

EPIDEMIOLOGY AND MANAGEMENT OF WALNUT BLIGHT

J. E. Adaskaveg, H. Förster, D. Thompson, G. Driver, J. Connell and R. Buchner
Cooperators: T. Prichard, J. Hasey, and J. Grant

SUMMARY

Environmental conditions in the spring of 2005 were highly conducive for walnut blight. Favorable temperatures and rainfall occurred into May and consequently, disease incidence increased until late spring on susceptible varieties. Disease incidence was especially high in orchards where the disease was not managed properly or managed with minimal early-season programs in the previous season. This year's studies again indicated that under highly conducive environments the only consistently effective program was multiple applications of copper-Manex with timings based on calendar or our XanthoCast model in controlling walnut blight in California. Potential alternatives such as the non-registered antibiotics may provide new materials to use in alternation with copper-Manex treatments, but additional studies will be needed. Famoxadone as a potential companion treatment similar to Manex did not perform as well as Manex in mixtures with copper. The biological control Sonata showed some efficacy and more work is needed to evaluate the performance under different growing seasons. Thus, our research continues to identify only moderately effective bactericides for agricultural uses under conducive environments for disease. None of the potential alternatives can replace copper-Manex treatments with equivalent levels of disease management. Thus, no other material is immediately available for management of copper-resistant populations of the walnut blight pathogen in California. Alternative materials such as agricultural antibiotics still may have promise and additional testing will be required to increase the performance (i.e., mixtures with copper) without causing injury under favorable environments for disease. As in previous years, our research demonstrated that one or two applications of copper-Manex at catkin or bud break could not satisfactorily control the disease when infection periods occur during later rainfalls. Thus, calendar- or host phenology and calendar-based application methods (e.g., bud break treatments) will not provide consistent disease control on all cultivars and in different years with different environments. Thus, we will continue to evaluate programs that use a combination of early pistillate (or catkin) flower emergence i.e., bud break (initiation of the model based on host phenology) and the epidemiological model (i.e., XanthoCast) to optimize timing of bactericides and disease control while minimizing the total number of applications. The model and the importance of rainfall in the development of epidemics were again experimentally verified in field studies with simulated rain and under ambient conditions. This indicates that walnut blight can be effectively managed with properly timed in-season applications prior to favorable environments. XanthoCast was commercially available for the industry to use through AgVise, Inc. (www.irrigate.net) for the Sacramento valley. Improved automated forecasts were developed by Fox Weather and will be continued to be developed in 2006. Walnut genotype susceptibility to blight was evaluated in a research orchard under simulated rainfall. After four years, high levels of disease were established in the orchard and genotypes could be ranked based on disease incidence.

INTRODUCTION

Walnut blight, caused by *Xanthomonas juglandis*, is a major disease of walnut in central and northern California. The pathogen attacks catkins, female blossoms, green shoots, leaves, buds, and fruit of English walnut. Fruit infections account for most of the economic loss in California. These infections commonly occur in the spring under wet conditions. The bacterium survives from one year to the next in buds (healthy and diseased), diseased fruit that remain on the tree, and possibly in twig lesions (Miller and Bollen 1946; Mulrean and Schroth 1982; Teviotdale et al. 1985, Ogawa and English 1991).

The concept of the disease triangle is essential for the development of the disease. The development of walnut blight is highly dependent on environmental conditions in the spring. Since 1997, our epidemiological research using models for predicting disease in any one season has shown that wetness and temperature can account for most of the variability ($R^2 = 0.70$ to 0.82) in our data sets. In 1998, severe epidemics of walnut blight caused substantial yield losses in northern California (Adaskaveg et al., 1998). In 1999 to 2002 low rainfall and cool temperatures were not conducive for the development of walnut blight (Adaskaveg et al. 2001) regardless of bud populations of the pathogen observed during the dormant period. With extensive wetness periods in the spring, epidemics again occurred in 2003, 2004, and 2005. Models for seasonal disease progress indicated that in most years (70% of the time) the disease progresses as a monomolecular (simple-interest curve) epidemic and that only in high-rainfall years the disease becomes a logistic (compound-interest curve) epidemic. This indicates that in most years (i.e., 1999 to 2002) infection periods for disease are initiated from the over-wintering or primary inoculum source (buds, twig lesions, etc.), provided that favorable environments for disease occur. Only with extensive wetness periods like that observed in 2003, 2004, and 2005 when the rate of development of new bacterial-producing infections (secondary spread) exceeds the rate of loss of bacterial-producing over-wintering inoculum a logistic epidemic occurs. The importance of wetness for the occurrence of walnut blight epidemics was also demonstrated in our simulated rain field trials. Based on data collected at the Kearney AgCenter in 2000-2004 where sprinkler-irrigated plots were established in a cv. Chico orchard that was considered to have a low disease incidence, we were able to obtain a significantly higher incidence of disease in the weekly 4 to 6-hr irrigation treatment than in the monthly irrigation or control treatments. Furthermore, we showed that pathogen populations measured within one hour of sampling of fruit increased significantly in the irrigated as compared to the non-irrigated treatments. Thus, we confirmed the importance of one of the major components of our model, i.e. leaf wetness, but we also showed that pathogen populations logarithmically increase on the surface of diseased fruit during and after an irrigation event. This event, when repeated over several days, leads to disease epidemics that follow logistic population (i.e., diseased nuts) growth curves.

A microclimate model to predict walnut blight in a forecasting system that is developed with all components of the disease triangle (host, pathogen, and environment) will help in the management of this potentially destructive disease of walnut. The host component in the triangle is defined by the phenological stage of development as well as by differential host resistance among walnut cultivars. In the pathogen component, inoculum appears to be the most predictable parameter to estimate in commercial orchards. This is because the pathogen is endemic in established walnut orchards throughout California. The previous year's disease incidence is an

excellent indicator of inoculum potential in the orchard for the next season because the pathogen has a high reproductive potential under conducive environments (as we have shown in our simulated-rain studies). For characterization of the environmental component of the disease triangle, our research has yielded several years of environmental and disease data for describing the seasonal development of walnut blight. The interaction of daily wetness period duration and temperature during the wetness period is important. The optimum temperature for *in vitro* bacterial growth is 28 to 32 C with a minimum of about 5 C and a maximum of 37 C, whereas infection of walnut tissues can occur between 5 and 27 C (Miller and Bollen 1946). Miller and Bollen (1946) also concluded that rainfall was involved in dissemination. Furthermore, based on growth chamber studies with potted plants, they concluded that wetness periods of only 5 min were sufficient for fruit infection of very young tissues that were “water-congested”. We have been clearly demonstrating in our research in 1994-95 and 1997-2005, that extended wetness periods and temperature are critical for disease development of walnut blight epidemics (i.e., not bacterial growth). Other parameters such as wind and relative humidity are weather parameters that need to be more critically evaluated in the field under natural inoculum levels.

Our research on the epidemiology of walnut blight has yielded several years of environmental and disease data for describing the seasonal development of walnut blight on Vina and Ashley cultivars. In 2000, we initiated XanthoCast™ as a forecasting model for walnut blight in cooperation with FieldWise Inc. The accumulation model utilizes wetness period duration and temperature (the two micro-environmental parameters that were shown to be critical for disease development in growth chamber and field studies) for calculating the risk of disease based on current ambient conditions for each field weather station. In 2004 and 2005 XanthoCast™ was provided by a new website (www.Agwise.com) and in 2006 this website will be changed to www.irrigate.net. Weather stations of the network are located between Red Bluff and Davis. Additional networks will be available through Western Farm Services in the San Joaquin valley. On the current website, an option of setting up personalized orchard-specific files with spray dates can be entered, and actual and predicted XanthoCast indices are then automatically summarized with the XanthoCalculator. Subsequent recommended spray dates can be easily called up. Up to five-day forecasts of walnut blight (increases in XanthoCast indices) based on microclimate weather forecasts and satellite rain analysis from Fox weather service are also available. In comparative field studies over the past years the XanthoCast model reduced the number of bactericide sprays as compared to calendar-based applications and disease control was similar for both application timings. In ongoing studies each year, the model is being validated under different climatic conditions, e.g. highly conducive and less favorable disease conditions. In addition, development of an algorithm that is based on precipitation instead of leaf wetness would allow the model to be used in locations where weather records are available, but no leaf wetness data are provided.

For management of walnut blight, chemical treatments have been the most commonly used practice. Natural host resistance against the disease among walnut cultivars is an additional strategy that could be exploited in breeding programs. We initiated studies in an existing variety plot at Kearney Agricultural Center where irrigation treatments were used to increase the natural incidence of disease and data were obtained in our disease evaluations.

For chemical control, copper-based compounds have historically been the most efficacious and the most widely used. Very effective, high-gallonage Bordeaux mixture sprays were used by Miller and Bollen (1946). From comparisons between application strategies done in these latter studies to the ones currently being done we conclude that changes in copper bactericide use and application method may have contributed to reduced efficacy of walnut blight management programs and to the development of copper-resistant populations of the pathogen. This has resulted in the need for alternative treatments and improved application methods. The introduction of copper-maneb treatments by Conover and Genhold (1981) with the application of two active ingredients has improved the efficacy of fixed copper treatments against copper resistant pathogen populations. Still, these treatments are not as persistent as high-volume Bordeaux applications. This information indicates the need for additional studies to improve the persistence of copper-maneb treatments, as well as of new bactericide materials. Thus, in 2005, new copper compounds were evaluated that included commercial pre-mixes of copper and calcium hydroxide (Cuprofix 40DF[®] - Cerexagri) or cuprous oxide with zinc (Nordox 30/30[®] - Monterey Chemical). A new formulation of Kocide, an encapsulated copper (e.g., GFJ52-008 – DuPont Chemical), was also evaluated. Two formulations of the fungicide famoxadone (i.e., Tanos – DuPont Chemical) were evaluated for possible synergistic activity with Kocide 2000.

Because of the development of copper-resistant pathogen populations, management of walnut blight is dependent on applications with higher rates of copper, addition of other bactericidal compounds to copper treatments (e.g., Kocide[®]-Manex[®]), or on new bactericidal treatments with different modes of action. Potential alternatives that have been evaluated by us include natural bactericidal products (Serenade), bactericidal sanitation treatments (e.g., DBNPA, Zerotol, Oxidate, etc.), systemic acquired host resistance (SAR) compounds (e.g., Actigard[®], Milsana[®]), and antibiotics (Starner). Starner is currently registered in Japan for control of bacterial diseases including those caused by *Xanthomonas* species. Although effective, it was no longer evaluated in our trials because it is known to develop resistance in pathogen populations and because this class of antibiotics is used medicine. The DOW bactericide DBNPA was effective in our trials and improved formulations were more persistent on the plant surface and resulted in no phytotoxicity. The manufacturer, however, will not proceed with registration because of the high costs of additional testing in feeding studies that have to be done. Zerotol[®] is an acidified hydrogen dioxide compound (peroxyacetic acid is the active ingredient in this and other products such as Oxidate[®] and Storox[®]), and is registered for suppression of fungal diseases on a wide range of crops. This material showed promise in our 2002 and 2003 trials, but its efficacy in 2004 was inconsistent. The antibiotic Kasumin[®] (kasugamycin - Arysta) is registered for agricultural use on fungal and bacterial diseases in Japan. This class of antibiotics is not being used in human and animal medicine, has a different mode of action from streptomycin or terramycin, and there is no cross-resistance known to occur. It was evaluated in 2004 with promising results and was therefore included into our 2005 trials. Agrimycin[®] (active ingredient is the antibiotic streptomycin) is registered on pome fruits against fire blight, but not on walnuts because of phytotoxicity problems (Buchner et al., 1998). Because Topfilm is a new natural-based adjuvant that has been shown to reduce phytotoxic effects of pesticides, this adjuvant was used in combination with these antibiotics. Data on walnut blight management using this antibiotic were also promising in 2004, and thus, it was evaluated again in 2005. A new biological control material containing *Bacillus pumilus* (Sonata - Agrquest) was also included in the 2005 evaluations.

The timing and number of bactericide treatments necessary for good disease control has been extensively investigated in the past and has been re-evaluated in recent years. As summarized for a large number of field trials that were conducted between 1931 and 1945 using high-gallonage Bordeaux mixture sprays (Miller and Bollen, 1946), a minimum of one application for seasons with very little rain to three or four applications for rainy seasons were found to be necessary for satisfactory disease control. Miller and Bollen (1946) also stress that the proper timing of the spray applications in relation to the stage of pistillate flower development and to the occurrence of rainfall is extremely important for successful blight control. Thus, using the highly persistent Bordeaux mixture, early and late pre-blossom applications were found to be most effective. Additional post-blossom applications (up to 7 weeks after the first treatment) were only effective when prolonged rains occurred after bloom indicating the importance of wetness for disease development. Minimal spray programs were also evaluated by us and others (Olsen et al.) in recent years. We demonstrated that a single low-gallonage (100 gal/A) bud-break application (corresponding to the pre-blossom application by Miller and Bollen) with Kocide-Manex-Breakthru did not satisfactorily control the disease, especially when rain occurred after bloom or when additional simulated rain treatments were applied following the bud-break application. This confirms Miller and Bollen's conclusion that additional treatments are required in rainy seasons. Our goal is to develop a spray program where an initial treatment based on blossom phenology (pre-bloom; e.g., bud-break) is followed by XanthoCast-based treatments that are suggested based on imminent rain events. Unfortunately, Miller and Bollen (1946) do not clearly specify the exact timing of the critical initial treatment. This treatment is not based on rain events because presumably the emerging blossoms are highly susceptible to infection. Additionally, only light dews may be needed to provide enough wetness between the bud scales to reactivate overwintering bacteria that, because in close proximity to the susceptible tissues, easily can initiate infections. The subsequent bactericide treatments are most economically applied just before predicted rains (new infection periods). Treatments done after rains are much less or not effective in preventing disease development from infections that occurred during the rain event. Miller and Bollen (1946) report on one trial in 1933 where half of the orchard was sprayed before and the rest after a rainy period and disease incidence was 5.4% as compared to 51.5%, respectively, with 84.2% disease in the control.

Still, progress has been made in the forecasting of infection periods based on environmental modeling that allows for a more targeted timing of bactericide applications. In 2005, we continued the evaluation of treatment timings. The XanthoCast system offers flexibility to changes in the micro-environment during each season, whereas calendar-based programs are limited to host phenology and dates. Thus, XanthoCast is a very robust program that provides regional or grower-specific forecasts that can change from year to year. It allows a judicious use of pesticides because no applications are done when no conducive environmental conditions are forecasted, thus, often reducing the number of applications. Our data over the years have indicated that following the XanthoCast program, optimal disease management can be provided, similar to the fixed numbers of applications in calendar-based programs.

Objectives

- I. Evaluate the toxicity of alternative, non-copper based chemicals to *X. campestris* pv. *juglandis*. Compare, in laboratory, greenhouse, and small-scale field tests, the toxicity and efficacy of protective treatments including fungicidal-bactericidal treatment (e.g., Kasumin) and the DuPont fungicide Tanos for control of walnut blight as compared fixed-copper compounds.
 - A) Comparative efficacy of new bactericides using handgun and air-blast spray application methods in field trials on walnut under ambient or simulated rain systems at the Kearney AgCenter (KAC), UC Davis-Plant Pathology Field Station, and in commercial orchards in Butte Co. Crop destruction costs will be included in budget.
 - B) Studies with new copper-zinc and copper-lime mixtures with and without maneb as compared to copper-maneb (Manex v. Dithane) mixtures for improving efficacy with adjuvants and rate comparisons. The adjuvant Vaporgard will be applied at maximum-labeled rates to evaluate if a rain-repellant can reduce infections by *X. campestris*. This adjuvant will also be mixed with copper-maneb to improve persistence of the bactericide.
- II. Continue to evaluate disease development throughout the spring and monitor environmental parameters (e.g., wetness periods, temperatures, and relative humidity) that are conducive to bacterial infection of walnut tissues using dataloggers. (This will be done in orchards with other ongoing blight research programs).
 - A) Continue to determine the reproduction potential of the pathogen on the plant surface using spiral plating technology for potential incorporation in the existing XanthoCast model that is based on leaf wetness and temperature.
 - B) Investigate the kinetics of stomatal behavior and the importance of stomata as infection sites for the bacterial pathogen on walnut fruit (plant growth regulators that effect stomatal function will be used).
- III. Continue to develop and evaluate XanthoCast as a model for forecasting the incidence of walnut blight.
 - A) Evaluate the automated model of XanthoCast with up to a 5-day forecast included in the latest version (Ag Vise will cooperate with Fox Weather through a link on their website).
 - i) Evaluate start dates (e.g., male (catkin) vs. female (pistillate) flower emergence) under early- and late-season simulated rain events.
 - ii) Compare version 481 with a second version, 484, to reduce accumulation of XanthoCast indices at high temperatures.
 - B) Apply bactericide treatments based on the forecasting model to determine if the total number of applications can be applied in a judicious and responsive system to micro-climate conditions as compared to fixed-application timing, calendar-based programs (e.g., minimal and weekly programs)
 - i) Evaluate arbitrary thresholds for initiating management practices.
- IV. Continue to evaluate walnut genotypes for natural host resistance to walnut blight under simulated rainfall conditions at the KAC.

PROCEDURES

Evaluation of alternative bactericides for management of walnut blight – Laboratory and field studies. Stock cultures of *X. juglandis* were maintained at -80°C. In vitro toxicity studies were done with kasugamycin, streptomycin, and polyoxin using the spiral gradient dilution method where a bactericidal concentration gradient is being established in agar media in Petri dishes. After inoculation of the media with the test pathogen and incubation for 2 days at 20 C, inhibitory concentrations were obtained using a computer program and the materials were ranked based on their bactericidal activity.

Field trials were established in experimental orchards in Solano (UC Davis) and Fresno Co. (Kearney Agricultural Center) and in a commercial orchard in Butte Co. In the Solano Co. trial on cv. Hartley walnuts, six weekly applications were done between April and mid-May 2005 (4/5, 4/13, 4/21, 4/29, 5/10, and 5/17) under ambient rain conditions. In the Fresno Co. trial on cv. Chico walnuts, applications were done on 3-18, 3-30, 4-6, 4-12, and 4-15-05 under simulated rain conditions (rain applied by high-angle sprinklers for 4-6 h on 3-31, 4-7, 4-14/4-15, 4-22, 4-28, and 5-5-05). In the Butte Co. trial on cv. Vina walnuts applications were done weekly from April to mid-May. Treatments were evaluated under ambient as well as under simulated rain conditions (rain applied with overhead sprinklers for 4-6 h one day after each application). Treatments in all trials were applied using an air-blast sprayer (100 gal/A). Incidence of disease was based on the number of infected fruit in a sample of 50-200 fruit for each of four single-tree replications. Data were evaluated using analysis of variance and least significant difference mean separation procedures or general linear model and LSD mean separation procedures of SAS 8.2.

Experimental validation of the XanthoCast model in irrigation plots. Evaluation of the effect of rain events on walnut blight development and disease incidence was conducted at field sites in Solano and Butte Co. In the cv. Vina plot in Butte Co., six weekly irrigations with overhead sprinklers were done from April through mid-May. In the Fresno Co. plot on cvs. Chandler, Hartley, and Vina, six approximately weekly irrigations with high-angle sprinklers were done between early April and early-May. Trees that were not irrigated received wetness periods from natural rain only. Disease was evaluated in early-June and statistical comparisons were performed between non-irrigated and irrigated sub-plots using SAS 8.2.

Disease evaluations and environmental monitoring using dataloggers in commercial walnut orchards and weather data from AgVise and UCIPM-CIMIS. In a commercial orchard in Butte Co. single-tree replications were tagged and monitored periodically (every 7-10 days) for the development of walnut blight from mid-April to mid-June 2005. Fruit were carefully examined for lesions and positive evaluations were re-checked in subsequent evaluations and in isolations of sub-samples of infected fruit as described previously. Disease incidence was determined as the number of infected fruit per total fruit sample minus the missing fruit. The cumulative disease incidence was plotted with XanthoCast indices (7-day and seasonal accumulation). In over 14 sites of the AgVise network in the Sacramento valley, electronic sensors and dataloggers (Campbell Scientific or Adcon Telemetry) were used to monitor leaf wetness, temperature, relative humidity, and rainfall. Dataloggers were programmed to make readings every minute and to calculate quarter-hourly, hourly, and daily averages for each micro-environmental parameter throughout the evaluation period. Environmental data were downloaded and summarized as hourly and daily summaries. CIMIS environmental data were also downloaded

from Butte and Fresno Co. for the same time period. XanthoCast™ V.481 calculates a forecasting index based on duration of leaf wetness for three temperature scales. The forecast is 14 to 21 days in advance of actual disease based on a latent period for disease expression after infection has occurred. This is the accumulation model described in previous reports.

Evaluation of minimal spray programs based on host phenology, calendar dates, and/or XanthoCast using Kocide-Manex. Trials were set up in Solano Co. on cvs. Hartley and Chico and in Butte Co. on cv. Vina. Treatment timings for two to four applications of Kocide-Manex were based on host phenological stages, calendar dates, and/or XanthoCast indices as indicated in Figs. 11 to 13 of the Results section. For the XanthoCast program, as infection periods occurred, bactericide treatments were applied and accumulation was delayed for 7 days. If no infection periods occurred, bactericides were not applied. The treatments were designed to evaluate and improve timing and to reduce the total number of applications of bactericide treatments. Disease incidence was evaluated in early June for the two trial locations. Fruit evaluations were based on 40-100 nuts for each of the four single-tree replications. Data were evaluated using analysis of variance and least significant difference mean separation procedures and LSD mean separation procedures of SAS 8.2.

Development of 2- to 5-day automated forecasts using XanthoCast parameters. Forecasts using the XanthoCast model for predicting walnut blight were developed in conjunction with AgVise Inc. and Fox Weather. Automated predictions were done using a new microclimate-automated forecasting model that was based on numerical weather prediction model data that are initialized by site observations using Fox Weather's forecast method. From the forecasted leaf wetness and temperature data for each AgVise weather station, XanthoCast parameters were used to generate daily and seven-day XanthoCast indices for 2-, 3-, 4-, and 5-day forecasts. These were graphed out and compared with actual XanthoCast indices. The goal of an automated system was to reduce the high costs that are associated with manual predictions that were done in previous years.

Evaluate walnut genotypes in simulated-rain field studies at KAC for natural host resistance to walnut blight. Walnut genotypes selected in Dr. McGranahan's program were again evaluated for disease incidence after six simulated rain events using an overhead sprinkler irrigation system. Fifty to one hundred and thirty fruit on each of four to five single-tree replications were evaluated for blight. Data were analyzed using ANOVA and LSD mean separation procedures of SAS version 8.2.

RESULTS AND DISCUSSION

Weather conditions at the trial sites in 2005. Due to high rainfall and favorable temperatures, environmental conditions were highly conducive for walnut blight in the spring of 2005. At the Fresno Co. trial site, 98 mm of rainfall occurred between March 1 and June 30, 2005, whereas in 2004 for the same period it was only 1.5 mm (Fig. 1). Average temperatures at this site were approximately 2 C lower in 2005 than in 2004. At the Butte Co. trail site, 103.5 mm of rainfall occurred in 2005 during this spring period as compared to 32.1 mm in 2004 (Fig. 2). Average temperatures at this location were 16.3 C and 17.7 C for 2005 and 2004, respectively. Thus, our field trials on walnut blight management in 2005 were subjected to highly favorable conditions with very high disease pressure similar to 1993-94.

Evaluation of new formulations of copper, a fungicide, antibiotics, and a biological control for managing walnut blight in laboratory and field studies. In vitro toxicity studies were done with the antibiotics kasugamycin, streptomycin, and polyoxin using the spiral gradient dilution method. Using two isolates of *X. juglandis*, streptomycin and kasugamycin were the most inhibitory, whereas, polyoxin was the least inhibitory. With increasing concentrations of the antibiotics, there was a gradual decrease in bacterial growth. Bacterial growth was not inhibited by a concentration of 50 ppm of polyoxin.

In field studies to evaluate new materials and compare them to copper-maneb treatments, trials were conducted in Fresno, Solano, and Butte Co. In the Fresno plot, where copper-sensitive and -resistant strains of the pathogen were present, 6-h simulated rain treatments were made one or two days after each of six approximately weekly bactericide treatments. All materials evaluated in this trial, including the new antibiotics, performed statistically similar, reducing the disease incidence from 42% in the control to between 8 and 20% (Fig. 3). Numerically, Kocide-Manex was the most effective, whereas Polyoxin with 20% disease incidence was the least effective treatment of the treatments evaluated. Numerically, Kocide-Manex performed better than Kocide-famoxadone.

In the trial in Solano Co. with only copper-sensitive strains of *Xanthomonas juglandis*, six bactericide applications were made. No simulated rain was applied in this orchard. All materials performed statistically similarly, significantly reducing the incidence of walnut blight from 28% in the control to 3 to 9.75% (Fig. 4). Numerically, the 200-ppm rate of Kasumin performed very similar to the best treatment, Nordox 30/30–Manex. Thus, this antibiotic was very effective in this trial under non-simulated rain conditions, but less effective in the Fresno Co. trial, where disease pressure was higher due to application of simulated rain. Sonata was the least effective treatment in the Solano Co. trial with 9.75% disease incidence. Agrimycin in a mixture with Topfilm performed well in this trial and no phytotoxicity was observed.

In the third trial in Butte Co. where copper-resistant strains are present, the study was conducted as a split plot with the main plots comparing simulated rain and ambient conditions and the sub-plots comparing bactericide treatments. As shown in Fig. 5, a significant increase in disease incidence occurred in the simulated rain plot as compared to the ambient environment plot. Furthermore, a significant interaction occurred between bactericide treatments and main plot (simulated rain). Thus, the bactericides performed differently under ambient or simulated rainfall conditions and are presented separately. In the ambient environment plot, only the GFJ52-Manex and the Kocide 2000-Manex treatment containing 6 lb Kocide were effective and significantly reduced the incidence of blight compared to the non-treated control (Fig. 6). A trend for lower disease also occurred in the treatment with the half rate (e.g., 3 lb) of Kocide 2000-Manex. No differences were found between any of the remaining treatments evaluated including the Kocide 2000, the famoxadone or famoxadone-Manex treatments, and the control (Fig. 6). Kocide 2000 was ineffective due to the presence of copper-resistant strains of the pathogen in this orchard. No benefits were observed in reducing disease incidence with famoxadone or with famoxadone with copper. In previous studies in 2004 (see Adaskaveg et al., Walnut Board of California Annual Report 2004) famoxadone had no in vitro toxicity to the pathogen and it was speculated that any effect would be from systemic acquired resistance (SAR) properties of the compound.

The bactericides evaluated were less effective in the simulated rainfall plot (Fig. 6). This was probably because an excessive amount of simulated rain was applied to this orchard in addition to abundant natural rain events during the experimental period between mid-March and June 1.

Still, similar trends were observed in bactericide performance. The most effective treatments were GFJ52-Manex and both rates of Kocide 2000-Manex (Fig. 6). Famoxadone treatments were intermediate in their performance, whereas Kocide 2000 was the least effective with 78% disease incidence as compared to 80.3% in the control. This trial was conducted in the same orchard in the last several years and the high level of disease incidence was probably due increased inoculum levels. Thus, this trial further demonstrated the need for effective treatments in programs that are implemented consistently each year to reduce inoculum and prevent infections.

Experimental validation of the XanthoCast model in irrigation plots. The importance of rainfall for disease development, which is one of the basic requirements of the XanthoCast model, was again experimentally verified in 2005 in two simulated-rain trials in Butte (cv. Vina) and Fresno Co. (cv. Chico). Although natural rainfall was high as indicated above, disease incidence among all treatments in the Butte Co. trial was still significantly higher in the simulated rain sub-plots of the trial as compared to the sub-plots that only received natural rain (Fig. 5). These results are consistent with previous years' data and this further validates the role of wetness in the model and also the role of moderate temperatures (12-18 C) as being most conducive. Temperatures outside of this range are markedly less conducive to disease even with high rainfall. In the second trial in Fresno Co. on cvs. Chandler, Hartley, and Vina, six weekly rain treatments significantly increased the disease only on cv. Hartley in 2005, whereas in 2004 disease was increased on all three cultivars (Fig. 7). This difference between the two years was probably due to differences in inoculum potential and in environmental conditions. Thus, because of inoculum built-up from previous years' simulated rain treatments in this orchard and with the highly conducive ambient conditions in 2005 (see Fig. 1), additionally applied simulated rain in 2005 did not further increase the disease potential. Disease incidence on the less susceptible cvs. Chandler and Hartley was less than 10%, whereas for the susceptible walnut cv. Vina it was 56.8%. As reported in 2004, simulated-rain irrigation had also increased disease in our variety trial in Fresno Co. Disease was not detected in this orchard previously, but within three seasons of simulated rain we were able to increase natural inoculum and disease incidence to allow for genotype comparisons in susceptibility to walnut blight.

Disease evaluations and environmental monitoring using dataloggers in commercial walnut orchards and weather data from AgVise and UCIPM-CIMIS. In 2005, XanthoCast was again provided by AgVise (<http://www.ag-vise.com/>), a company for site-specific soil moisture and weather monitoring based in Chico, CA. In 2006, the same service will be provided on the new website www.irrigate.net. Fourteen weather stations provided microclimate data and XanthoCast indices from Red Bluff to S. Davis in the Sacramento valley. Fox weather was commissioned to develop in cooperation with AgVise an automated model for providing two- to five-day forecasts of site-specific leaf wetness, temperature, and XanthoCast indices to help users in making decisions on forecasting the disease. XanthoCast indices based on forecasted rain (satellite rain analysis), dew, and temperatures for each weather station were automatically summarized. The XanthoCalculator allowed site-specific web-based forecasting for different grower fields and localities. This was very useful and we were again very successful in demonstrating that XanthoCast could be used to predict infection periods and to time applications of bactericides in management programs. The number of applications of bactericides could be reduced from a calendar-based program (see below).

Environmental conditions, including simulated rain applications, and disease progress that were monitored in an orchard in Butte Co. were plotted against daily, 7-day, and cumulative (seasonal) XanthoCast indices provided by AgVise (Fig. 8). Environmental conditions are shown in Fig. 8A. In Fig. 8B the increase in disease is shown as it relates to the environmental conditions. Disease was first detected in mid-April, when after a rainy period temperatures slightly increased. Subsequently, with additional rain, there was an exponential increase in disease with a steeper slope for the simulated rain sub-plot. Cumulative disease incidence increased through the month of May and then started flattening out. Peaks in the 7-day XanthoCast index correspond with actual increases in disease with a 14-18-day latency (Fig. 8C). The seasonal cumulative XanthoCast index parallels the actual cumulative disease incidence, again with a 14- to 18-day latency (Fig. 8C). Parameters shown in selected groups in Figs. 8A-C are all displayed together in Fig. 8D. Thus, as illustrated by the correlation between increases in XanthoCast indices and actual disease incidence, this study again shows, as in our previous years' research, that the XanthoCast model closely predicts actual infection periods and can be used to effectively time bactericide applications.

The difference in disease pressure and the responsiveness of the XanthoCast model is also demonstrated in a comparison of XanthoCast indices and actual disease accumulation in the Butte Co. trial site for 2004 and 2005 (Fig. 9A,B). With less conducive conditions in 2004 as compared to 2005 (see Fig. 2), the seasonal index accumulation and actual disease incidence were much lower in 2004 (Fig. 9A) than in 2005 (Fig. 9B). In addition, the 7-day indices in 2004 followed rather shallow slopes. Steep increases in the index as observed in 2005 were not evident in 2004. The critical parameter is the start date of the model and, as indicated below and as shown in the progress curves (Figs. 9A, B) both the catkin and pistillate flower emergence timings are very important in combination with the environmental conditions during bloom in comparisons of 2004 and 2005 (3/23 to 3/30).

Because data on leaf wetness are only available from the AgVise (irrigate.net) weather stations, but not from CIMIS stations, and to possibly make XanthoCast available also to locations that are not covered by AgVise, we initiated studies to find out if XanthoCast indices could also be calculated from precipitation data. As shown in Fig. 10, XanthoCast indices based on precipitation (and temperature) start accumulating at the same time (ca. March 20) as indices provided by AgVise that are based on leaf wetness (and temperature). The increase in the seasonal index, however, is slower and the final cumulative index lower for the precipitation-based calculation. This is probably due to the lack of determining total duration of wetness. In comparing the two 7-day indices, some of the increases in the indices are identical for the two calculations. Thus, based on these preliminary data, XanthoCast indices might also be calculated based on precipitation (and temperature) data. Algorithms, however, will have to be further modified.

Evaluation of minimal spray programs based on host phenology, calendar dates, and/or XanthoCast using Kocide-Manex. Three field trials were done for the evaluation of spray timings. In the first trial in Butte Co. on walnut cv. Vina, all treatment programs started at terminal bud break (March 24) and three additional XanthoCast applications (April 11, April 25, May 9 – a total of 4 applications) resulted in statistically similar disease levels as compared to five additional (a total of 6) calendar-based applications (Fig. 11). These latter two programs

significantly reduced the disease incidence from that in the untreated control. The XanthoCast program with VaporGard added to the Kocide-Manex mixture was not effective. VaporGard was evaluated as a rain-repellant to possibly reduce the wetting of the walnut fruit.

In trials on cvs. Chico and Hartley in Solano Co., combinations of catkin, bud break, and 1 week after bud break applications were applied in addition to two (cv. Chico) or three (cv. Hartley) XanthoCast applications. In the cv. Chico plot, all treatments significantly reduced the incidence of disease from 23.9% in the control to between 2.1 and 11.2 % (Fig. 12). The most effective program included the catkin, budbreak, and two XanthoCast treatments. The program that did not include catkin or bud break treatments (DB+X'Cast) was numerically the least efficacious. With high rainfall between March 18 and March 23 (as shown in Fig 12), the latter program had missed the early infection periods that occurred at this time. Still the later spray timings provided approximately 50% control (similar to last year's results). On the later-blooming cv. Hartley, numerically the program with bud break plus three XanthoCast applications had the lowest disease incidence (Fig. 12). The program with a single bud break application was not effective, because with abundant rainfall this spring both earlier and later infection periods had occurred and trees were not protected at this time using only a bud break application. This demonstrates that the early applications are very important in reducing inoculum levels but are not self-standing for the entire season when additional rainfall may occur.

In another timing study in Butte Co. simulated rain treatments in addition to natural rainfall were done either early (March 18 to April 1) or later (April 8 to April 22) in the season. Programs with combinations of catkin and bud break treatments with or without additional XanthoCast treatments were evaluated. XanthoCast treatments were not based on natural rainfall predictions, but were done one day before simulated rain treatments (e.g., simulated XanthoCast treatments). In both simulated rain timings, only the programs that included XanthoCast applications (three or four applications total) significantly reduced the disease incidence as compared to the control (Fig. 13). This again indicates that catkin and bud break eradication treatments alone are not sufficient to effectively control the disease and protect the host tissue during later infection periods. Again, disease levels were high in this orchard because timing studies and minimal bactericide application trials were conducted here for several years and inoculum levels were very high. In addition, XanthoCast treatments were only applied based on simulated rain, but not on natural rainfall that was also very high in the spring of 2005. Still, the treatments are relative and the plot is considered valid. In PMA trials in 2005 on cv. Vina Walnut (T. Prichard, *personal communication*), the efficacy of six calendar-based applications (i.e., grower standard) was compared to five applications that were done using the XanthCast program. On 6/20/05, disease incidence was 53%, 5%, and 4% for the untreated control, grower standard, and XanthoCast program, respectively.

Working with farm advisors we will continue trying to determine start dates for the XanthoCast model in 2006 based on host phenology and environmental forecasts. Programs starting at catkin development, terminal bud break, or one week after bud break will have to be compared again on several walnut cultivars. Previously, we concluded that early-minimal management programs could not satisfactorily control the disease under high rainfall conditions. Furthermore, a 'carry-over effect' was seen with significantly increased nut drop in the 'eradicator' program similar to the non-treated control in the second year even when both first-year treatments were treated with

a six half-spray program of copper-maneb in the second year. Minimum spray programs, however, can be effective perhaps for different reasons in the same year with low rainfall. For instance, early timings may reduce inoculum below thresholds needed for disease, whereas XanthoCast provides protection of fruit during favorable environments and the build-up of inoculum for contaminating buds in late spring. Early-minimal programs alone (without XanthoCast or additional calendar applications), however, are not sufficient for satisfactory disease control in years conducive for disease. Historically, others have tried minimal programs with the conclusion that at least three to four applications are required depending on the amount and occurrence of seasonal rainfall (see introduction). The XanthoCast system offers flexibility by responding to changes in the micro-environment during each season, e.g. less conducive years (e.g., 2001-02) and years with very favorable environments (e.g., 2003-05).

Development of 2- to 5-day automated forecasts using XanthoCast parameters. A new automated weather forecast algorithm to predict increases in XanthoCast indices and predict walnut blight was developed in conjunction with AgVise Inc. and Fox Weather. Automation is required to reduce the high costs that are associated with manual predictions that were done in previous years. Using the algorithms developed in 2004, predictions overall were qualitatively accurate for the most part, but quantitatively there were dramatic differences between observed and forecasted values. This contrasted the manually calculated predictions done in 2002 and 2003 where a high correlation between actual and predicted values was obtained. In 2005, a new proprietary algorithm was developed and used by Fox Weather. From the forecasted leaf wetness and temperature data for each AgVise weather station, XanthoCast parameters were used to generate daily and seven-day XanthoCast indices for 2-, 3-, 4-, and 5-day forecasts. The forecasts were qualitatively and quantitatively compared to the actual 7-day XanthoCast indices in predicting the occurrence and magnitude of infection events during the spring season.

Comparisons between the predicted and actual XanthoCast indices for three weather stations are shown in Figs. 14-16. A good correlation is evident in visual comparisons for the Cana Highway and Gerber stations ($R^2=0.5$), and increases in the actual index follow closely the predicted indices in most instances. Moreover, 5-day forecasts were still quite accurate. More inconsistencies are evident for the Durham station. Still, many of the infection events were predicted and progress was made toward an automated system.

Evaluation of walnut genotypes in simulated-rain field studies at KAC for natural host resistance to walnut blight. Simulated-rain irrigation increased disease in our variety trial at Kearney Ag Center (Fresno Co.) over the last three years, allowing us to compare 15 genotypes for their susceptibility to walnut blight (Fig. 17). In 2004 cv. Payne was clearly the most susceptible of the cultivars evaluated. With increased inoculum levels in the orchard and under highly favorable environmental conditions (Fig. 1), disease was higher for most of the cultivars in 2005. But again, cv. Payne was the most susceptible, and many of the cultivars that were among the least susceptible in 2004 were also less affected by the disease in 2005, including cvs. Cheinovo, Franquette, 76-80, and Sinensis 5. Our long-term goal is to provide data on blight susceptibility among new and old walnut genotypes to assist the breeding program in the Horticulture Department at UC Davis, to establish relationships between environmental conditions and inoculum levels for each genotype, and to evaluate mechanisms of host resistance.

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