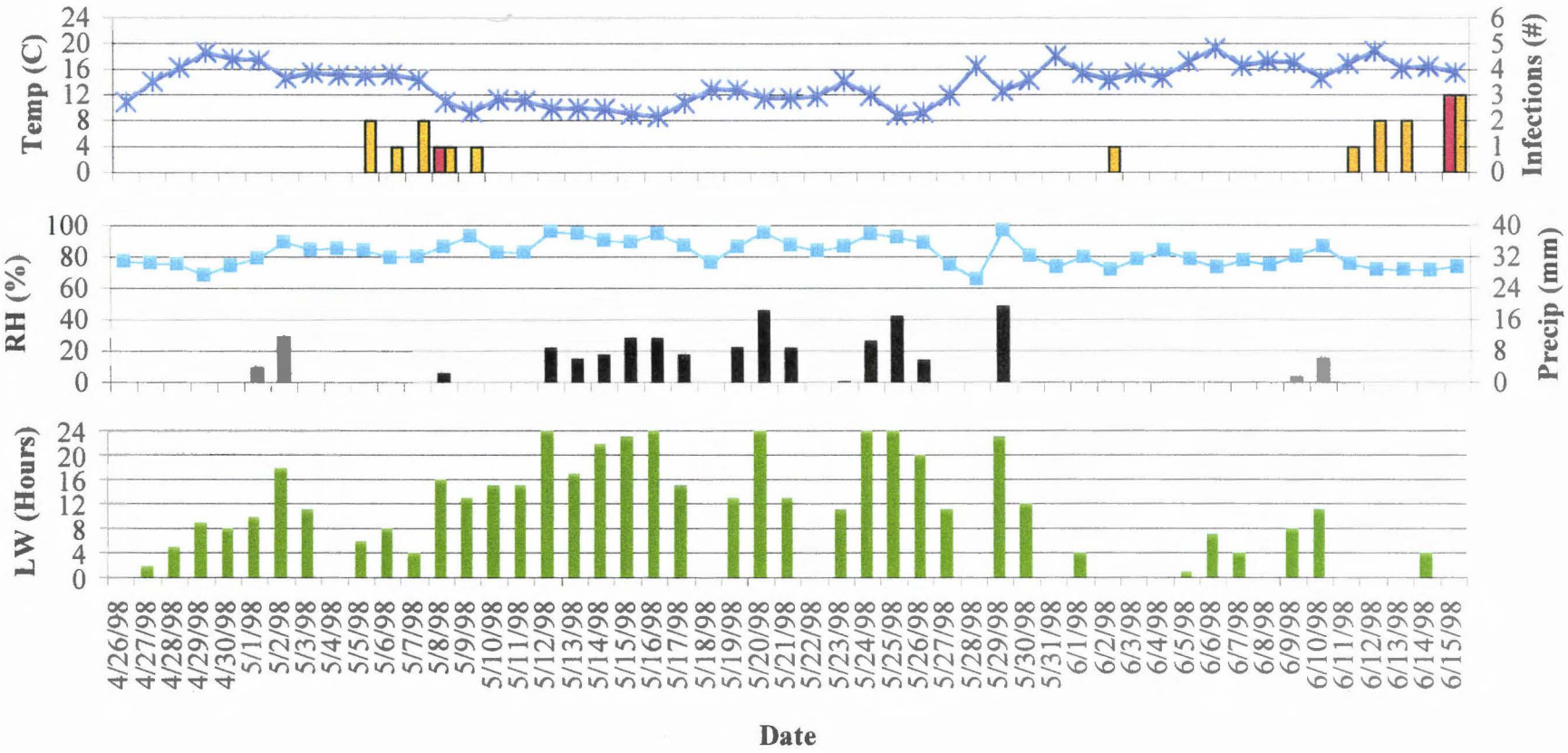

Figure 3: Detection of initial infection and summary of environmental data for 1998. Infections were detected with trap leaves placed in untreated or water treated Pinot Noir blocks (red bars) and an abandoned block of untreated unidentified grapes (yellow bars). Environmental data was calculated at 15 min intervals and is represented as the daily average temperature (dark blue line – cross marks), daily average relative humidity (light blue line – box marks), daily total precipitation (black bars), and daily hours of leaf wetness (green bars).

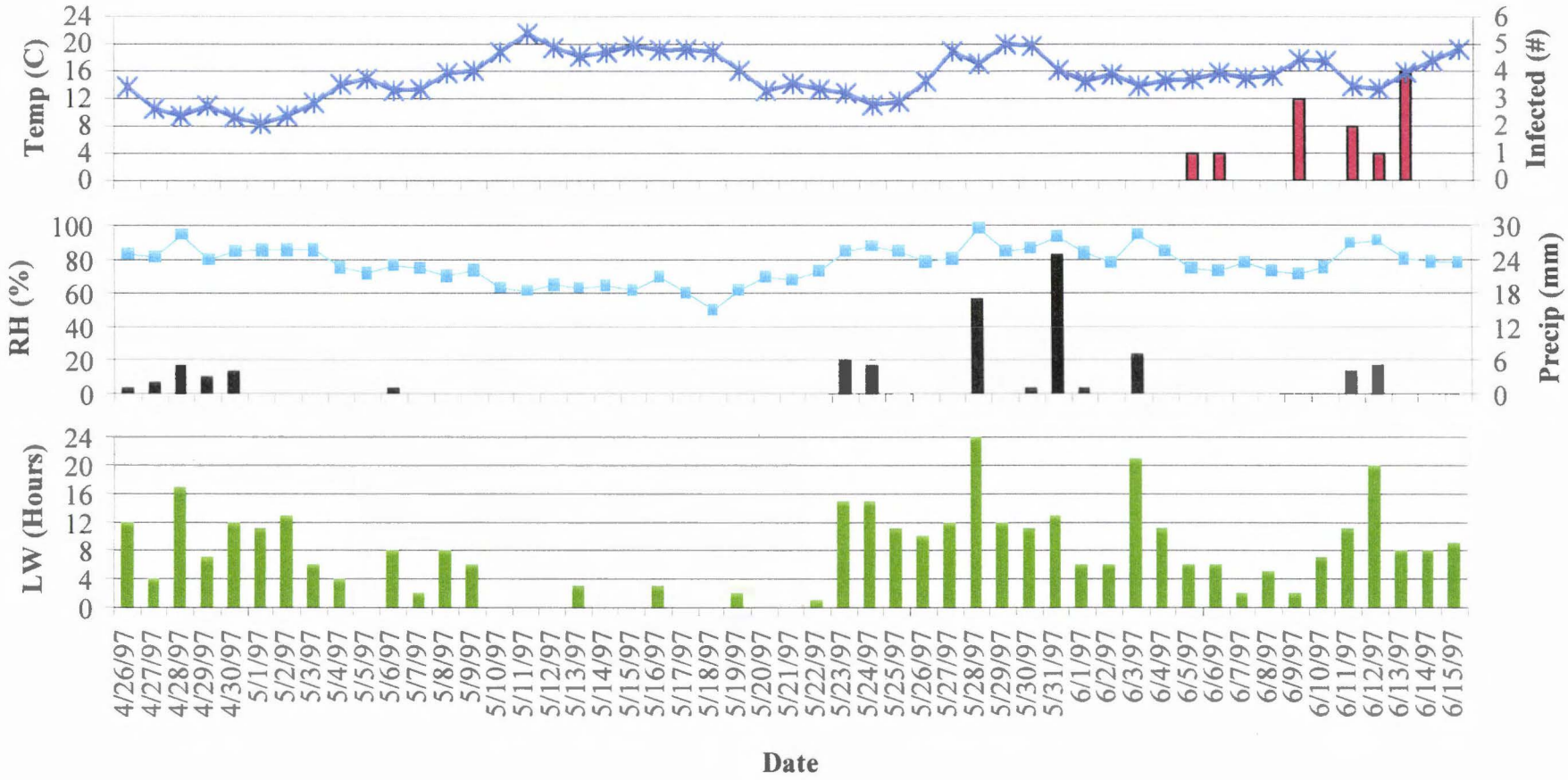

Figure 2: Detection of initial infection and summary of environmental data for 1997. Infections were detected with trap plants placed in untreated or water treated Chardonnay blocks (red bars). Environmental data was calculated at hourly intervals and is represented as the daily average temperature (dark blue line – cross marks), daily average relative humidity (light blue line – box marks), daily total precipitation (black bars), and daily hours of leaf wetness (green bars).

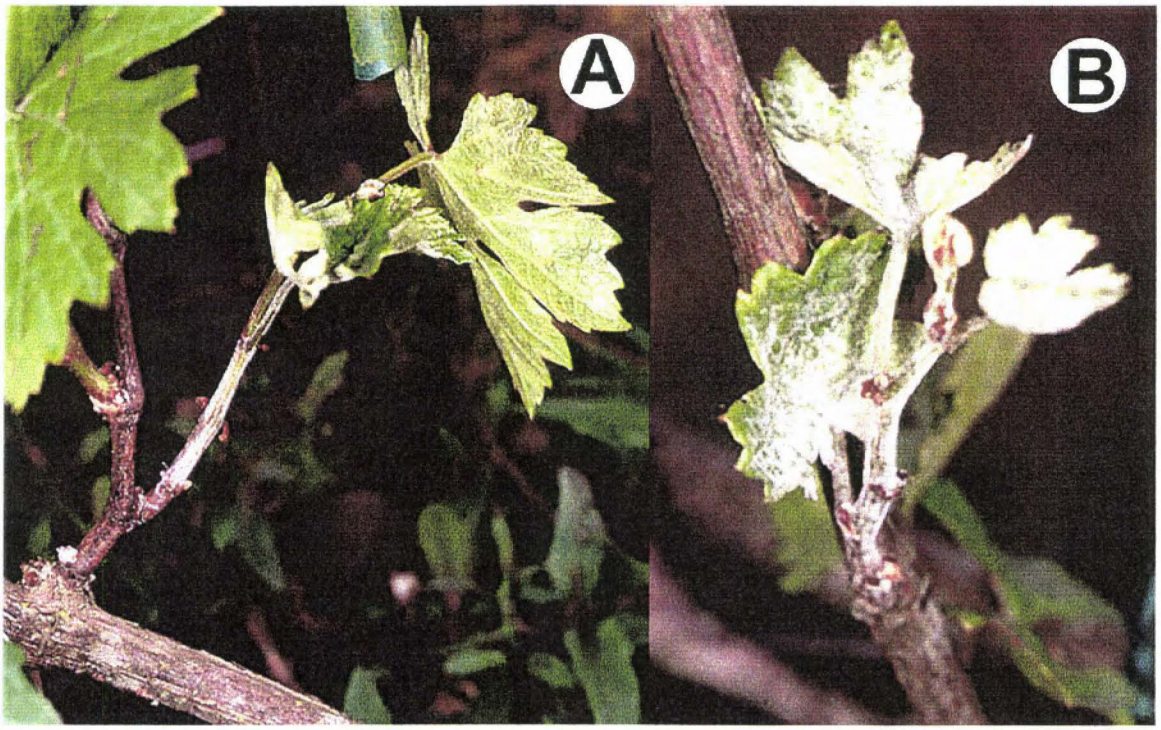

Figure 4: First documented flag shoots in Oregon. Flag shoots were discovered on an abandoned block of grape at the Oregon State University Botany and Plant Pathology Experimental Farm, in Oregon. Flag shoot (A) and (B) were discovered on the same vine. The cane in each photograph is approximately 1.0 cm in diameter for scale.

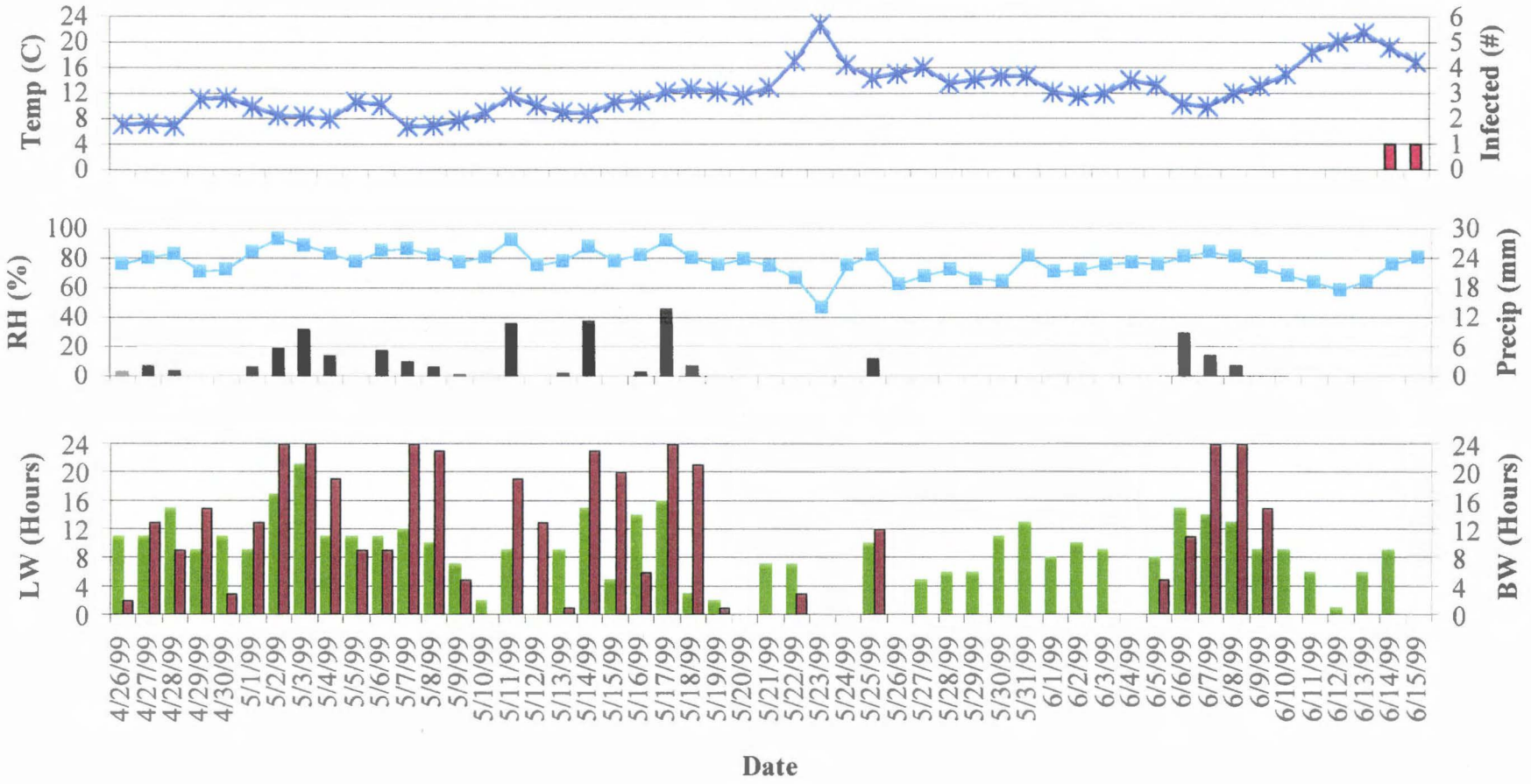

Figure 5: Detection of initial infection and summary of environmental data for 1999. Infections were detected with trap leaves placed in untreated or water treated Chardonnay blocks (red bars). Environmental data was calculated at 15 min intervals and is represented as the daily average temperature (dark blue line – cross marks), daily average relative humidity (light blue line – box marks), daily total precipitation (black bars), daily hours of leaf wetness (green bars), and daily hours of bark wetness (brown bars).

4.3.2 Ascospore Release Validation

In 1999, infections on trap leaves were detected from the positive control cordon piece on June 21st and from a field inoculated cordon control on June 28th. Two infected trap leaves were also detected from the negative control cordon piece on June 19th, indicating spore movement or contamination from an unexpected source, or from viable cleistothecia still remaining on the negative control cordon piece.

4.3.3 Cleistothecial Dispersal

The number of cleistothecia dispersed increased steadily throughout the sampling period and the total number of cleistothecia dispersed directly under the canopy was 74,475 cleistothecia/linear meter of canopy (width of canopy = 0.5 m)(Figure 6). Dispersal within 0.3 m from the cordon on the windward and leeward side of the canopy accounted for 95 and 77% of the total number of dispersed cleistothecia, respectively (Figure 7). Dispersal numbers rapidly decreased as the sample distance increases away from the cordon. Windward samples beyond 0.9 m and leeward samples beyond 1.2 m did not contain any cleistothecia. The total number of cleistothecia dispersed from the canopy based on this dispersal gradient was estimated to be approximately 95,300 cleistothecia/linear meter of canopy.

Viability of ascospores within the sub-sampled melanized cleistothecia after storage varied with sampling date (Figure 6). Ascospore viability was determined to peak at 15 % for cleistothecia collected between October 12th to October 26th, while

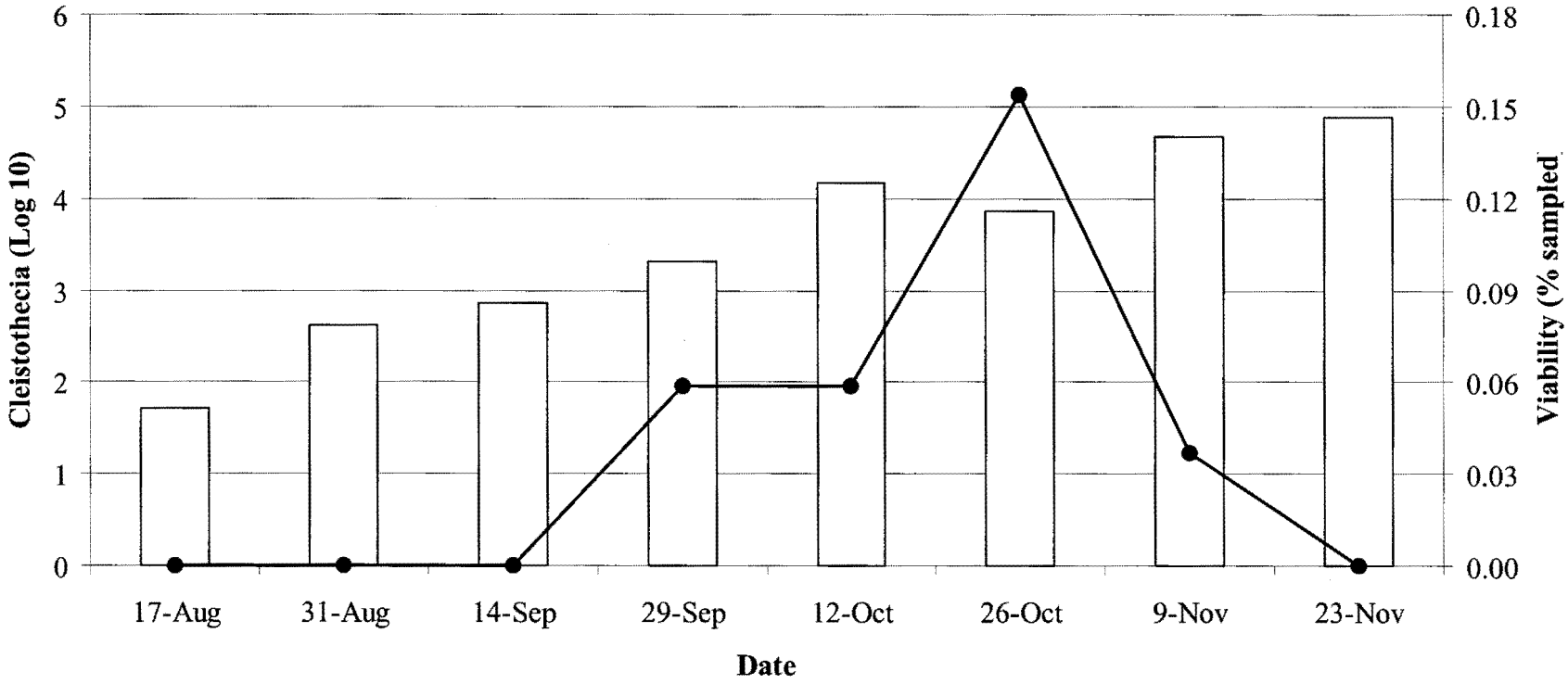

Figure 6: Total cleistothecia dispersed from mature untreated grape canopy and percent viability of stored cleistothecia at bud break. Cleistothecia were collected with filter paper funnels pinned to the cordons of mature grape. Collection was in two week intervals beginning August 17 and ending November 23, 1998. Total cleistothecia dispersed (white bars) were calculated for dispersal in one square meter. A sub-sample of melonized cleistothecia were stored in water at 4°C from time of collection until bud break (April 26) 1999. Percent viability (line with black data points) was determined using a FDA (0.001%) staining technique (17).

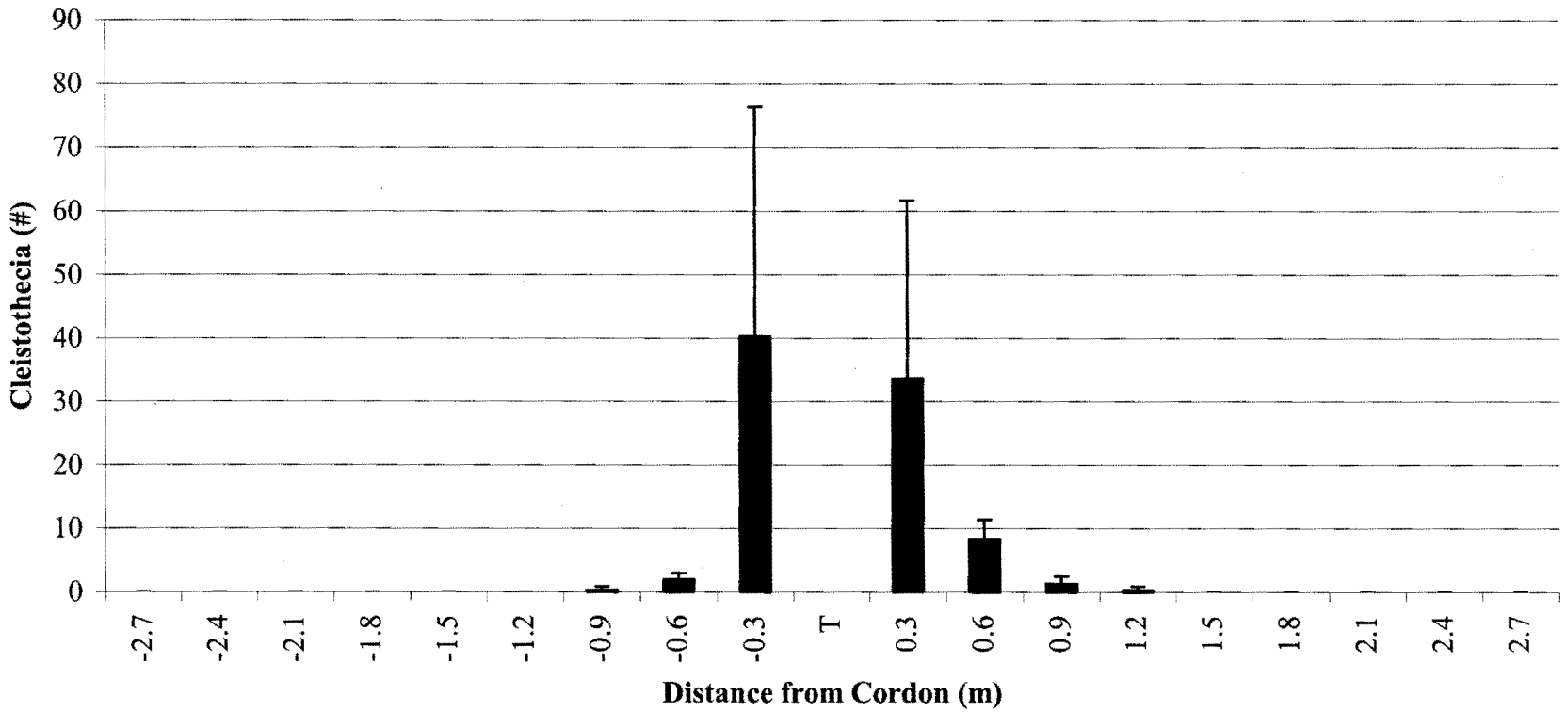

Figure 7: Distribution of naturally dispersed cleistothecia from a mature grape canopy. Cleistothecia were captured with filter paper funnels held at cordon level with wooden stakes. Dispersal was measured in 0.3 meter intervals from the trellis (T) to the west (- distance from cordon) and east (+ distance from cordon).

cleistothecia between September 14th and October 12th were observed to be 6 % viable. All other sample periods displayed no viable ascospores in the sub-sampled cleistothecia.

4.3.4 Environmental Data

Environmental data between bud break and disease onset is summarized in Figures 2, 3 and 5. No one distinct environmental parameter was found to account for disease onset during the three years of this study. Periods of precipitation followed by periods of dryness and conducive temperature for infection were not consistently followed by the detection of infection on trap leaves. Adjusted dates of disease onset (below) did not consistently correlate to patterns in the environmental date.

4.3.5 Bark Wetness Data

Initial bench tests of the response to wetting by the bark wetness sensors indicated relative dryness between 750 to 1000 Ω (Figure 8). Resistance measurements below 750 Ω indicate saturated bark and above 1000 Ω indicate bark that may be damp in some sites, but is generally dry. A typical field response of the bark wetness sensors to wetting from natural precipitation was compared to leaf wetness sensors (Figure 9). Comparing seventeen individual wetting events indicated that bark took longer to become saturated by an average of 2.6 (+/- 1.5) hours, and stayed saturated for an average of 3.8 (+/- 5.7) hours after dryness was indicated by the leaf wetness sensor (Figure 10). Field response of the bark wetness sensors was typical of cyclic wetting and drying events due to rainfall and subsequent drying.

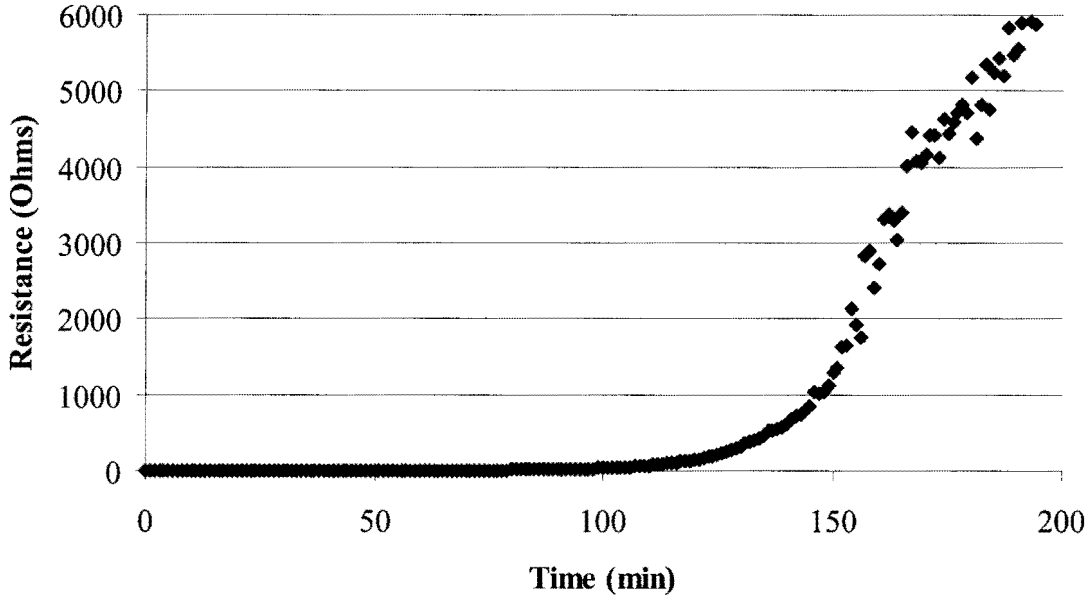

Figure 8: Response of bench tested bark wetness sensors. Two bark wetness sensors were saturated with water at time zero and allowed to dry at room temperature. Wetness is indicated as low electrical resistance, which increases as the bark dries. Dryness is estimated between 750 and 1000 Ohms.

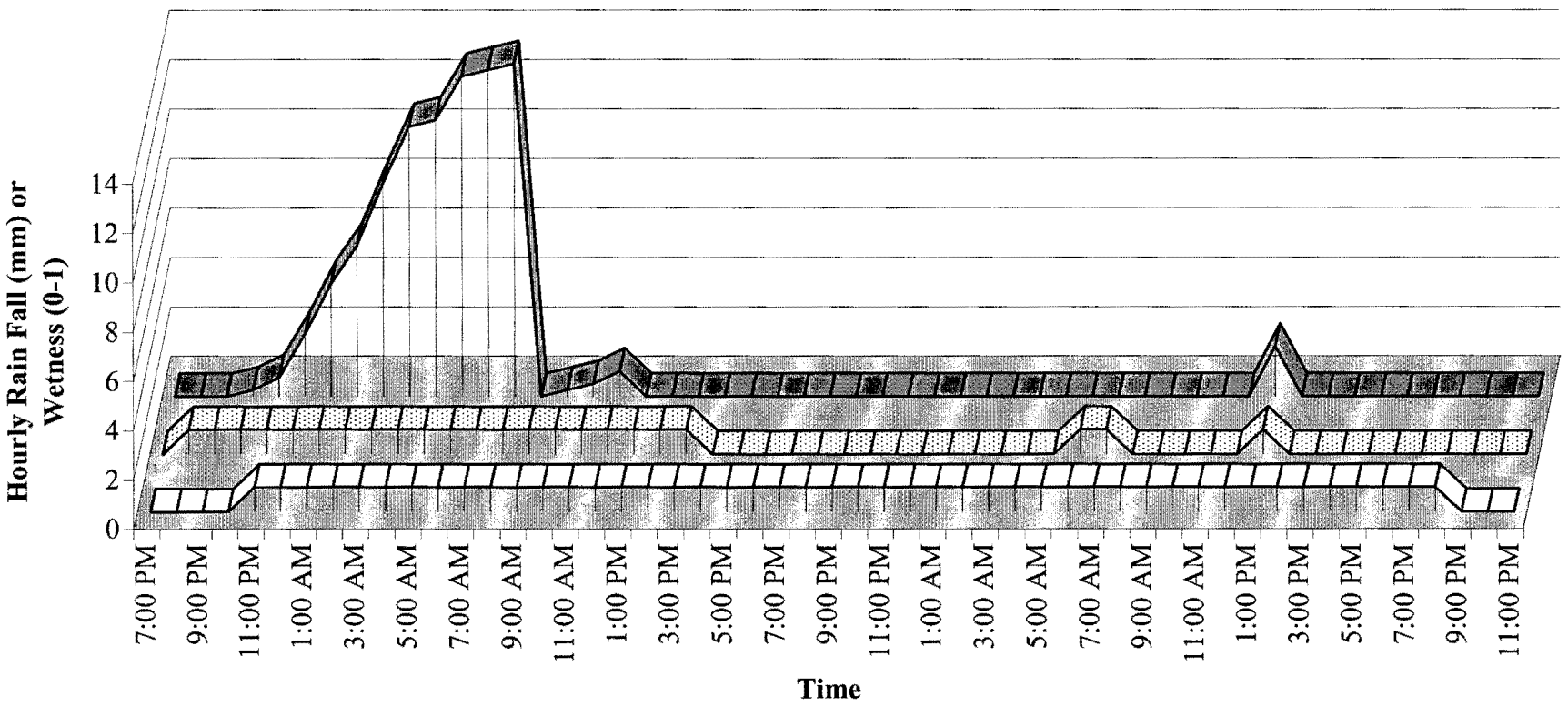

Figure 9: Leaf and bark wetness sensor response to a typical precipitation event. All sensors were located within 6 feet of each other in a mature grape canopy. The precipitation event (dark gray bars) data was collected with a single tipping bucket precipitation sensor at 15 minute intervals and averaged over the hour. Bark wetness (white bars) data was collected from two independent bark wetness sensors located adjacent to the grape cordon. Wetness from Bark sensors was calculated with a 1000 Ω wetness threshold. Leaf wetness (white bars with dots) data was collected from three independent leaf wetness sensors located near the top of the canopy, mid height in the canopy, and near the grape cordon. Data from bark and leaf wetness was collected on 15 minute intervals and averaged for the hour.

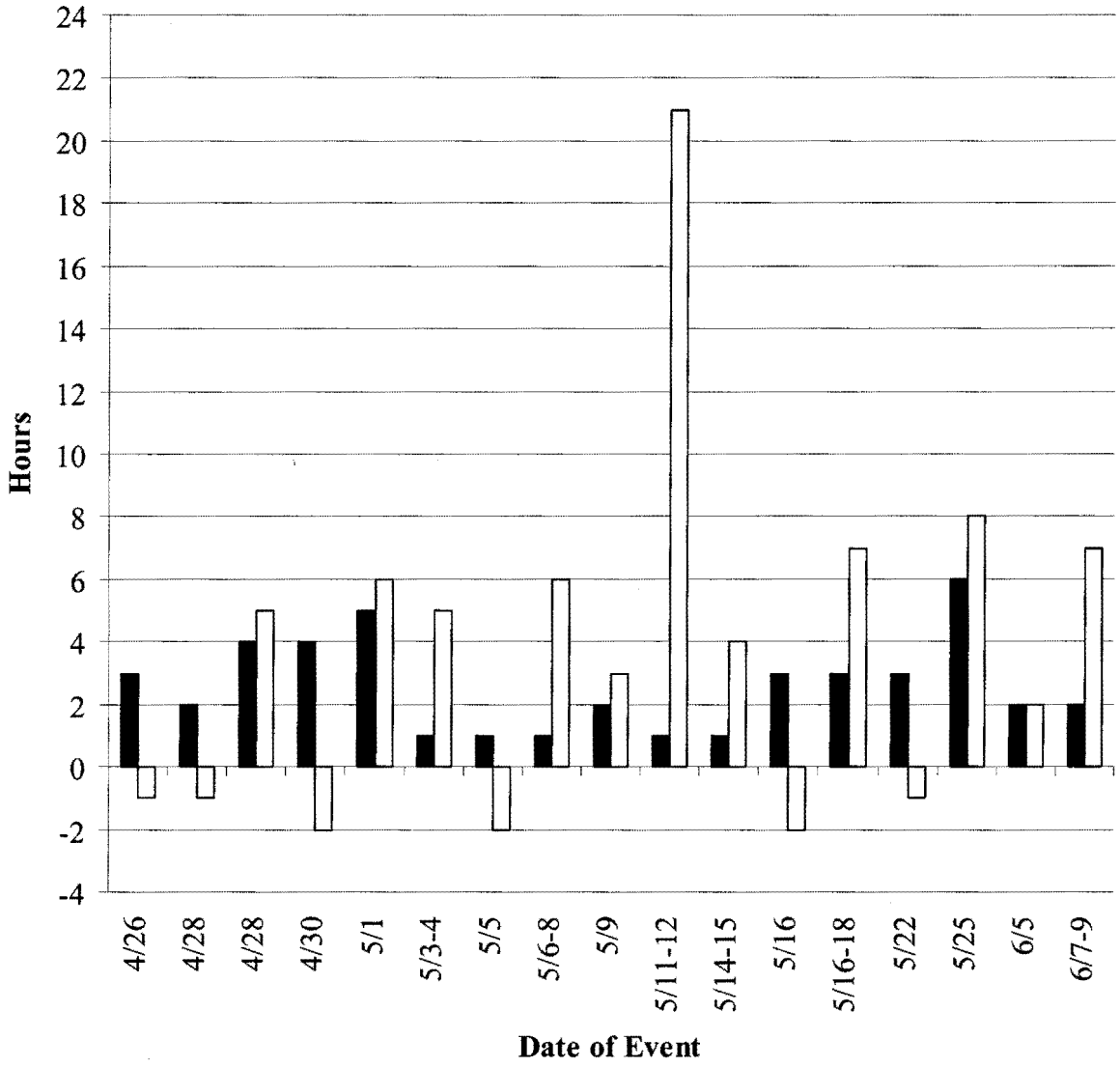

Figure 10: Relationship of seventeen distinct wetting events as recorded with leaf and bark wetness sensors in 1999. Black bars represent hours of delay in the time for the bark wetness sensors to indicate wetness with respect to the leaf wetness sensors. White bars represent hours of delay for the bark wetness sensors to indicate dryness with respect to the leaf wetness sensors. All sensors were located in the same block of mature grape.

4.3.6 Disease Onset Adjustments

Adjusted dates of disease onset were estimated for the possibility that the observed disease onset dates were actually the first or second round of secondary spread. Estimated disease onset dates based on the actual detection of the first round of secondary spread were between 6 to 7 days earlier than the actual detection of disease onset for each year (Table 4). Estimated disease onset dates based on the actual detection of the second round of secondary spread were between 13 to 16 days preceding the actual detection of disease onset for each year.

4.3.7 Forecasting Program Evaluation

The forecasting programs predicted initial fungicide applications an average of 41 days early than the detection of onset with the trapping systems for the three evaluated years (Table 5). In most cases, the forecasting programs predicted initial spray events during or after bud break. Bud break occurred on April 28, 1997, April 27, 1998, and April 26, 1999. It is unlikely that a grower would apply fungicides at bud break, so predictions of initial spray dates at, or before, bud break where discarded when possible. The Oi Diag program predicted initial sprays before bud break in 1997 and 1999, and no additional predictions could be made with the program in its current state. The New York program predicted initial spray events during bud break in 1997 and 1999. The next prediction of the New York program occurred two and five days following bud break in 1997 and 1999, respectively. The UC – Davis program predicted the initial

Table 4: Observed dates of powdery mildew infection onset and estimated previous infection periods based on time to sporulation at actual average temperatures.

	Year		
Infection Period	1997	1998[y]	1999
Observed Infection	June 5	June 15	June 12-14
Estimated First Round[w]	May 30 (7)[z]	June 8 (7)	June 6 (6)
Estimated Second Round[x]	May 23 (14)	June 2 (13)	May 29 (16)

[w]Estimated initial infection dates if the actual infection dates were the first round of secondary spread.

[x]Estimated initail infection dates is the actual infection dates were the second round of secondary spread.

[y]Dates for 1998 are based on detection of disease with trap leaves in the mature grape blocks.

[z]Difference in days between observed disease onset and estimated previous infection period

Table 5: Evaluation of three forecasting programs in predicting initial fungicide application dates in comparison to the actual and estimated dates of disease onset.

Forcasting Program	Predicted Initial Spray[w]	Days Preceding Observed and Estimated Onset		
		Observed Onset[x]	Estimated First Secondary[y]	Estimated Second Secondary[z]
Oi Diag				
1997	April 23	45	38	31
1998	May 3	44	37	31
1999	April 11	62 - 64	58	48
New York				
1997	April 30	38	31	24
1998	May 6	38	31	25
1999	May 1	42 - 44	36	26
UC - Davis				
1997	May 23	13	7	0
1998	May 3	43	36	30
1999	May 4	39 - 41	33	25

[w]Dates represent first predictions or prediction that occurred after bud break if available from forecasting program.

[x]Onset of disease based on actuall observed infection with trap plant (1997) or trap leaves (1998-1999).

[y]Onset of disease based on estimated date preceding observed infection by one round of secondary spread.

[z]Onset of disease based on estimated date preceding observed infection by two rounds of secondary spread.

spray event of 1997 during bud break. The next prediction of the UC – Davis program was 24 days later.

The difference in average days between the predicted initial spray for the three programs and disease onset was reduced when accounting for the possibility that the actual observed disease onset was either the first or second round of secondary spread. Average days between predicted initial spray dates and estimated onset dates were 34 and 27 days for the first and second rounds of secondary spread, respectively.

The forecasting program that performed the best over the duration of the study was the UC – Davis program with an average initial spray application of 32 days before the actual detection of disease onset. Additionally, the UC – Davis program predicted the initial spray event on the day flag shoot infections were discovered in 1998.

No attempted modifications provided consistent improvements to the predictive ability of the models. A modification to the UC – Davis program including the addition of a 10° C temperature threshold resulted in the elimination of two initial spray predictions delaying the initial spray prediction by a total of 13 days in 1999. This simple modification used the temperature requirement for release of the New York program (10° C) as a lower temperature threshold for the evaluation of infection periods. Infection periods occurring during temperatures below 10° C were ignored. Other lower temperature thresholds were tried and where determined to impaired the ability of the program to produce predictions with leaf wetness as the driving wetness parameter. Bark wetness was also substituted for leaf wetness in 1999 to determine the initial spray event by the UC – Davis program, but did not result in improved predictions.

4.4 Discussion

Over the three-year period of the study, all three forecasting programs were too conservative in initiating the first fungicide application. The forecasting programs called for the first control application an average of 44 days before disease could be detected in the field. This would result in an average of 3 – 6 additional control applications based on a 7 – 14 day application interval. Controlling powdery mildew early in the disease cycle has been shown to be the most effective period in controlling the disease (11,63). The importance of controlling the infections early has lead to forecasting programs that are extremely conservative in the initiation of their control program in Oregon. The destructive nature of *U. necator* and the low acceptable threshold of disease have lead to forecasting programs with a large initial spray event prediction buffer. Ideally, restricting the additional control applications by 1 or 2 sprays would allow for an initial spray event buffer, but also reduce the total number of unnecessary sprays.

Modification of the UC – Davis program produced the best results with the actual disease onset date closest to the initial spray predictions. Modifications included the substitution of bark wetness data for leaf wetness in the 2/3 Mills table and additional lower temperature requirements for the initiation of control measures. Bark is the overwintering location of cleistothecia and should provide better moisture results for the conditions in bark than estimations with leaf wetness sensors. The additional temperature parameters should be tested in subsequent years and could provide a basis for the adjustment of the 2/3 Mills table. Ultimately, substitution of the 2/3 Mills table for a table based on the biological parameters of *U. necator* may provide an adequate forecasting model, but the underlying biology being modeled needs to be improved.

The possibility that disease onset data collected with the plant and leaf trapping system could have been detecting secondary spread could not be ruled out. However, it is unlikely that disease onset was missed by more than two secondary spread periods due to the intensity of field scouting during the trapping observations. Additionally, disease was first encountered at relatively low levels when discovered in the field, and was only discovered on leaves immediately adjacent to cordons. Modified disease onset dates still did not consistently correlate with environmental data for likely release periods.

Cleistothecia have been assumed to be the primary source of initial inoculum in the Willamette Valley. However, in 1998 we observed flag shoots in two separate groups of abandoned vines. The winter previous to the discovery of flag shoots was particularly mild and may have contributed to the survival of *U. necator* within infected buds. It has been shown that infected buds are more susceptible to winter damage and therefore increased survival of flag shoots can be expected during mild winters (59). Also, both groups of vines had been abandoned for several seasons allowing severe, uncontrolled, and early powdery mildew infection the year before the detection of flag shoots. Flag shoots were not discovered in multiple surveys of an abandoned vineyard in its first season of abandonment. Harsher winter conditions and early disease levels in the previous season could have not been conducive to vegetative overwintering. Flag shoots have not been reported in commercial vineyards with currently active control measures, but spread from escaped vines could be a previously unconsidered source of initial inoculum. This is the first known report of the presence of flag shoots in Oregon.

Cleistothecia are still believed to be the primary source of initial inoculum in commercial vineyards of the Willamette Valley. The location and low intensity of initial

infections support this hypothesis. Cleistothecia are distributed in high numbers to the cordon of the parent plant. Ascospore release was believed to be detected for naturally dispersed and artificially collected cleistothecia in the validation experiment, even though other forms of contamination could have been possible. The negative control in the ascospore validation experiment did result in infections on one day of the trial. Grape plants with infected leaves were placed inadvertently within the proximity of the validation area and conidia could have spread from the grape material to the validation area. Other possible explanations could be that ascospores had traveled from nearby cordon pieces into the negative control area, or cleistothecia could have remained viable for two winters after the cordon wood was removed from the parent vineyard. However, it is interesting that the infections detected in the validation were detected shortly after disease onset detection in the field.

5. Conclusion

This study was intended to be an introductory investigation into the underlying parameters of the epidemiology of powdery mildew of grape in the Willamette Valley of Oregon. Focusing on two distinct areas of *U. necator* research has allowed for a diverse initial investigation, which will be used to set the future direction of research for the region.

Vine shelters have proven to be adequate in limiting the distribution and intensity of powdery mildew infections in newly established vineyards. Increased temperatures within the vine shelters are believed to be the primary factor limiting the ability of *U. necator* to infect and proliferate. Exclusion of powdery mildew spores is also believed to contribute to the observed reduction in powdery mildew infections with proper vine shelter use. The only limiting factors of powdery mildew reduction associated with vine shelter use are the necessity of proper installation and the maintenance of the installation during the growing season. Both limiting factors require additional costs of installation and maintenance that should be weighed against the cost of controlling the disease with conventional methods.

An effective method for determining the onset of disease in the field was developed for aiding the investigation of the adequacy of three prominent forecasting programs. These forecasting programs were developed in different grape growing regions and have proven to be inadequate in their present form for the proper initiation of a disease control program for the Willamette Valley. However, this investigation has generated some testable modifications to the UC – Davis program that could prove useful with subsequent testing. Additionally, interest has been expressed in a forecasting

program that will predict control spray events with the use of two to three day weather forecasts. Using forecasted weather events would allow a grower the flexibility of getting control sprays into the field before an actual infection event. A forecasting program for the Willamette Valley will be the ultimate goal of future research into this area. Additional research will be necessary to understand the requirements of cleistothecial overwintering, and the parameters associated with the release and subsequent infection from ascospores. A forecasting model based on the epidemiological parameters of *U. necator* should provide a valuable tool to the grape industry in the Willamette Valley.

The discovery of flag shoots could have epidemiological significance for determining disease onset in Oregon. Environmental parameters resulting in bud perennation should be investigated and the presence of flag shoots should be monitored to determine how often this form of overwintering is occurring.

Bibliography

1. Oregon's rank in the nation's agriculture: 1996. 1996 - 1997 Oregon Agricultural & Fisheries Statistics. Salem, Oregon: USDA: National Agriculture Statistics Service, 1997.

2. 1997 Oregon Vineyard Report. Portland, Oregon: Oregon Agricultural Statistics Service, 1998.

3. 1998 Oregon Vineyard Report. Portland, Oregon: Oregon Agricultural Statistics Service, 1999.

4. Bleyer G, Huber B, Kassemeyer HH. Investigations on relationships of treatments before bloom against *Uncinula necator* appearance of flag shoots and epidemics on leaves and grapes in 1993-1997. Magarey PA, Tschirpig KL, Scarfe BF. Third International Workshop on Grapevine Downy and Powdery Mildew - Book of Abstracts. 1998. (SARDI Research Report Series; vol 22).

5. Bulit, J., and Lafon, R. 1978. Powdery mildew of the vine. Pages 525-48 in: The Powdery Mildews. D. M. Spencer, eds. Academic Press.

6. Candolfi-Vasconcelos CM. The history and development of integrated production in Europe. Oregon State University, 1997.

7. Candolfi-Vasconcelos CM, Edge DW, Fisher GC, Hellman E, Pscheidt JW, William RD. 1998 Pest management guide for wine grapes in Oregon. Oregon State University Extension Service, 1998.

8. Chellemi, D. O., and Marois, J. J. 1988. Environmental effects on conidia production by *Uncinula nector*. Phytopathology. 78:1573.

9. Chellemi, D. O., and Marois, J. J. 1991. Effect of fungicides and water on sporulation of *Uncinula necator*. Plant Disease. 75:455-457.

10. Chellemi, D. O., and Marois, J. J. 1992. Influence of leaf removal, fungicide applications, and fruit maturity on incidence and severity of grape powdery mildew. American Journal of Enology and Viticulture. 42:53-57.

11. Chellemi, D. O., and Marois, J. J. 1991. Development of a demographic model for *Uncinula necator* by using a microcomputer spreadsheet program. Phytopathology. 81:250-254.

12. Cortesi, P., Bisiach, M., Ricciolini, M., and Gadoury, D. M. 1997. Cleistothecia of *Uncinula necator* - An additional source of inoculum in Italian vineyards. Plant Disease. 81:922-926.

13. Cortesi, P., Gadoury, D. M., Seem, R. C., and Pearson, R. C. 1995. Distribution and retention of cleistothesia of *Uncinula necator* on the bark of grapevines. Plant Disease. 79:15-19.

14. Delp, C. J. 1954. Effect of temperature and humidity on the grape powdery mildew fungus. Phytopathology. 44:615-626.

15. Delye, C., Laigret, F., and Corio-Costet, M.-F. 1997. A mutation in the 14α-Demethylase gene of *Uncinula necator* that correlates with resistance to a sterol biosynthesis inhibitor. Applied and Environmental Microbiology. 63:2966-2970.

16. Diehl, H. J., and Heintz, C. 1987. Studies on the generative reproduction of grapevine powdery mildew (*Uncinula necator* Berk.). Vitis. 26:114-122.

17. Doster, M. A., and Schnathorst, W. C. 1985. Effects of leaf maturity and cultivar resistance on development of the powdery mildew fungus on grapevines. Phytopathology. 75:318-321.

18. Due, G. 1990. The use of polypropylene shelters in grapevine establishment - A preliminary trial. The Australian Grapegrower & Winemaker. June:29-33.

19. Due, G. 1996. Vineguards: How to get the results you want. The Australian Grapegrower & Winemaker. May:32-36.

20. English-Loeb G, Norton AP, Gadoury DM, Seem RC, Wilcox WF. Mycophagous mites as regulators of powdery mildew on grape. Magarey PA, Tschirpig KL, Scarfe BF. Third International Workshop on Grapevine Downy and Powdery Mildew - Book of Abstracts. 1998. (SARDI Research Report Series; vol 22).

21. Evans, K. J., Scott, E. S., and Whisson, D. L. 1997. Heterothallism among South Australian clonal lines of *Uncinula necator*. Australasian Plant Pathology. 26:10-20.

22. Falk, S. P., Gadoury, D. M., Cortesi, P., Pearson, R. C., and Seem, R. C. 1995. Parasitism of *Uncinula necator* cleistothecia by the mycoparasite *Ampelomyces quisqualis*. Phytopathology. 85:794-800.

23. Falk, S. P., Gadoury, D. M., Pearson, R. C., and Seem, R. C. 1995. Partial control of grape powdery mildew by the mycoparasite *Ampelomyces quisqualis*. Plant Disease. 79:483-490.

24. Farr, D. F., Bills, G. F., Chamuris, G. P., and Rossman, A. Y. 1989. ***Uncinula***. Pages 1006 in: Fungi on Plants and Plant Products in the United States. D. F. Farr, G. F. Bills, G. P. Chamuris, and A. Y. Rossman, eds. APS Press.

25. Fessler, C., and Kassemeyer, H. H. 1995. The influence of temperature during the development of conidia on the germination of *Uncinula necator*.

26. Gadoury DM, Seem RC, Wilcox WF. The early development of ontogenic resistance to powdery mildew in fruit of *Vitis labrucana* and *Vitis vinifera* grapevines. Magarey PA, Tschirpig KL, Scarfe BF. Third International Workshop on Grapevine Downy and Powdery Mildew - Book of Abstracts. 1998. (SARDI Research Report Series; vol 22).

27. Gadoury, D. M., and Pearson, R. C. 1988. Initiation, development, dispersal, and survival of cleistothesia of *Uncinula necator* in New York vineyards. Phytopathology. 78:1413-1421.

28. Gadoury, D. M., and Pearson, R. C. 1990. Ascocarp dehiscence and ascospore discharge in *Uncinula necator*. Phytopathology. 80:393-401.

29. Gadoury, D. M., and Pearson, R. C. 1990. Germination of ascospores and infection of *Vitis* by *Uncinula necator*. Phytopathology. 80:1198-1203.

30. Gadoury, D. M., and Pearson, R. C. 1991. Heterothallism and pathogenic specialization in *Uncinula necator*. Phytopathology. 81:1287-1293.

31. Gadoury, D. M., Pearson, R. C., Riegel, D. G., Seem, R. C., Becker, C. M., and Pscheidt, J. W. 1994. Reduction of powdery mildew and other diseases by over-the-trellis applications of lime sulfur to dormant grapevines. Plant Disease. 78:83-87.

32. Gemmrich, A. R., and Seidel, M. 1996. Immunodetection of overwintering *Oidium* mycelium in bud scales of *Vitis vinifera* . Vitis. 35:63-64.

33. Grove, G., Davis, G., Duplaga, B., and Boal, R. 1999. Powdery mildew of grape: Perennation of uncinula necator in eastern Washington. Phytopathology. 89:S30.

34. Gubler, W. D., Fogle, D. G., and Chellemi, D. O. 1988. Viability and pathogenicity of *Uncinula necator* ascospores in California. Phytopathology. 78:1572.

35. Gubler, W. D., and Hirschfelt, D. J. 1992. Powdery Mildew. Pages 57-63 in: Grape Pest Management. D. L. Flaherty, P. L. Christensen, T. W. Lanini, J. J. Marois, P. A. Phillips, and L. T. Wilson, eds. Division of Agricultural and Natural Resources, University of California

36. Gubler WD, Thomas CS. Control of grapevine powdery mildew using the U.C. Davis risk assessment model. Magarey PA, Tschirpig KL, Scarfe BF. Third International Workshop on Grapevine Downy and Powdery Mildew - Book of Abstracts. 1998. (SARDI Research Report Series; vol 22).

37. Gubler, W. D., Ypema, H. L., Ouimette, D. G., and Bettiga, L. J. 1996. Occurence of resistance in *Uncinula necator* to Triadimefon, Mycobutanil, and Fenarimol on California grapevines. Plant Disease. 80:902-909.

38. Hansen, M. 1998. Grow tubes are hot in grape production. Good Fruit Grower. 49(3).

39. Jailloux, F., Thind, T., and Clerjeau, M. 1998. Release, germination, and pathogenicity of ascospores of *Uncinula necator* under controlled conditions. Canadian Journal of Botany. 76:777-781.

40. Jordan D. Sustainable viticulture scorecard evaluation. Devnonport, Auckland, New Zealand: Vine to Wine, 1996.

41. Kappor JN. *Uncinula necator*. C.M.I. Descriptions of Pathogenic Fungi and Bacteria No. 160. Kew, Surrey, England: Commonwealth Mycological Institute, 1967.

42. Kast WK. Experience about the Oidiag-System against powdery mildew (*Uncinula necator*) in 1994 to 1997. Magarey PA, Tschirpig KL, Scarfe BF. Third International Workshop on Grapevine Downy and Powdery Mildew - Book of Abstracts. 1998. (SARDI Research Report Series; vol 22).

43. Lakso, A. N., Pratt, C., Pearson, R. C., Pool, R. M., Seem, R. C., and Welser, M. J. 1982. Photosynthesis, transpiration, and water use efficiency of mature grape leaves infected with *Uncinula necator* (powdery mildew). Phytopathology. 72:232-236.

44. MacDonald, A. 1997. An Integrated Production Program for Oregon Vineyards . Personal Communication.

45. Main, G. 1997. Use of grape grow tubes. Viticulture Science Symposium and Workshops. June 5-6.

46. Messelink G, Balasubramaniam R, Magarey PA, Alspach P, Emmett RW. Modeling grapevine powdery mildew epidemics in Australia and New Zealand for threshold based spraying. Magarey PA, Tschirpig KL, Scarfe BF. Third International Workshop on Grapevine Downy and Powdery Mildew - Book of Abstracts. 1998. (SARDI Research Report Series; vol 22).

47. Mills, W. D. 1944. Effective use of sulfur dust and sprays during rain to control apple scab. Cornell Extension Bulletin. 630:4.

48. Northover, J., and Schneider, K. E. 1996. Physical modes of action of petroleum and plant oils on powdery and downy mildews of grapevines. Plant Disease. 80:544-550.

49. Orlandini S, Bellesi S, Moriondo M, Rosa M. Agrometeorological models for downy and powdery mildew on grapevine. Magarey PA, Tschirpig KL, Scarfe BF. Third International Workshop on Grapevine Downy and Powdery Mildew - Book of Abstracts. 1998. (SARDI Research Report Series; vol 22).

50. Ough, C. S., and Berg, H. W. 1979. Research Note: Powdery mildew sensory effect on wine. American Journal of Enology and Viticulture. 30:321.

51. Pady, S. M., and Subbayya, J. 1970. Spore release in *Uncinula necator*. Phytopathology. 60:1702-1703.

52. Pascal, R. C. 1997. Soil, climate, passion: Blazing the Oregon Trail, Part 1. American Vineyard. May:6-9.

53. Pearson, R. C. 1994. Fruit and foliar diseases caused by fungi: Powdery Mildew. Pages 9-11 in: Compendium of Grape Diseases. R. C. Pearson and A. C. Goheen, eds. APS Press

54. Pearson, R. C. 1982. Chemical control of *Botrytis cinerea* on grapes in New York (USA). EPPO Bulletin. 12:101-104.

55. Pearson, R. C., and Gadoury, D. M. 1987. Cleistothecia, the source of primary inoculum for grape powdery mildew in New York. Phytopathology. 77:1509-1514.

56. Pearson, R. C., and Gadoury, D. M. 1992. Powdery Mildew of Grape. Pages 129-46 in: Plant Diseases of International Importance. J. Kumar, H. S. Chaube, U. S. Singh, and A. N. Mukhopadhyay, eds. Prentice Hill, Englewood Cliffs, New Jersey

57. Pearson, R. C., and Gartel, W. 1985. Occurrence of hyphae of *Uncinula necator* in buds of grapevine. Plant Disease. 69:149-151.

58. Pearson, R. C., and Taschenberg, E. F. 1980. Benomyl-resistant strains of *Uncinula necator* on grapes. Plant Disease. 64:677-680.

59. Pool, R. M., Pearson, R. C., Welser, M. L., Lakso, A. N., and Seem, R. C. 1984. Influence of powdery mildew on yield and growth of rosette grapevines. Plant Disease. 68:590-593.

60. Pscheidt JW, Wallace LD, Hall T, Mahaffee W. Evaluation of grape powdery mildew forecasting programs, 1997. Pscheidt JW. Extension Plant Pathology: Fruit and Ornamental Disease Management Testing Program. Corvallis, OR: Oregon State University, 1998.

61. Pscheidt JW, Wittig HPP, Candolfi-Vasconcelos MC. Evaluation of grape powdery mildew forecasting programs, 1996. Pscheidt JW. Extension Plant Pathology: Fruit and Ornamental Disease Management Testing Program. Corvallis, OR: Oregon State University, 1997.

62. Sall, M. A. 1981. Mildew severity related to vineyard environment. California Grape Grower. September:20 & 24.

63. Sall, M. A. 1980. Epidemiology of grape powdery mildew: A model. Phytopathology. 70:338-342.

64. Sall, M. A., and Wrysinski, J. 1982. Perennation of powdery mildew in buds of grapevines. Plant Disease. 66:678-679.

65. Sall, M. A., Wrysinski, J., and Schick, F. J. 1983. Temperature-based sulfur applications to control grape powdery mildew . California Agriculture. July-August:4-5.

66. Salmon ES. A monograph of the Erysiphaceace. Mem. Torrey Bot. Club., 1900.

67. Schneider S, Gadoury DM, Kassemeyer HH. The role of cleistothecia in the epidemiology of grape powdery mildew in Germany. Magarey PA, Tschirpig KL, Scarfe BF. Third International Workshop on Grapevine Downy and Powdery Mildew - Book of Abstracts. 1998. (SARDI Research Report Series; vol 22).

68. Seem, R. C. 1984. Disease incidence and severity relationships. Annual Review of Plant Phytopathology. 22:133-150.

69. Shoemake, J., Wample, R., and Mills, L. 1999. Grow tubes impact vine performance. Washington State University Grape Research News. 10:5-8.

70. Silvapalan, A. 1993. Effects of water on germination of powdery mildew conidia. Mycological Research. 97:71-76.

71. Smith, C. G. 1970. Production of powdery mildew cleistocarps in a controlled environment. Transactions British Mycological Society. 55:355-365.

72. Stadornov, O. I. 1969. O zimovke vozbuditelya oidium Vinograda [Overwintering of the causal agent of oidium of Grapevine]. Review of Applied Mycology. 48:566.

73. Stapleton, J. J., Gubler, W. D., Fogle, D., Chellemi, D., Bettiga, L., Leavitt, G., et al. 1988. Relationships among climate, primary inoculum source, dormant and post-emergence control sprays, and grape powdery mildew in California. Phytopathology. 78:1531.

74. Steinkellner, S. 1998. Overwintering of *Uncinula necator* in Austrian vineyards. Vitis. 37:193-194.

75. Thomas, C. S., Gubler, W. D., and Leavitt, G. 1994. Field testing of a powdery mildew disease forecast model on grapes in California. Phytopathology. 84:1070.

76. van der Spuy, J. E., and Matthee, F. N. 1977. Overwintering of the oidium stage of *Uncinula necator* in the buds of the grapevine. Plant Disease Reporter. 61:612-615.

77. Wicks, T. J., and Magarey, P. 1985. First report of *Uncinula necator* cleistothecia on grapevines in Australia. Plant Disease. 69:727.

78. Widholm, J. M. 1972. The Use of Fluorescein Diacetate and Phenosafranine for Determining Viability of Cultured Plant Cells. Stain Technology. 47:189-194.

79. Wilcox, W. F., Gadoury, D. M., and Seem, R. C. 1997. Recent findings on control of grapevine powdery mildew. Grape Research News. 8:1-6.

80. Willocquet, L., Berud, F., Raoux, L., and Clerjeau, M. 1998. Effects of wind, relative humidity, leaf movement, and colony age on dispersal of conidia of *Uncinula necator*, causal agent on grape powdery mildew . Plant Pathology. 47:234-242.

81. Willocquet, L., and Clerjeau, M. 1998. An analysis of the effects of envirinmental factors on conidial dispersal on *Uncinula necator* (grape powdery mildew) in vineyards. Plant Pathology. 47:227-233.

82. Willocquet, L., Colombet, D., Rougier, M., Fargues, J., and Clerjeau, M. 1996. Effects of radiation, especially ultraviolet B, on conidial germination and mycelial growth of grape powdery mildew. European Journal of Plant Pathology. 102:441-449.

83. Yarwood, C. E. 1957. Powdery Mildews. The Botanical Review. 23:235-298.

84. Ypema, H. L., and Gubler, W. D. 1997. Long-term effect of temperature and Triadimefon on proliferation of *Uncinula necator*: Implications for fungicide resistance and disease risk assessment. Plant Disease. 81:1187-1192.

85. Ypema, H. L., Ypema, M., and Gubler, W. D. 1997. Sensitivity of *Uncinula necator* to Benomyl, Triadimefon, Myclobutanil, and Fenarimol in California. Plant Disease. 81:293-297.