ABSTRACT

The incidence of walnut blight in 2009 was low to moderate at most locations because environmental conditions in the spring were low to moderately conducive for the disease. Still, data were obtained on the evaluation of new bactericide treatments for walnut blight in seven field trials that were conducted with or without the application of simulated rain. This year's studies again indicated that copper-EBDC treatments are the most consistent treatment in controlling walnut blight in California. Two formulations of the coordinated EBDC mancozeb, a dry flowable (DF) and a flowable (F), were evaluated as replacements for the recently (2009) cancelled maneb that was registered and marketed as Manex. In most trials, Manzate was similarly effective as Manex. Thus, this efficacy data supports the emergency registration of mancozeb as Manzate and its full registration including other products such Dithane and Penncozeb as replacements of maneb. Several copper products (i.e., copper hydroxide, copper oxychloride) were also evaluated including Kocide 3000 and Kentan DF, as well as newly registered copper products such as Badge SC and Badge X2 (both containing mixtures of copper oxychloride and copper hydroxide). Newly formulated copper materials, i.e., Kocide 3000 and Badge products, contain lower metallic copper equivalents (30 and 28%), respectively, and can be applied at lower rates per acre than previous products and still are highly efficacious as compared to other products that require higher amounts of copper. Thus, these treatments are a step in reducing copper usage and allowing walnut blight management to have less impact on the environment. Among new alternative treatments evaluated, kasugamycin (Kasumin) is one of the top-rated alternatives that demonstrated very good to excellent efficacy when applied in combination with copper or an EBDC material. The efficacy of the antibiotic-EBDC combination was equivalent or better than copper-EBDC treatments in orchards where copper resistance has occurred. Kasugamycin was submitted to the IR-4 program in 2006, field studies have been completed, and the proposed registration has been submitted to EPA with a federal registration expected in 2011 and California registration by 2012. This antibiotic represents the first new antibiotic in US agriculture in more than 40 years and the first alternative to copper in the management of walnut blight. In addition, several products were evaluated that could potentially be used in organic production. Actinovate (a fermentation product containing the actinomycete Streptomyces lydicus) and Cerebrocide (an extract of shiitake mushrooms) showed promising results in several trials in 2009. Regalia (an extract of Reynoutria sachalinensis) also performed well in reducing blight in some trials where disease pressure was relatively low in 2008 and 2009. These materials were less effective under higher disease levels (>12-14%) incidence) and thus, were inconsistent when compared to the performance of copper-EBDC mixtures. As in previous years, our research demonstrated that the management of walnut blight requires management programs that use a combination of bactericide applications based on host phenology (i.e., catkin or pistillate flower emergence - bud break stages) and environmental conditions (moderate to high precipitation, leaf wetness and moderate temperatures) that have been quantified using an epidemiological model (i.e., XanthoCast) that forecasts favorable
environmental conditions for disease development. Minimal spray programs of one to two applications of copper-EBDC at the beginning of female flowering have been repeatedly demonstrated as inconsistent and have led to higher disease incidence later in the season and in subsequent seasons. XanthoCast indices have been successfully correlated to blight development and they have been experimentally verified in simulated-rain studies and under ambient conditions in statewide (regional) and yearly evaluations. Thus, the use of XanthoCast optimizes timing of bactericides and disease control while minimizing the total number of applications. Additional refinements to the model include dew point temperatures and high temperature limits in determining bactericide applications. Long-term goals in blight management include the development of walnut blight-resistant varieties from genotypes identified as less susceptible in our simulated rain, screening programs.

INTRODUCTION

Walnut blight, caused by *Xanthomonas axonopodis* pv. *juglandis* (formerly *X. juglandis*), is a major disease of walnut in central and northern California. The pathogen infects catkins, female blossoms, green shoots, leaves, buds, and fruit of English walnut with fruit infections accounting for most of the economic loss. Infections commonly occur in the spring under wet conditions. The bacterium survives from one year to the next in healthy and diseased buds, 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).

For management of walnut blight, short- and long-term goals include properly timed bactericidal treatments including biological products for organic growers and the use of natural host resistance in breeding programs, respectively. Both aspects have been a focus of our research over the years. New effective copper-based and non-copper-based bactericides have been identified and our disease forecasting model XanthoCast assists in the proper timing of these treatments. In a walnut variety plot we have been ranking cultivars and genotypes for their disease susceptibility over several years.

In developing a microclimate model to predict walnut blight all components of the disease triangle (host, pathogen, and environment) have to be incorporated. The host component in the triangle is defined by the phenological stage of development and by differential host resistance among walnut cultivars. In the pathogen component, inoculum appears to be the most predictable parameter to estimate because the pathogen is endemic in established walnut orchards throughout California and has a high reproductive potential under favorable environments. The environmental component critically determines the disease risk and is defined by the continually changing wetness and temperature conditions during the spring season.

Based on analyses of environmental data and actual disease progression over several seasons at several locations, we developed XanthoCast™ as a model to predict infection periods for walnut blight. This accumulation model utilizes wetness period duration and temperature parameters obtained from weather stations. Irrigate.net and Agtelemetry.com provide the basic XanthoCast™ information with an up to five-day weather forecast and prediction of XanthoCast indices for individual weather stations between Red Bluff and Davis to any grower, PCA, or farm advisor. The XanthoCalculator allows individual web-based forecasting for different grower fields and locations. As confirmed by us and IPM specialists, the forecasting model reduces the total number of applications while maintaining the same level of management as a calendar-based program. The XanthoCast system offers flexibility to changes in the micro-environment during each season and
is a very robust program that provides regional- or grower-specific forecasts, judicial use of pesticides, and disease control similar to calendar-based programs. In ongoing studies each year, the model is being validated under different climatic conditions, e.g. highly conducive and less favorable disease conditions.

Field studies in 2009 focused on timings and total number of bactericide treatments that are necessary for providing a high level disease control. In seasons with low rainfall and unfavorable temperatures, one or two early-season (bloom) applications should be followed up with a mid- to late season application around a favorable environmental event (i.e., as predicted by XanthoCast) to provide disease control and to reduce pathogen populations for the following season, whereas in seasons with more rain and favorable temperatures, additional post-bloom applications are necessary. In several trials using minimal spray programs, we demonstrated that a single low-gallonage (100 gal/A) bud-break application with Kocide-EBDC (with or without Breakthru) did not satisfactorily control the disease and resulted in epidemics especially when wetness occurred after bloom. The early-season treatments should be based on phenology and on rain events because catkin bactericide applications were beneficial during early bloom in wet seasons. Furthermore, dews may provide enough wetness between the bud scales to reactivate overwintering bacteria that can initiate infections. Our goal has been to develop a management program where bloom applications are based on blossom phenology describing bud break stages of bloom (i.e., catkin “CFE” and pistillate flower emergence “PFE”) and environmentally-based XanthoCast forecasts. Thus, protective bloom and subsequent treatments during fruit development are based on predicted imminent rain or wetness events and favorable temperatures to prevent new infections.

Perpetual, over-usage of copper-based products for walnut blight management over several decades has resulted in copper-resistant populations of the pathogen and environmentally unsustainable programs (higher usage rates and more frequent applications). Thus, there is 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. Furthermore, new formulations of copper-based products that we tested in previous years have lower usage rates when used in combination with EBDC (e.g., maneb or mancozeb) treatments. Thus, we continued our evaluations of new copper materials in 2009 and included Kocide 2000, Kocide 3000, Kentan (all copper hydroxide), and Badge X2 and SC (mixtures of copper oxychloride and copper hydroxide). The EBDC materials Manzate (mancozeb; coordination product of zinc ion and manganese ethylene bis-dithiocarbamate), and Mankocide (a pre-mixture of Kocide and mancozeb) were evaluated because of the cancellation of maneb (Manex; manganese ethylene bis-dithiocarbamate).

Because of the development of copper-resistant pathogen populations and because of environmental concerns regarding over-use of copper, management of walnut blight is also dependent on the development of new bactericidal treatments with different modes of action. Numerous potential alternatives have been evaluated by us over the years with results ranging from ineffective or inconsistent, weakly to moderately effective; or the material could not be registered. The antibiotic kasugamycin (Kasumin® - Arysta Life Sciences) is registered for agricultural use for managing plant diseases caused by fungi and bacteria 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. In our previous years’ trials we obtained very good to excellent results with kasugamycin against walnut blight. Based on our research, kasugamycin was submitted to the IR-4 program, field studies are completed, and registration is in progress. This antibiotic was again included into our 2009 trials either by itself or in selected mixtures. Kasugamycin/EBDC or copper combinations are expected to be excellent alternatives or rotational treatments for managing walnut blight. In addition, we evaluated several natural compounds including Regalia and Cerebrocide, as well as Actinovate – a biocontrol that contains the actinomycete Streptomyces lydicus. Additionally, the plant stress response inducer BioForge and ReZist that contains plant nutrients that are thought to be important in plants to maintain their health and vitality under adverse conditions were evaluated as potential treatments to manage walnut blight.

OBJECTIVES

I. New treatments - Evaluate the toxicity of alternative copper (i.e., Kentan, Badge, and the low-copper-concentration product Kocide 3000) and non-copper based chemicals (e.g., the antibiotic Kasumin, EBDC fungicides, new natural products – formulations of Regalia, Cerebrocide), numbered biologicals (e.g., Actinovate), and other experimental materials such as enhancers of plant stress response (e.g., BioForge, ReZist, etc.) against X. juglandis and evaluate the efficacy of these materials for managing walnut blight in laboratory and small-scale field tests as compared to fixed-copper compounds. Crop destruction costs will be included in budget.

A) Comparative efficacy of new bactericides (synthetic and natural products) using airblast spray application methods in field trials under ambient and simulated rain systems at the Kearney AgCenter (KAC), UC Davis, and in commercial orchards in Butte Co.

B) Studies using mixtures of copper or kasugamycin with EBDC fungicides (e.g., Manzate, Dithane).

II. Epidemiology - Continue to evaluate disease development throughout the spring and monitor environmental parameters (e.g., leaf wetness, precipitation, temperature, and relative humidity) that are conducive to bacterial infection of walnut tissues using dataloggers and CIMIS data. (This will be done in orchards with other ongoing blight research programs).

A) Develop and evaluate a precipitation-temperature-based version of XanthoCast (ongoing) in cooperation with UC-IPM and CIMIS programs for utilizing leaf wetness data and dew point temperature for XanthoCast to be used on university websites.

B) Evaluate early, mid-, and late-spring timings (e.g., male (catkin) vs. female (pistillate) flower emergence or delayed emergence in respect to “Bloom Cycle”, as well as mid- to late spring season timings) under natural and simulated rain environments.

C) Continue to determine the reproduction potential of the pathogen on the plant surface using spiral plating technology.

D) Evaluate previous years’ disease levels as a general indicator for “start time” for using the XanthoCast model.

III. Host resistance - Continue to evaluate walnut genotypes for natural host resistance to walnut blight under simulated rainfall conditions at KAC.
PROCEDURES

Evaluation of alternative bactericides for management of walnut blight in field studies. Seven trials were established in experimental orchards in Fresno Co. (Kearney Agricultural Center) and Solano Co. (UC Davis), and in a commercial orchard in Sutter Co. In Fresno Co., trials were conducted on cvs. Chico and Chandler. Simulated rain was applied in these orchards for 6-8 h after each of the four or five bactericide applications. In Solano Co., trials on cvs. Hartley, Vina, and Tulare were conducted with three to five bactericide applications following XanthoCast indices. Six calendar-based applications were done in the commercial orchard on cv. Vina in Sutter Co. Treatments in all trials were applied using an air-blast sprayer (100 gal/A) and treatment timings (i.e., dates of application) are indicated in Figs. 1-7. Incidence of disease was based on the number of infected fruit in a sample of 50-150 fruit for each of four or five 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 9.1.

Evaluation of minimal spray programs based on host phenology, calendar dates, and/or XanthoCast using Kocide-Manzate. Trials under natural rainfall conditions in Solano Co. on cv. Chico and under simulated rain conditions in Fresno Co. on cv. Vina were set up to design programs to evaluate and improve timing and to reduce the total number of applications of bactericide treatments. Treatment timings for one to five applications of Kocide-Manzate or Badge X2-Manzate were based on host phenological stages (catkin or pistillate flower emergence) and/or XanthoCast indices. In the Solano Co. trial, XanthoCast bactericide applications were done as infection periods occurred after treatments (according to the model) and accumulation was then delayed for 7 days. If no infection periods occurred, bactericides were not applied. In the Fresno Co. trial, three XanthoCast bactericide applications were done before each of two, 6-8 h simulated (‘burst’) rain treatments that were done three to four days apart. Disease incidence was evaluated in late May in Fresno Co. and in early-June in Solano Co. Fruit evaluations were based on 100-200 nuts for each of the four single-tree replications. Data were evaluated using analysis of variance and LSD mean separation procedures of SAS 9.1.

Disease progress and environmental monitoring in walnut orchards using data from AgTelemetry and UCIPM-CIMIS. In an experimental orchard in Solano Co. at UC Davis and in a commercial orchard in Sutter Co., pistillate flowers of three single-tree replications were tagged and monitored periodically (every 7-10 days) for the development of walnut blight from late-April to late May/early June 2009. Fruit were carefully examined for lesions and positive evaluations were re-checked in subsequent evaluations and in isolations of sub-samples of infected fruit. Disease incidence was determined as the number of infected fruit per total fruit sample minus the missing fruit. Using the Irrigate.Net or AgTelemetry.com networks, and CIMIS in the Sacramento and San Joaquin valleys, dew point temperature, air temperature, relative humidity, and rainfall were monitored. Environmental data were downloaded and summarized as hourly and daily summaries from selected sites. Dew point temperature is being evaluated as an additional parameter for the XanthoCast™ model. Data were graphed into figures using 7-day indices, host phenology, and dew point periods (3 consecutive days of dew) as daily values for selected stations and cultivars.
In an ongoing project, we collaborated with AgTelemetry.com to allow XanthoCast™ V.481 to be used with the company’s network of weather stations in northern California. The website also provides XanthoCast™ 4-day forecasted indices of the model to allow planning for protective bactericide applications. The model calculates a forecasting index based on duration of leaf wetness at three temperature scales using environmental data from each weather station. The website also allows users to name and store their data for individual locations using a subroutine called XanthoCalculator™. With this, weather monitoring for individual walnut cultivars and their phenology over diverse geographical ranges can be done. The disease forecast for each site is 14 to 21 days in advance of actual disease development based on a latent period for disease expression after infection has occurred. This is the model that has been described in previous reports. Thus, we followed the model in a commercial orchard near Rio Oso where a bactericide trial was also done. In this orchard, high-angle impact sprinklers and a movable pipe system were used for irrigation beginning in late April.

**Disease evaluations of walnut genotypes in a variety block at the Kearney AgCenter (KAC).** Walnut genotypes selected in the walnut breeding program under Dr. Chuck Leslie and planted in a variety block located at KAC were evaluated for disease incidence under simulated-rain conditions. Natural host resistance to walnut blight was evaluated after six weekly 8-h simulated rain events using an impact sprinkler irrigation system. These irrigation periods provided leaf wetness across all bloom stages (catkins and pistillate flowers) and early fruit development of the cultivars evaluated. 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 9.1 and compared to previous years’ results.

**RESULTS AND DISCUSSION**

**Weather conditions at trial sites in 2009 and websites for XanthoCast.** Due to generally low rainfall and either low or high temperatures in the spring of 2009, environmental conditions for walnut blight were low to moderately favorable at most locations. At the Fresno Co. trial site (Parlier, CA), 8.8 mm of rainfall occurred from March 15 to May 31, 2009 (as compared to 12.8, 25.5, and 189.6 mm in 2008, 2007, and 2006, respectively). At the Solano Co. trial site, 61.8 mm of rainfall occurred during this period (as compared to 32.6, 53.6, and 144.1 mm in 2008, 2007, and 2006, respectively) and at the Sutter Co. trial site, 44.5 mm of rainfall occurred (as compared to 2, 58.8, and 140.2 mm in 2008, 2007, and 2006, respectively). Simulated rain from sprinkler irrigation that was used in the Fresno Co. plots to induce the disease, however, with daily high temperatures relatively high and reaching over 30°C by mid-April and May, the number of infection periods in the spring season was reduced as compared to other years. This resulted in lower disease levels this year as compared to last year. In the northern California trials, disease levels were higher in all trials as compared to last year. The different disease incidences that developed in our trial locations over the years support our epidemiological understanding of walnut blight in that the magnitude of blight epidemics is not only determined by the level of bud populations of the pathogen at the beginning of the season (the result of the previous year’s disease), but by current-season environmental conditions (i.e., temperature and wetness) that allow for the pathogen to increase population size and have a great impact on the seasonal development of the disease on susceptible and early blooming cultivars.
XanthoCast was again provided by Irrigate.Net (www.irrigate.net) and AgTelemetry (www.agtelemetry.com) for the walnut districts in northern California. 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 these websites one- to four-day automated forecasts of site-specific leaf wetness, temperature, and XanthoCast indices to help users in making decisions on forecasting the disease.

**Evaluation of alternative bactericides for management of walnut blight.** Copper materials, EBDC fungicides, antibiotics, enhancers of plant stress response, a biocontrol agent, and natural products were evaluated for managing walnut blight in field studies. These products were used alone or in mixtures. Overall, mixtures of copper materials with an EBDC resulted in the highest and most consistent control of walnut blight. Still, alternatives that provided good control efficacy at the trial sites where often a high disease pressure prevailed (sometimes induced by using simulated rain treatments) were identified.

Among the coppers (all in combination with an EBDC) that were evaluated in comparisons, Kocide 2000 (6 lb), Kocide 3000 (4 lb), and Badge X2 (4 lb) performed similarly in a UC Davis trial where 22.1% disease was observed in the untreated control (Fig. 1). In another trial in Solano Co. with 11.3% disease incidence in the control, Kentan (5.25 lb) was similarly effective as Badge X2 and Kocide 2000, but Kocide 3000 was somewhat less effective (Fig. 2). In the Sutter Co. trial with a very high disease pressure (72.8% disease in the control), Badge SC, Kentan, and Kocide 3000 were all highly effective, reducing disease to an incidence of 5.6% or less (Fig. 3).

The EBDC Manzate applied by itself provided intermediate control in some trials (Figs. 2, 3, 4), but was not very effective in another trial in Fresno Co. where simulated rain was applied (Fig. 5). In this latter trial, the Kocide 3000-Manzate mixture also was not very effective, whereas in other trials it improved the efficacy of copper (Figs. 3, 4). An explanation for the inefficacy of Manzate in the Fresno Co. trial is that this material is not very easily suspended in water and possibly the material did not mix well in the application equipment without mechanical agitation that was used in this trial. The copper-EBDC pre-mixture Mankocide was only very effective when applied at the higher 8-lb rate (Figs. 2, 4).

The antibiotic kasugamycin (Kasumin), when applied alone, significantly reduced the incidence of disease in two trials in Fresno and Solano Co. (Figs. 2, 3, 5) and the efficacy was similar to copper-EBDC (Fig. 2), copper alone (Fig. 3), or Manzate alone (Fig. 3). In another trial in Solano Co., disease incidence was numerically, but not significantly, reduced from that of the control (Fig. 4). In combination with an EBDC, kasugamycin was equally effective as when applied alone (Figs. 2, 3, 4), whereas in combination with a copper material the efficacy of the antibiotic was not affected (Figs. 2, 5) or was increased (Figs. 3, 4). Thus over the years of evaluation, although often not as effective as copper-EBDC treatments, kasugamycin or kasugamycin mixtures have been shown to be valid walnut blight treatment alternatives that, once registered, should be included into a seasonal rotation program to reduce copper and EBDC use and to minimize resistance development against copper materials. Kasugamycin is currently in the registration process with an expected federal registration for 2011.
The natural products Regalia and Cerebrocide both significantly reduced the incidence of disease from the control in three of the four trials (Figs. 3, 5, 6) and they were both equally effective (Figs. 3,6). In the forth trial, Regalia and another formulation of this plant extract (i.e., MOI 106B) were statistically ineffective but numerically reduced the incidence of disease (Fig. 7). Regalia, but not Cerebrocide, was also shown to be effective in our tests in 2008. Treatments with BioForge that also significantly reduced the incidence of blight in 2008, this year was again effective in one test (Fig. 6), but ineffective in another one (Fig. 7). Interestingly, in two trials this inducer of plant stress responses improved the efficacy of the kasugamycin-Manzate mixture (Figs. 4, 5). ReZist that contains nutrients that are thought to be important to maintain a plant’s health and vitality under adverse environments provided inconsistent results. It significantly reduced the incidence of disease in one trial where it was evaluated by itself, but was not as effective as Kocide-Manzate (Fig. 7). In a mixture with Kocide it did not improve the activity of Kocide 3000 (Figs. 3,5) or Kocide 3000-Manzate (Fig. 3) but numerically improved the efficacy of Kocide-Manzate in another trial (Fig. 5). As shown in Figs. 3, 5, and 6, the biocontrol Actinovate was quite effective against walnut blight in three trials and also numerically decreased the incidence of blight in another test in Solano Co. (Fig. 7).

Summarizing our evaluations of natural products and biocontrols, the performance of Regalia, Actinovate, and possibly Cerebrocide in reducing the incidence of blight was quite consistent with 60-70% reductions when disease levels were low to moderate (<12-14%). Thus, pending additional evaluations, these products could be of interest for organic walnut production in providing rotation treatments to organically approved copper products where copper resistant populations have developed. The potential benefits of using BioForge or ReZist for walnut blight were less clear because of the inconsistency in reducing blight using these treatments.

**Evaluation of minimal spray programs with Kocide-Manzate starting at catkin and pistillate flower development.** One field trial was done under simulated rain on walnut cultivar Vina in Fresno Co. and another one under natural rain conditions on cv. Chico in the Solano Co. Studies for the evaluation of spray timings in Solano Co. In the Fresno Co. trial on cv. Vina every Kocide 3000-Manzate treatment was followed by two simulated rain bursts (2 rain events 3 to 4 days apart). With low disease levels due to the high temperatures, all treatment timings of Kocide-Manzate or BadgeX2-Manzate significantly reduced the incidence of disease to a similar level (Fig. 8). As mentioned above, daily maximum temperatures were higher than 30°C by mid-April and remained high in May. This reduced the total number of infection periods to two (ca. April 5 and April 12) for the season as shown in the environmental conditions graph in Fig. 8. Thus, the disease never entered into a polycyclic phase. The “burst” simulated rain did provide a conducive wetness period that was perhaps too favorable for disease and thus, some disease (<4%) occurred in all the bactericide treatments.

In the timing trial on cv. Chico in Solano Co. under natural rainfall conditions, four application programs of Kocide-Manzate were evaluated with timings using one to four applications (Programs 2-5) from early pistillate bloom (emergence of female flowers), full pistillate bloom, and timings based on XanthoCast (Fig. 9). Daily environmental factors (high and low temperatures, rainfall, and dew period) are shown in Fig 9A. XanthoCast 7-day indices for this orchard are shown for bactericide application (Kocide-Manzate) program 4 (Fig. 9B) and for the control (no bactericide applications) treatment (Fig. 9C). Program 4 demonstrates a reduced
number of infection periods (4 peaks as opposed to 5 in the control) and a reduction in the intensity (i.e., lower peak heights) of the infections periods as illustrated by the 7-day index (Figs. 9B). The five infection periods resulted in a disease incidence of 19.5% in the control (Fig. 9D). A single application at early pistillate flowering (Program No. 2) was ineffective in reducing walnut blight as compared to the control (Fig. 9D). Thus, as in previous years, we demonstrated that multiple applications that are properly timed around wetness events and that included or did not include catkin and pistillate flower emergence sprays resulted in less disease than single “eradicative” or minimal application program treatments. Programs 3, 4 and 5 with three to four applications all resulted in significantly less disease than the control. Program 3 was the best treatment with the lowest disease incidence of 1.6%. This program had timed one of the applications on 5-7-09 immediately after the largest infection event of the season, whereas programs 4 and 5 did not include this timing (Fig. 9D). Thus, during this large infection event with a total of 16.5 mm of precipitation, the bactericide treatment may have been largely removed and the post-infection-event application helped to keep the plant tissue protected from infection. In contrast, the infection period indicated by XanthoCast that was associated with a 31-mm rainfall event on May 22 apparently did not increase disease substantially because temperatures immediately after this rain exceeded 28C (and reached as high as 35C) (Fig. 9A, C). This suggests that additional adjustments could be made to the XanthoCast model if maximum disease control is desired, i.e., a bactericide application after large rainstorms; adjustment of the temperature range that is conducive for disease; and the use of dew periods (an environmental parameter that correlated well with infection periods – Fig. 9A). Additionally, it warrants the investigation of a comparison of rain-fastness among bactericide treatments.

Timing of walnut blight treatments to date can be summarized as follows:

- Early applications at catkin and female flower emergence may be important in reducing inoculum levels but are not self-standing for the entire season when additional rainfall may occur.
- Combination programs that include delayed female (pistillate) flower emergence applications followed by applications based on the XanthoCast environmental model proved the most consistent disease control.
- Occasionally, starting a program at catkin flowering can be beneficial. This is most likely explained by bud populations of the pathogen and environmental conditions at the beginning of the season that allow for high bacterial populations at early female flowering (pistillate flower emergence).
- Subsequent applications during fruit development reduce fruit infections and minimize pathogen populations from increasing and thus, these treatments reduce disease from mid-to late spring and minimize re-contamination of developing buds by the pathogen.
- Once daily high temperatures exceed 28C, additional bactericide applications may not be necessary even when precipitation is forecasted.


**Disease progress and environmental monitoring in walnut orchards using data from AgTelemetry and CIMIS.** Environmental conditions and disease progress were monitored in an orchard in Sutter Co. and are shown in Fig. 10. This is the same orchard where a bactericide efficacy trial was conducted (see Fig. 3). Daily environmental parameters (precipitation, min/max temperatures, and dew period) and application dates of bactericides are illustrated for the spring season (Fig. 10A). Between pistillate flower emergence and May 31, two rainfall events and four dew periods occurred. The 7-day XanthoCast indices indicated three prolonged infection periods during this time period (Fig. 10C). Thus, the cumulative season-long XanthoCast index reached 55 (for this region); whereas the actual disease incidence reached 70% (in the test orchard). The slope of the disease progress curve increased rapidly in this time period from late April to May 20 (Fig. 10C). This resulted from leaf wetness, high humidity (data not shown), and subsequent dew periods that were more conducive for disease than predicted by the XanthoCast model (Fig. 10C). When a bactericide program is followed using the XanthoCalculator, once a bactericide is applied, then no index values are accumulated for 7 days. Following the disease management program used in this orchard (Fig. 10A), the 7-day index is shown in Fig 10B. This illustration shows the reduced number of infection periods (1 peak as opposed to 3 in the control – see Fig 10C) and a reduction in the intensity (i.e., lower peak heights or no peaks) for the infections periods occurring approximately on April 22 and May 6 (Fig. 10B).

**Disease evaluations of walnut genotypes in a variety block at the Kearney AgCenter (KAC).** Walnut genotype comparisons were conducted in a variety orchard in Fresno Co. where simulated rain was applied. Disease incidence among 15 genotypes was the highest for cv. Payne with 24% disease (Fig. 10). As shown in a comparison of data from 2005 to 2009 in this figure, this cultivar has been the most susceptible to walnut blight in all years. Over the years, PI159568, Franquette, Cheinovo, Sinensis 5, and PI18256 were among the least susceptible varieties evaluated. For others, there were some differences in the ranking over the years. We are currently evaluating leaf surface characteristics of selected varieties that possibly could correlate with the observed differences in blight susceptibility. For example, stomatal structure and frequency has been implicated in the resistance of tomato genotypes against infection by *Xanthomonas campestris*. Our long-term goal is to provide data on blight susceptibility among new and old walnut genotypes and identify phenotypic markers for resistance to assist the breeding program in the Horticulture Department at UC Davis.

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REFERENCES
Fig. 1. Efficacy of selected copper treatments on cv. Vina walnut under natural rainfall conditions - Solano Co. 2009 -

Applications were done on 4-1, 4-23, and 4-30-09. Disease was evaluated in early June. Incidence of disease is based on 50-150 fruit for each 5 single-tree replications.

Kocide 3000 = 30% mce
Kocide 2000 = 35% mce
Badge X2 = 28% mce

Fig. 2. Efficacy of new bactericide treatments on cv. Hartley walnut under natural rainfall conditions - Solano Co. 2009 -

Applications were made on 4-6, 4-23, 4-30, and 5-20-09. Bioforge was used at 1 pt at the first application and at 0.5 pt at the following applications. Disease was evaluated in early June. Incidence of disease is based on 50-150 fruit of each of four single-tree replications.

Fig. 3. Efficacy of selected copper treatments on cv. Vina walnut under natural rainfall conditions - Yuba-Sutter Co. 2009 -

Applications were done on 4-1 (catkin), 4-7 (pistillate), 4-16, 4-21, 5-1, and 5-6-09. Disease was evaluated on 5-21-09. Incidence of disease is based on 50-100 fruit for each 5 single-tree replications.
Fig. 4. Efficacy of new bactericide treatments on cv. Hartley walnut under natural rainfall conditions
- Solano Co. 2009 -

Applications were made on 4-6, 4-23, 4-30, and 5-20-09. Disease was evaluated in early June. Incidence of disease is based on 50-150 fruit for each 5 single-tree replications.

Fig. 5. Efficacy of new bactericide treatments on cv. Chico walnut with simulated rain applied
- Fresno Co. 2009 -

Applications were made on 4-2, 4-16, 4-22, 5-1, and 5-10-09. Bioforge was used at 1 pt at the first application and at 0.5 pt at the following applications. Simulated rain was applied for 6-8 h on 4-8, 4-18, 4-24, 5-2, and 5-11-09. Disease was evaluated on 5-22-09. Incidence is based on the number of diseased nuts of the total of 60-100 nuts evaluated of each of four single-tree replications.

Fig. 6. Efficacy of new bactericide treatments on cv. Chandler walnut with simulated rain applied
- Fresno Co. 2009 -

Applications were made on 4-6, 4-15, 4-22, and 4-29-09. Bioforge was used at 1 pt at the first application and at 0.5 pt at the following applications. Simulated rain was applied for 6-8 h on 4-8, 4-18, 4-24, 5-2, and 5-11-09. Disease was evaluated on 5-22-09 and is based on the number of diseased nuts of a total of 60-100 nuts evaluated of each of four single-tree replications.
Fig. 7. Efficacy of new chemical and biological treatments on cv. Tulare walnut under natural rainfall conditions - Solano Co. 2009

Applications were done on 4-2, 4-23, and 4-30-09. Bioforge was used at 1 pt at the first application and at 0.5 pt at the following applications. Disease was evaluated in early June. Incidence of disease is based on 50-150 fruit evaluated for each 5 single-tree replications.

Kocide 3000 and Badge X2 were applied at a rate of 4 lb and Manzate at a rate of 2.4 lb/100/A. Burst simulated rain: Two 6-8 h rain events 3-4 days apart. Natural rain occurred on 4-10-09 (4.5 mm). Total precipitation between 4-1 and 5-21-09 was 6.6 mm. Disease was evaluated on 5-21-09.
Fig. 9. Timing study with Kocide-Manzate treatments in a cv. Chico orchard under natural rainfall conditions - Solano Co. 2009

A. Precip (mm) Max Air Temp (°C) Min Air Temp (°C) Dew Period

B. 7-day XanthoCast indices with spray program 4

C. 7-day XanthoCast indices without spray program

D. Efficacy of programs on cv. Chico

<table>
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<th>No.</th>
<th>Trt</th>
<th>Early pistillate bloom</th>
<th>Pistillate full bloom</th>
<th>X'Cast</th>
<th>X'Cast</th>
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<td>2</td>
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<td>4-27</td>
<td>5-7</td>
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<td>5-20</td>
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XanthoCast indices were obtained from the AgTelemetry weather station in Winters, CA.

Kocide 300 was applied at a rate of 4 lb and Manzate at a rate of 2.4 lb in a volume of 100 gal/A. Natural rainfall occurred on 4/7/09 to 4/10/09 (14.2 mm), 5/1/09 to 5/9/09 (3.8 mm), and 6/2/09 to 6/5/09 (6.8 mm). Total precipitation from 4/1/09 to 6/10/09 was 34.5 mm. Disease was evaluated in early June.
Fig. 10. Environmental conditions, XanthoCast 7-day indices, and disease progress in a commercial cv. Vina orchard under natural rainfall conditions - Sutter Co. 2009

XantoCast indices were obtained from the AgTelemetry weather station in Rio Oso, CA.
Fig. 11. Walnut variety susceptibility to blight in a simulated rain-treated orchard
- Fresno Co. 2005-2009 -

Five to six weekly simulated rain events were applied using a high-angle sprinkler system between April and May.